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

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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 (with100% 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 late, water saving irrigation techniques has received renewed attention [2]. Production of "more rice for every drop of water used" will be a guiding principle for rice cultivation in future. There are several options to improve the water use efficiency in rice production. Zero tillage, Alternate Wetting and Drying (AWD), Aerobic rice, Integrated Crop Management (ICM) and System of Rice Intensification (SRI) are some of the alternative technologies that reduce the requirements of water. SRI among the methods has an edge over other water saving methods as water-saving does not have a yield penalty in this system. Therefore, efforts are being made in many countries to popularize SRI to overcome the challenges of water shortages. System of rice intensification (SRI) management proposes the use of single young seedlings raised in raised bed under aerobic conditions, drastically reduced plant densities (16 hills/m2), keeping fields unflooded and use of a mechanical weeder which aerates the soil, and use of more organic manures, all the practices with the aim of providing optimal growth conditions for the plant, to get better performance in terms of yield and input productivity. The system of rice intensification (SRI) has been promoted for more than a decade as a set of agronomic management practices for rice cultivation that enhances the yield and reduces water requirements [3]. Remarkable progress in the last 50 years in agricultural production and 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.

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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's 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 adoptability. 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^{0}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 an integrated rice ecosystem in an undisturbed field lay out with permanent bunds around each plots separated with a plastic sheet to a depth of 1 meter. The experimental field was under rice mono cropping for the past twenty years using inorganic fertilizers only. 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, P_2O_5, K_2O/ha during WS and 120-60-40-10 kg N, P_2O_5, K_2O 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. Nematodes 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 m^2) 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 of the treatment effect was determined using on F-Test and 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.

Zone		Location	Soil type	pH	Varieties (local)	Available NPK (kg/ha)		
						N	P	K
Hilly areas	**1**	Almora	Silty clay loam	5.5	VL Dhan-61	310	25.4	210
	2	Malan	Silty clay loam	5.70	HPR-2143	403	31	177
North western	**3**	Kapurthala	Clay Loam	8.5	PR-115	-	-	-
	4	Chatha	Loam	7.14	PC-19	174	15.2	140
	5	Pantnagar	Silty loam	8.02	Pant Dhan-4	-	22	200
Eastern	**6**	Jagdalpur	Sandy loam	6.3	Swarna	198	10.2	236
	7	Raipur	Loam	7.20	Mahamaya	205	32.5	310
	8	Varanasi	Sandy loam	7.30	ProAgro-6201	184.60	28.3	215
	9	Ranchi	Silty loam	6.10	IR-64	230	38.2	165
	10	Patna	Clay	7.20	Rajendra Sweta	278.00	40	415
	11	Umiam	Sandy loam	-	RCPL-1-87-8	-	-	-
	12	Titabar	Clay loam	5.30	Ranjit	212	22	321
	13	Pusa	Silty clay loam	8.20	Prabhat	-	-	-
	14	Karimganj	Clay loam	5.5	Ranjit	250	9	-
	15	Arundhatinagar	Clay loam	5.60	-	0.13	16	190
	16	Chiplima	Silty loam	6.40	Lalat	245	9.3	248
Western	**17**	Nawagam	Sandy loam	7.33	GR-11	-	94.9	554
	18	Karjat	Clay loam	6.5	Sahyadri-1	212	22	-
Southern	**19**	ARI, R' Nagar	Clay loam	7.8	M-7	310	25	375
	20	Coimbatore	Clay loam	7.30	CO-47	225	17	524
	21	Aduthurai	Clay loam	7.09	ADT-47	260.00	27	350
	22	Siruguppa	Clay	7.7	IET-16937	337	25	400
	23	Karaikal	Clay loam	7.5	ADT®-45	188	16	155
	24	Maruteru	Clay Loam	-	MTU-100	-	-	-
	25	Madya	Silty loam	7.10	BR-2655	281	2.7	186

Table 1: Details of the Locations.

S.No.	Practices	SRI Method	Normal transplanting (NTP)
1	Nursery	Uniformly distributed 5 kg /ha organic manured raised bed (100 m^2/ha) and irrigated with rose can 3-4 times a day.	30 kg/ha in an area of 1000 m^2 and grown in flooded situation
2	Seedling 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	Three seedlings per hill were transplant at a spacing of 20×15 cm
4	Weed management	Four weedings by cono-weeder were performs 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)	
		In case of SRI organic (method-1) differed with SRI (method–II) only in application of nutrients through organic sources which is equivalent to the N dosage applied. No pesticide and chemical control measures were applied in these treatments.	

Table 2: Crop management practice for comparative evaluation of SRI and Normal Transplanting (NTP).

Locations	2004	2005	2006	2007	Mean
Aduthurai	56.6	11.6	18.7	92.9	45.0
Rajendranagar	20.1	9.6	34.0	20.1	20.9
Arundhathinagar	41.6	67.0	93.4	58.9	65.2
Chatha	-	5.9	5.0	22.6	11.2
Coimbatore	3.1	46.2	15.2	-	21.5
Jagdalpur	12.3	7.8	1.8	2.5	6.1
Karjat	4.0	9.4	6.4	5.3	6.3
Pantnagar	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
Titabar	16.4	8.4	5.5	7.7	9.5
Umiam	-	13.7	12.8	15.9	14.1
Mean	**13.7**	**18.75**	**12.4**	**12.76**	**14.32**

Table 3: SRI performance (% yield increase) over Normal transplanting (NTP) in different 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 tillering (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

	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Harvest index (%)		
	Kharif	Rabi		Kharif	Rabi		Kharif	Rabi	
Treatment	08, 09	08, 09	Mean	08, 09	08, 09	Mean	08, 09	08, 09	Mean
SRI-Organic	3.92	5.41	4.67	4.33	4.49	4.41	47.52	54.65	51.08
SRI (Org+inorg)	5.34	6.73	6.04	6.5	5.06	5.78	45.12	57.08	51.1
NTP	4.97	5.17	5.07	6.27	4.88	5.58	44.22	51.44	47.83
LSD (0.05)	0.514	0.554		0.528	0.748		2.79	1.56	

Table 4: Comparison of grain yield t/ha, straw yield and HI (%) as influenced by SRI and NTP.

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.

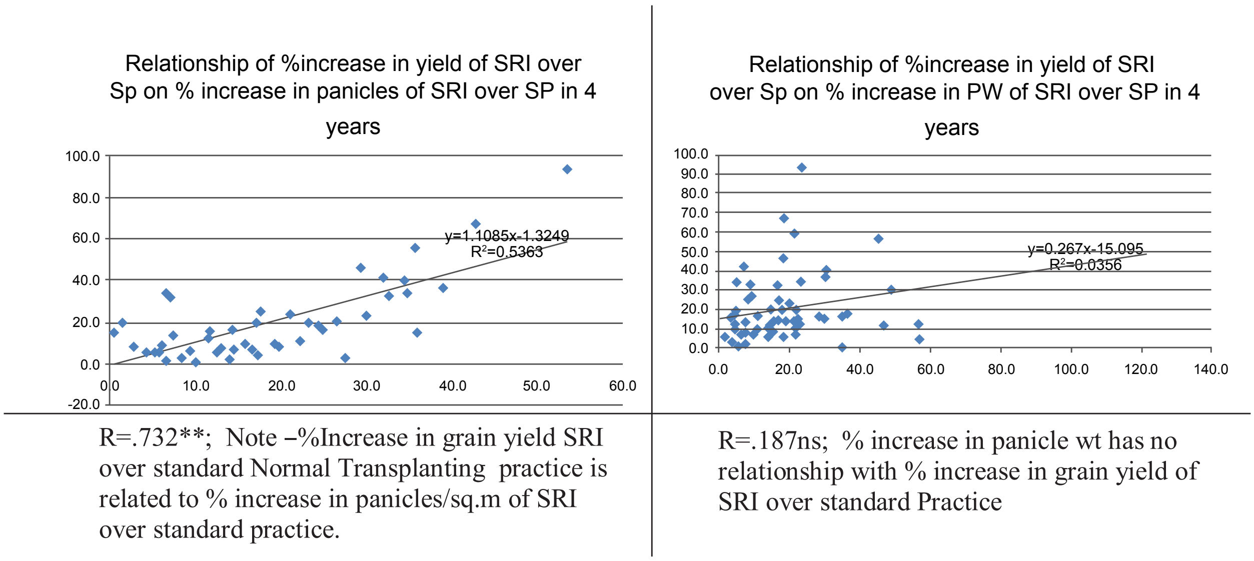

Figure 1: Relationship of % increase in yield of SRI over NTP on increase in panicles m^2 and panicle weight of SRI over NTP (4 years 2004-05 to 2007-08).

	Total N (ppm)			Available P (ppm)			Available K (ppm)			OC (%)		
	Kharif	**Rabi**		**Kharif**	**Rabi**		**Kharif**	**Rabi**		**Kharif**	**Rabi**	
Treatment	08, 09	08, 09	Mean	08, 09	08, 09	Mean	08, 09	08, 09	Mean	08, 09	08, 09	Mean
SRI-Organic	782	880	831	66	64	65	78	109	94	1.26	1.27	1.27
SRI (Org+inorg)	782	875	829	60	63	61	92	94	93	1.2	1.17	1.19
NTP	739	835	787	54	60	57	75	65	70	1.18	1.17	1.18
LSD (0.05)	172.3	113.9		11.2	8.2		29.4	58.5		0.103	0.191	

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

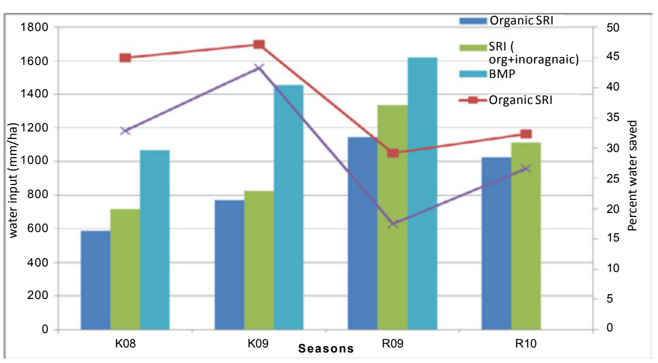

Figure 2: Water input and percent water saving in different methods of crop establishment.

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].

Season	Treatment	Water Parameters			
		Water input (m^3/ha)	**Water productivity (kg grain/m^3)**	**Litres per kg grain**	**(%) water saved over NTP**
Wet season 08 (Kharif)	SRI-Organic	5885.2	0.576	1736	44.90
	SRI (Org+inorganic)	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+inorganic)	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+inorganic)	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+inorganic)	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 DS 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, K and Zn 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 lively hood.

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