Invited Paper

Research Experiences on System of Rice Intensification and Future Directions

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Abstract

System of Rice Intensification (SRI) developed in Madagascar 25 years ago is gaining wider acceptance in many countries including India. SRI method claims to greatly enhance water productivity and grain yield but there is lack of understanding of scientific principles underlying. Hence, in the present studies SRI method was evaluated across the country at 25 locations for four years. Results clearly indicated 7-20 per cent higher grain yield over the traditional irrigated transplanted rice. The varieties having better tillering ability and hybrids were found promising and recorded higher grain yield over HYVs with moderate tillering and scented cultivars. Root volume, dry mass, and dehydrogenase activity in soil (measure of microbial activity) was found to be higher in SRI method as compared to conventional method. SRI method reduced the seed rate by 80%, water requirement by 29% and growth duration by 8 – 12 days; thereby enhancing the water productivity and per day productivity of rice cultivars. The water saving alone should be a strong justification for adopting SRI method wherever water is not abundant. There is a need for further enhancing the productivity of rice under the SRI method by identifying the suitable cultivars, modification of practices to suit local agroclimatic conditions and by understanding the synergic effects among the different practices.

Rice is the staple food for more than half of the world's population and plays a pivotal role in food security of many countries. More than 90% of the global production and consumption of rice is in Asia (IRRI, 1997). As for India, rice is not only a food commodity but also a source of foreign exchange earning about 11,000 cores annually. At the current rate of population growth (1.5%), the rice requirement by the year 2025 would be about 125 Mt. Enhancing the rice production from the current 99 million tons to the projected demand is a gigantic task. The projected trends indicate that the country has to add 1.7 Mt of additional rice every year under declining rice area, increasing cost of cultivation and shrinking natural resources like water.

Among the constraints, water scarcity appears to be a major challenge affecting rice production across the globe. More than 80% of the fresh water resources in Asia are used for agriculture of which about half of the total irrigation water is used for rice production (Dawe *et al.*, 1998). Water, which was abundant earlier, will increasingly become scarce in the years to come. Reliable estimates indicate that fresh water availability in India will be reduced to one-third of what is available today by 2025. Therefore, future rice production depends on how we improve the water use efficiency of the rice crop. Production of "more rice crop from every drop of water" will have to be the guiding principle for the future. Reducing amount of water in irrigated rice production has become a matter of global concern and of late water saving irrigation techniques have received renewed attention (Bouman and Tuong 2001).

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 alterntive technologies to combat water scarcity (Bouman and Tuong 2001). SRI method has an edge over the former methods as water-saving does not have penalty on yields in this system. Therefore, efforts are being made in many countries to popularize SRI to overcome the challenges of water shortages.

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System of Rice Intensification (SRI) refers to a set of practices initially adopted in Madagascar to overcome the problem of soil acidity in early eighties and follows a more comprehensive approach addressing various management practices simultaneously with promising results (Uphoff, 2001; Stoop *et al.,* 2002). Efforts to popularize SRI were revived in many countries including India since 2003. SRI mainly emphasises on utilizing early growth vigor of seedlings, facilitates less competition for light and nutrients, enhances resource use efficiency (seeds, water, fertilizer, pesticides) and brings down over dependence on chemical fertilizers, breaking soil anoxia condition and promoting healthy root growth and increased soil microbial activity; and there by enhancing soil organic matter content. The set of six simple practices such as planting young seedlings (10-12 days), planting seedlings at wider spacing (25 x 25 cm), alternate wetting and drying during vegetative phase to keep soil moist, applying organic manures, weeding with cono weeders and incorporating the weed biomass and crop protection by bio pesticides and bio control agents are emphasized. Aggressive efforts are being made to popularize SRI by international agencies, government and non-government agencies. Looking into the potential of SRI as an environment friendly, input saving and yield enhancing strategy, Government of India has included SRI as one of the components under the National Food Security Mission (NFSM).

However, research backing is necessary for ensuring wider adoption and sustainability of SRI. Therefore, Coordinated research efforts were initiated under the All India Coordinated Rice Improvement Project (AICRIP) of the Directorate of Rice Research (DRR), Hyderabad since 2004 and these multilocation trials are still continuing. The research results of last four years trials at DRR, Hyderabad as well as from the multilocation AICRIP trials across the country are summarized in this paper.

Materials and Methods

DRR organized multi-location (25 locations) trials (MLT) during 2004-2007 to evaluate SRI method vs normal transplanting to understand the scientific basis of the merits of the system and to fine tune the system for wider adaptability and to identify limitations, if any. The treatments included three methods of crop establishments *viz*., S1 – Standard transplanting (ST), S2 – System of rice intensification (SRI) and S3 – Integrated crop management (ICM) with modified mat nursery. Three genotypes viz., variety Krishnahamsa, rice hybrid KRH-2 and a local check varieties were used. Studies were conducted under identical nutrient management practices across the treatments.

Field experiments at DRR were conducted during *rabi* (dry) and *kharif* (wet) seasons of 2006 at Ramachandrapuram farm of DRR in ICRISAT campus in sandy clay loam soil. The soil was alkaline [pH 7.5 - 9.3 at surface (0-15 cm) and sub surface (30-60 cm) depths, respectively]; non-saline (EC- 0.47-0.67 in surface and sub surface depths, respectively); with high organic carbon (0.76-1.27%) content). Available N was medium (291kg/ha); available P_2O_5 was high (328 kg/ha) and available K_2O was also high (507 kg/ha). Experiment was laid out in a split-plot design with cultivars as sub plots (MTU 1010, Shanti & DRRH2 in *rabi*; BPT 5204, Swarna & DRRH2 in *kharif*) and methods of crop establishment (ECO-SRI, SRI and Conventional) as main-plot treatments in four replications. In SRI method , young seedlings (8-12 days), with wider spacing of 25 x 25 cm planted singly at shallow depth, with saturation of soil to keep moist and weed incorporation mechanically with cono weeder. While 15-18 day old seedlings, with two seedlings per hill planted in 20 x 15 cm spacing, weedicide application, alternate wetting and drying was practiced and compared with standard transplanting (30 day old seedlings, 3-4 seedlings planted with a spacing of 20 x 10 cm, flooded irrigation water for major growth period). In SRI and conventional method the inputs applied were same while in ECO-SRI treatment, total nutrients were supplied through organic source only. The lead research results of 4 years trials at DRR as well as collaborative research results from multilocation trials are summarized below.

Results and Discussion

*Response of SRI method on grain yield across the locations***:** The results of MLT clearly indicated that the performance of SRI varied from location to location indicating that response of SRI is location specific. SRI recorded higher yield than ICM and ST at half of the locations (10-12). SRI and ICM were comparable in 5-6 locations and found promising over ST. The mean yield advantage of SRI over ST ranged from 7-20 per cent irrespective of soil and locations across the years (Fig. 1). The mean grain yield increase in SRI method was 6 to 65% in 13 locations where SRI performed consistently superior across 4 years (Tables 1 & 2). This increase in grain yield under SRI could be

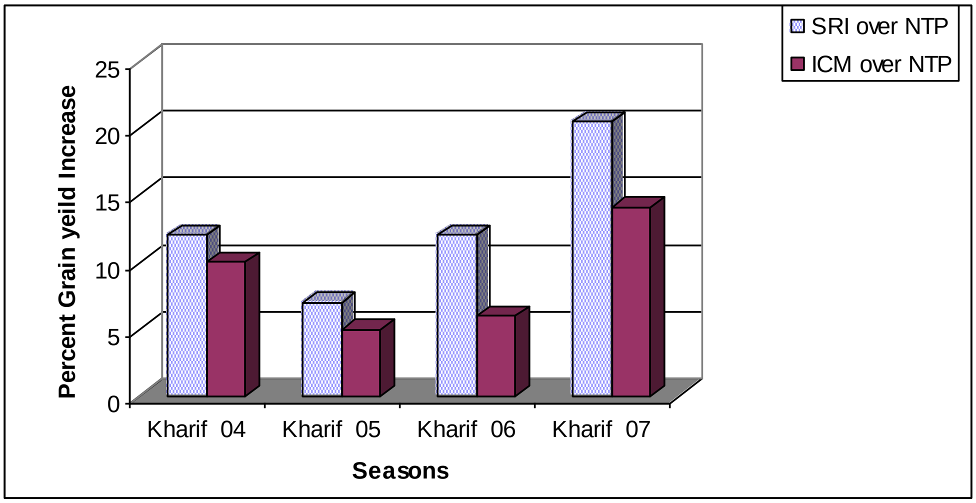

Fig. 1 Grain yield increase with SRI and ICM over NTP across the locations (*Kharif* 2004-07)

Table 1: Performance of SRI in different locations across India

S. No.	Item	Performance	No. of locations	Name of the locations
1.	SRI superior over standard Transplanting (ST)	50% or more	19	Aduthurai, ARI-R’Nagar, Arundhatinagr, Jagdalpur, Kapurthala, Patna, Rajendranagar, Siriguppa, Titabar, Chatha, Coimbatore, Pantnagar, Umiam, Malan, Mandya, Maruteru, Nawagam, Pusa
2.	SRI superior over ICM	50% or more	17	Siriguppa, Ranchi, Patna, Nawagam, Arudhatinagar, Raipur, Karjat, Jagdalpur, Chatha, Aduthurai, Upper Shillong, Puducherry, Maruteru, Mandya, Coimbatore
3.	ICM superior over standard transplanting (ST)	50% or more	17	Titabar, Siriguppa, Ranchi, Patna, Karjat, Chiplima, ARI-R’Nagar, Aduthurai, Umiam, Pantnagar, Coimbatore, Pusa, Nawagam, Mandya, Malan, Karjat, Jagdalpur.
4.	ICM over SRI	5-10% yield advantage	5	Karaikal, Karjat, Chiplima, Sabour, Kapurthala
5.	ST over SRI	5-10% yield advantage	3	Kapurthala, Karaikal, Sabour
6.	ST over ICM	5-27% yield advantage	15	Wangbal, Arudhatinagar, Ludhiana, Puducherry, ARI-R’Nagar, Patna, Nawagam, Coimbatore, Almora, Jagdalpur, Chatha, Kota, Raipur, Siriguppa, Upper Shillong

attributed to profuse tillering, improved soil aeration achieved through the soil disturbance by cono weeder operation, in addition to effective weed suppression (Thiyagarajan *et al.,* 2002 and 2005).

Table 2: SRI performance (% yield increase) over standard transplanting in different locations

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

Varietal response to SRI: Contrary to the perception that SRI method is genotype neutral, significant differences were observed between the varieties under SRI. In general, it was observed that hybrids (4 - 42% yield advantage) performed better over the varieties (2 -17%) under SRI as against ST. The hybrids KRH2, HRI 126 and PHB-71 and DRRH2 performed better as compared to the varieties (Fig. 2). Since seed requirement is quite low in SRI, this could be the best method for cultivating hybrids whose seed cost is relatively higher compared to inbreds. Most of the varieties generally performed better but there are reports that some varieties perform much better than others. Therefore, to identify the response of different genotypes to SRI practice at different locations, locally popular varieties of different duration were tested at 16 locations. Results indicated that there was a significant differential response of genotypes to SRI method of cultivation. Based on the mean over the locations and among the group of cultivars, the performance of late and medium duration varieties, and hybrids was found to be better as compared to early duration varieties at most of the locations . It is imperative that, under SRI method, due to wider spacing, those varieties which have high tillering ability perform better as compared to the shy tillering ones.

Nursery area and seed saving: As a result of adopting wider spacing and planting of a single seedling/hill at a spacing of 25 x 25 cm there would be only 16 hills/m^2 as against 44/ m^2 or more in the conventional method. Sufficient nursery required for one ha under SRI could be raised using just 5 kg seed as against 20-30 kg/ha under ST. In case of hybrids, 66% seed cost could be saved by adopting SRI method. The significant seed saving will promote seed multiplication rate, purity of seed (single seedling planting) and faster availability/spread of released varieties. Further the nursery area for SRI method is just 100 m^2/ha which is one tenth of area required for ST. There will be reduction in the cost of nursery preparation, labour saving and of inputs for nursery, mainly water which is scarce during the period of nursery raising in both the seasons.

Saving in water: Systematic studies conducted at DRR by using digital water meters during wet and dry seasons 2006 and 2007, revealed that water saving in SRI could be up to 25- 38%. SRI method received only 91.89 m^3 of water which is 38% less of that for ST (149.3 m^3). Total water productivity (after accounting rain fall) of the SRI was 29% higher as compared to conventional method. (Table 3 and Fig. 3). SRI saved nearly 25% irrigation water without any penalty on yield compared to conventional transplanting (Chowdhary et al., 2005). Using intermittent irrigation, Thiyagarajan et al. (2002) reported water saving of 50% in SRI over the traditional flooding without any adverse effect on grain yield.

Root and shoot dry mass **:** Of the three cultivation methods – ST, SRI and SRI method with organic inputs (Eco-SRI), the plots of SRI rice had highest shoot mass (mean of all three cultivars), root mass and root-length density. For the root-length density, DRRH2 had biggest density

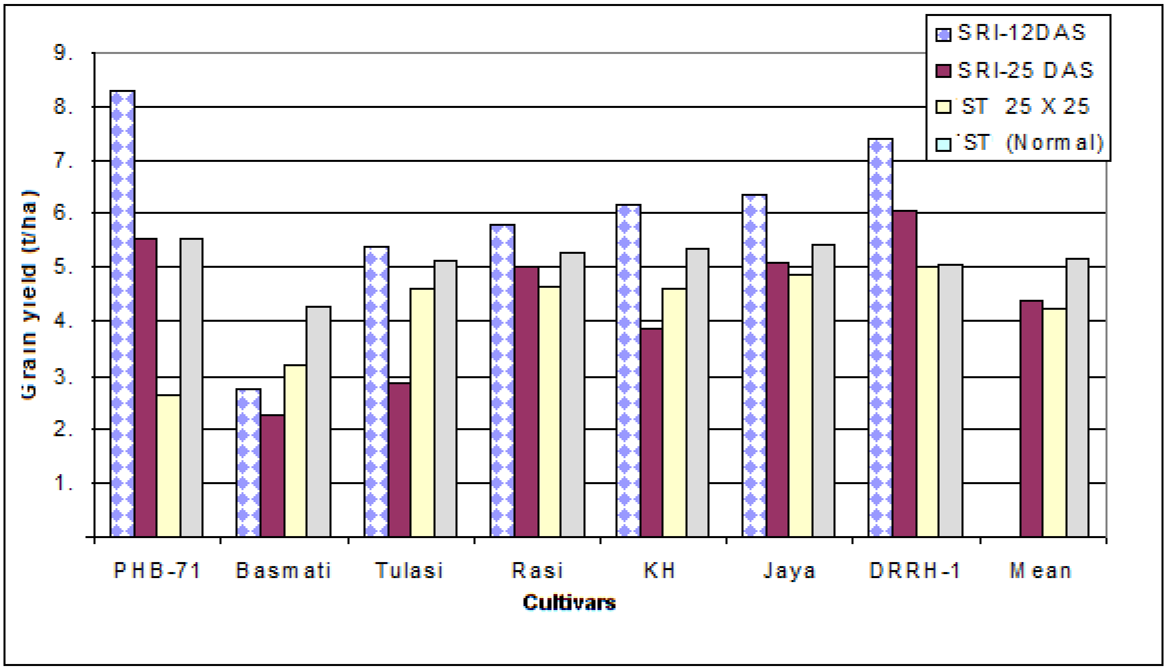

Fig. 2 Performance of cultivars under SRI vs ST

Table 3: Water productivity as influenced by conventional vs SRI method

	Method	**Irrigation (m^3)**	**(%) increase**
Water requirement	ST	149.33	38.0
	SRI	91.89	
Water Productivity kg/m^3	ST	1.18	
	SRI Org-ino-	2.23	46.0
Rainfall(m^3)		203.95	
Total water productivity (kg/m^3)	ST	0.48	
	SRI-method	0.68	29.0

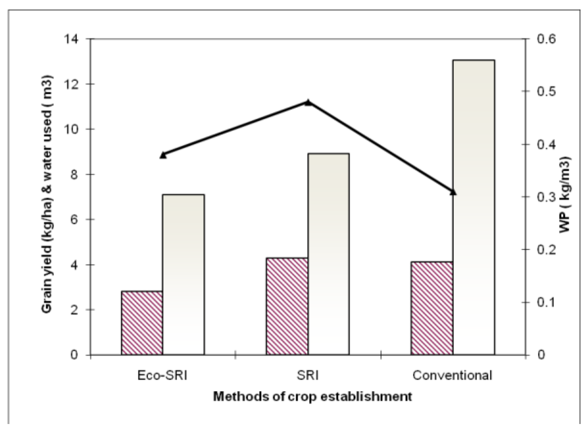

Fig. 3 Water productivity under SRI vs ST

with SRI and lowest in control while Shanthi had highest values in ST and lowest in Eco-SRI (Table 4). Similar results are reported by Barison (2002). The root system was much larger in SRI and root pulling resistance (RPR) per clump was more than double for SRI plants. Since SRI clumps are single plants and ST grown rice is transplanted with 3 or more seedlings/hill, per plant resistance is at least 6 times greater in SRI.

Nutrient use efficiency and status of soil available nutrients: The study conducted at DRR Farm, Ramachandrapuram on sandy clay loam soil with three varieties and three systems of crop establishment *viz.*, SRI, Eco-SRI (nutrients supplied through organics) and ST indicated that SRI and ST were on par and significantly superior to ECO-SRI with respect to N, P and K uptake in both the *kharif* and *rabi* seasons. Though the nutrients uptake remained the same, nutrient use efficiency was marginally higher in SRI (by 8, 8 and 12% for N, P and K, respectively, during *kharif* and 5% for N during *rabi*) compared to ST (Fig.4). The amount of accumulation of nutrients that leads to more vigorous plant growth and higher yields is due to changes in capacities of the plant itself, particularly its root system,. Barison, (2002) found considerably higher concentration of N, P and K in the foliage at late stage, reflecting better uptake of nutrients at later stages in SRI method. Soil analysis data indicated similar available nutrient status in SRI and ST after two seasons of experimentation. Thus, SRI resulted in higher productivity during *kharif*, similar nutrient uptake and marginally higher nutrient use efficiency without depleting the soil available nutrients compared to standard transplanting, after two seasons (Table 5).

Influence of SRI on microbial development: The dehydrogenage activity – a measure of microbial activity in the soil was estimated at two stages of crop growth in sandy clay loam soils comparing different methods of crop establishment indicated that the dehydrogenase activity did not differ at sowing (161-172). However, at vegetative growth stages, dehydrogenase activity was significantly higher in SRI over ST as well as ECO- SRI (Table 6). The amount of organics used in ECO-SRI is higher but the aeration provided with cono weeding might have had a significant effect on improvement of dehydrogenase activity in SRI. Magdof and Bouldin (1970) reported that BNF activity is greatly increased when aerobic and unaerobic soil horizons are mixed together. SRI water management practices and recommended weeding with a cono weeder would contribute to the juxtaposition of aerobic vis-à-vis saturated soil. N fixing bacteria are prolific at the interface between these two soil conditions. Detailed trials conducted in farmers' fields indicated no clear trend on microbial development (MBC, MBN and dehydrogenase activity in rainy season, mainly attributed to poor water management. However, SRI plots, generally had higher (7-25%) MBC, MBN and dehydrogenase activity only in post rainy season, as water management and controlled irrigation is practiced only during the post rainy season. (Kranthi, 2005).

Influence of SRI on incidence of insect pests: Field experiments were conducted in dry and wet seasons in 2005 and 2006 at Directorate of Rice Research – Ramachandrapuram farm (Figs. 5 & 6). 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 in Shanti grown under SRI (7.0%) as compared to ST (11.4%). At reproductive stage, the damage (white ear heads) was high in SRI (28.3%) than conventional method (21.2%). The study through survey (SRI – adopted village) indicated that SRI had low pest incidence resulting in lower or no-pesticide application. The benefit cost ratio was higher for SRI method (1.77 and 1.76) in two villages of Warangal district, Andhra Pradesh than conventional method (Padmavathi et al., 2008). 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 Gaspenillo (2002), Gani (2004) , Ravi *et al.* (2007). Total abundance and species richness was high in SRI as compared to conventional method. Among various guilds, natural enemies were found more in SRI than conventional method of rice cultivation. (Table.7).

Table 4: Shoot and root oven dry weight (g/ m^3), root length density (m /m^3) in top 30cm soil profile at vegetative growth stage

Treat-ment	Shoot weight (g /m^3)				Root weight (g/ m^3)				Root length density (m/ m^3)			
	MTU 1010	Shanthi	DRRH2	Mean	MT 1010	Shanthi	DRRH2	Mean	MT 1010	Shanthi	DRRH2	Mean
ECO	303	522	491	439	145	229	287	220	2483	2902	5356	3580
SRI	538	675	711	641	303	316	436	352	6604	5826	10029	7486
ST	599	636	466	567	253	257	217	242	4733	6416	3799	4983
SE±	$102.3^{NS}(100.4)^{NS}$			58.0^{NS}	$56.6^{NS}(46.2)^{NS}$			26.7^{NS}	$1395.2^{*}(987.0)^{*}$			569.8^{NS}
Mean	480	611	556		234	267	313		4606	5048	6394	
SE±	61.2^{NS}				42.2^{NS}				1138.9^{NS}			

*= Statistically significant at 0.05, NS= Not significant
SE in parentheses are to compare means within same treatment.

Table 5: Soil properties after 2 seasons as influenced by different crop cultivation methods

Treatments	pH	EC (dS/m)	SOC (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)
Eco-SRI	8.51	0.50	1.10	247.0	204	674
SRI	8.43	0.51	1.25	272.0	258	638
ST	8.44	0.51	1.18	251.0	256	609
Mean	8.44	0.51	1.18	257	239	641
C.D(0.05)	NS	NS	NS	NS	26	34

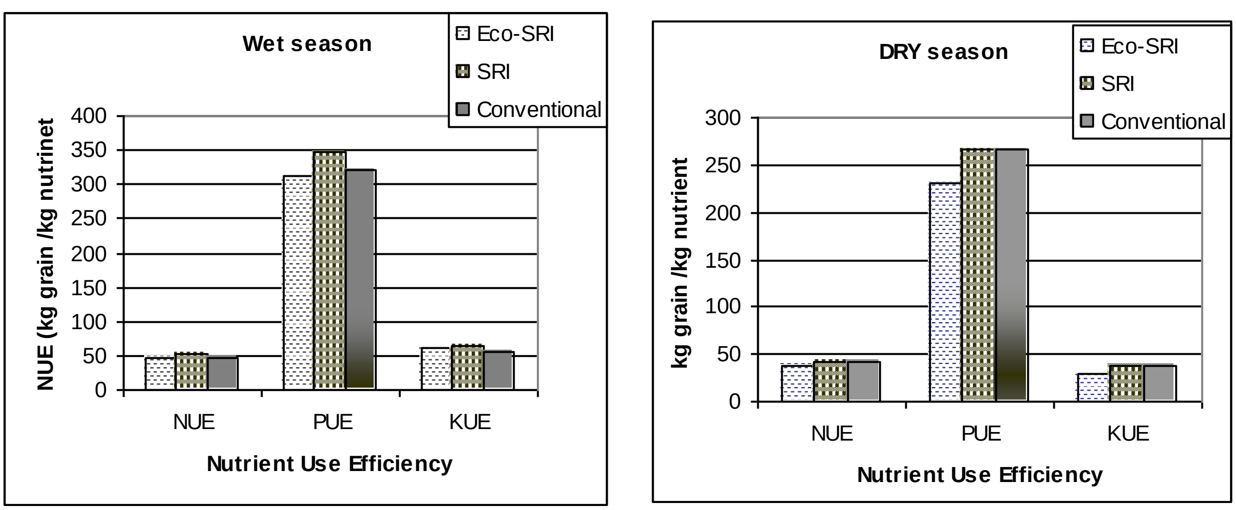

Fig. 4 Nutrient use efficiency as influenced by methods of crop establishment

Table 6: Dehydrogenase activity (µg TPF/g soil/24h) at sowing and at vegetative growth in the experiment

Treatment	At Sowing				At vegetative growth			
	MTU 1010	Shanthi	DRRH2	Mean	MTU 1010	Shanthi	DRRH2	Mean
ECO	177	154	177	169	219	199	247	222
SRI	166	176	141	161	294	350	356	333
ST	139	204	174	172	214	321	275	270
SE±	18.5(20.7)^{NS}			12.0^{NS}	54.3(36.0)^{NS}			20.8^{NS}
Mean	161	178	164		242	290	293	
SE±	7.4^{NS}				45.7^{NS}			
CV%	25				26			

NS = Not significant

SE in parentheses are to compare means within same treatment.

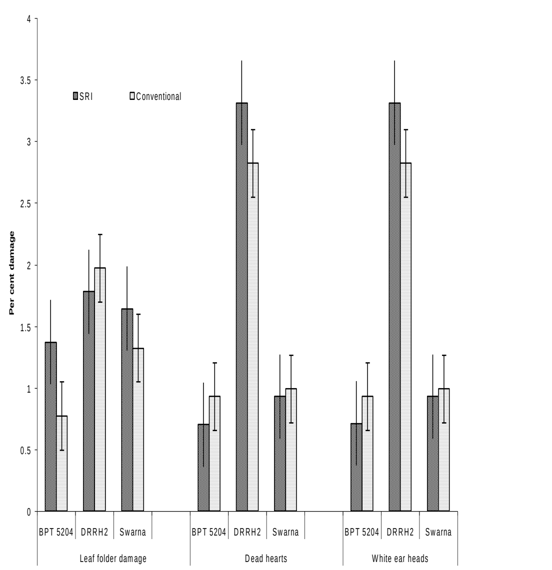

Fig. 5 Insect pest incidence in various methods of rice cultivation during dry season

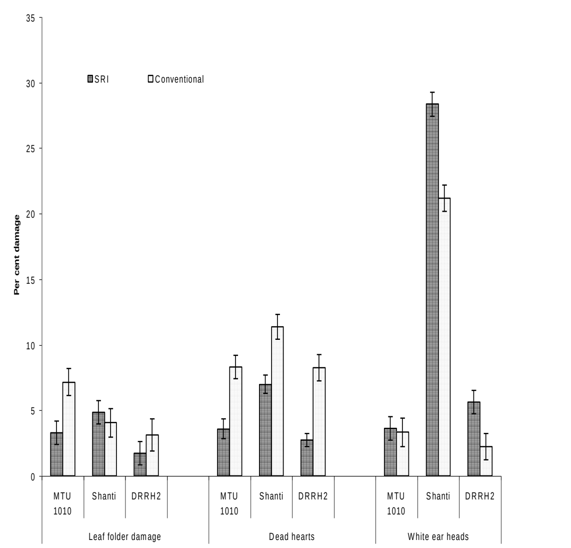

Fig. 6 Insect pest incidence in various methods of rice cultivation during wet season

Table 7: Diversity indices for arthropods in various methods of rice cultivation

	SRI	Conventional
Total abundance	263.34 ± 32.19	210.67 ± 27.90
Number of species	20.34 ± 0.67	18.67 ± 2.03
Shannons index (H)	1.92 ± 0.05	1.91 ± 0.04
Evenness (E)	0.33 ± 0.02	0.37 ± 0.04
Simpsons index	0.76 ± 0.02	0.78 ± 0.005
Berger Parker index	0.38 ± 0.04	0.35 ± 0.02
Menhinick index	1.27 ± 0.10	1.28 ± 0.05
Margalef index	3.48 ± 0.16	3.29 ± 0.29
McIntosh index	0.54 ± 0.02	0.57 ± 0.008

Reduction of the duration of the crop: Field experiments conducted for assessing the potential benefit of SRI especially in terms of reducing the duration of the crop. Three methods of crop establishment (SRI, SRI-eco and ST) were compared with three promising high yielding varieties (2 varieties and a hybrid) indicated that a mean reduction of days to 50% flowering was 11 days across seasons and varieties and also maturity of the crop. Further SRI method recorded higher grain yield in both the seasons (1.4 t/ha) with reduced duration of crop and helped to cultivate succeeding crop timely. Due to reduction in duration and increase in yields SRI recorded a higher per day productivity to an extent of 9.4 kg/ha/day and 21.7 kg/ha/day over ST during wet seasons of 2006 and 2007 respectively (Table 8). Similar trend of reduction in growth duration and increase in per day productivity under SRI have also been reported earlier (Ramesh Babu, 2007 and Subba Rao, 2007). This also helps to reduce the water requirement and facilitates to avoid water stress specially rice grown in tail end areas.

Table 8: Per day productivity of rice as influenced by methods of crop cultivation

2006 *kharif*				**2007** *kharif*			
Methods	DFF	Yield	per day yield		DFF	Yield	per day yield
ECO-SRI	95	4783	39.0	ECO-SRI	95	3189	25.8
SRI	104	5267	39.2	SRI	104	5604	41.8
Nor	115	4284	29.8	Nor	115	4874	33.7
CD(.05)	2	321	NS	CD(.05)	3	481	3.2
CV%	3	12	13.2	CV%	3	10	9.1
Varities							
BPT 5204	114	4320	30.1	BPT 5204	114	4812	33.3
DRR H2	94	4678	37.6	K.Hamsa	94	4390	35.4
Swarna	106	5336	40.1	KHR-2	106	4466	32.6
CD(.05)	2	148	3.6	CD(.05)	3	258	2.1
CV%	2	11	11.5	CV%	3	6	6.0

Socio-economic studies and frontline demonstrations : Studies during the past 2 – 3 years have clearly indicated the superiority of SRI as a sustainable method of rice cultivation. Participant farmers could perceive a unique opportunity in SRI for increasing their income through higher productivity while saving on cost of seed/chemicals/water. Experiences with SRI conducted across several types of soils indicated that SRI may not be suitable in saline sodic soils due to less tolerance of rice at early seedling stages in these soil types.

Discussion

The basic principle of SRI cultivation has been that rice plants do best when their roots grow profusely and extensively large. Because young seedlings are transplanted at shallow depths and at wider spacings, soil is kept well aerated and rich with diverse microorganisms (Uphoff, 2005). SRI differs from ST in 1) transplanting of 8-10 day old seedlings, 2) wider spacing 3) reduced use of water by avoiding continuous submergence and 4) use of larger quantities of compost and organic manures. SRI has been claimed to result in phenomenal increase in grain yields- as much as 2 to 4 folds, save water by 50% or more, besides saving on seed and fertilizer cost using only fraction of the quantity as otherwise recommended.

The present studies have addressed some of the issues involved with SRI method of cultivation. It is significant to note that in half of the locations (10 - 12 locations) during 2004-2007 significant yield advantage of SRI was seen. The quantum of this yield gain was also fluctuating between 6 to 65 per cent at 13 locations where SRI performed consistently better, over years. Failure to realize yield advantage at other locations may be either due to lack of stringent application of procedures involved in SRI or due to various other inherent limitations of the site. Though increased panicle number per unit area and panicle weight appear to be responsible for the reported yield advantage, more critical studies are certainly needed to investigate and establish a physiological basis.

The claim that SRI is genotype independent was not substantiated with the data from multi-location tests of 2008 and station trials at DRR. Thus choice of variety is important if not critical for SRI system. One of the critical claims of SRI system is water saving and in our studies, irrigation schedule was strictly followed as prescribed which led to considerable saving in water. Other independent studies at DRR in sandy clay loam soils indicated a saving of 29% in irrigation water with intermittent flooding which improved the water use efficiency by 46% depending on seasonal conditions and nutrient management. This alone should be enough justification for using SRI method for rice wherever water is scarce. Saving on seed cost was evident from the fact that only 5 kg seed per hectare for SRI method as against 30-40 kg for normal transplanting.

SRI, however, is a methodology that continues to raise more questions than we have sufficient answers for it. The increase in productivity with SRI based on concomitant increase in factor productivity is possible. There is a need for collaborative studies in different disciplines to help examine systematically the opportunities that SRI method is opening up for its wider adoptability to benefit the farming community in India.

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