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CONTENTS

System of Rice Intensification : Its Present Status, Future Prospects and Role in Seed Production in India

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ABSTRACT

System of Rice Intensification (SRI) as an alternate rice cultivation methodology, 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 and synergetic effects of the principles followed in SRI, especially in Indian conditions. The present paper is intended to discuss about significance and necessity of SRI along with performance of SRI at about 25 locations across the country for a period of four years. SRI was found to record 7-20% higher grain yield over the traditional irrigated transplanted rice in different agro-climatic situations of the country. SRI also recorded higher nutrient use efficiency without depleting soil available nutrients as compared to conventional transplanting after two seasons of the study. The varieties having better tillering ability as well as hybrids (KRH 2, HRI 126, PHB 71 and DRRH 2) were found promising and recorded higher grain yield over the high-yielding varieties and scented cultivars with moderate tillering. Root volume, dry mass and dehydrogenase activity in soil enhanced by 7-25% (measure of microbial activity) were found to be higher in SRI, compared with conventional method. There was reduction in seed rate by 80%, nursery area also obviously, water requirement by 29% and growth duration by 8-12 days, thereby enhancing water productivity and per day productivity of rice cultivars in SRI, which also proved to be helpful in producing more seed for faster seed multiplication and also quality seed for higher productivity. Water saving alone should be a strong justification for the adoption of SRI wherever water is not abundant. There is a need for further enhancing the rice productivity in SRI by identifying suitable cultivars, modifying practices to suit local agro-climatic conditions and understanding long term synergic effects among different practices.

Key words : Higher productivity, Seed production, System of Rice intensification, Water saving.

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Introduction :

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 crores of rupees annually. Since independence in 1947, India has witnessed a remarkable progress in rice production. There has been one and half times increase in area from 30 to 44 million hectare (m ha). The productivity increased by three times from 700 to 2000 kg ha^{-1} and the total annual rice production of the country has increased by more than four times from 22 to 103 million tons (mt) in 2011-12. Growth trends in rice area, production and productivity in last five and a half decades are given in Table 1.

Table 1. Trends of rice area, production, productivity and area under irrigation during the period from 1950-51 to 2005-06

Compound growth rate (%)	During the decade ending					2000-01 to 2005-06	Overall
	1959-1960	1969-1970	1979-1980	1989-1990	1999-2000		
Area	1.26	0.83	0.88	0.41	0.67	-0.45	0.68
Production	4.46	1.19	1.90	3:62	2.02	0.46	2.63
Productivity	3.15	0.36	1.02	3.19	1.34	0.91	1.94
Irrigated area	2.9	1.04	2.08	1.65	2.33	NA	-

NA: Figures not available

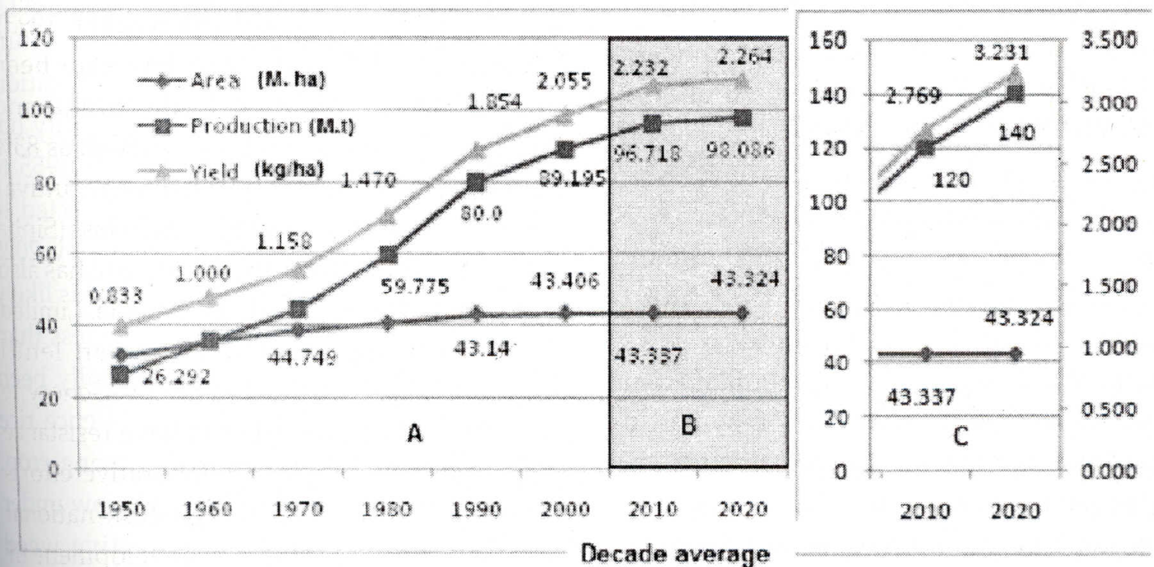

Fig. 1. Rice area, production and productivity during 1950-2020

India needs to produce two million tons of additional rice every year for the next 20 years (Fig. 1). Based on the current rate of population growth (1.4%) and per capita consumption (215-230 g day^{-1}), the projected demand for rice by 2025 would be around 130 mt. The rice production has to be invariably enhanced by more than 2 mt annually to meet the future requirements. The projected demand has to be met in the background of declining land and water resources, and growing scarcity of labour and costly inputs which are making rice cultivation too expensive. Reducing the cost of cultivation and making rice cultivation more profitable to the farmers is the need of the hour. Among these constraints, water scarcity will pose a major threat to rice cultivation and all out efforts are needed to enhance water productivity and to ensure production of more rice crop from every drop of water.

Water and Irrigated Rice :

Irrigated rice occupies 50% area and contributes nearly 70% to total rice production of the country with an average yield of 3.1 t ha^{-1}. India's food security largely depends on irrigated rice which consumes nearly 50-60% of our finite fresh water resources. Flooded rice requires 900-2250 mm of water (1500 mm on an average) depending on the water management, soil and climatic factors (Bouman and Tuong, 2001). It is estimated that rice needs about 3000-5000 litres of water to produce one kilogram of grains, which is 3-5 times more than that for other cereals like wheat, corn etc. The expenditure towards water alone accounts for 20-30% of the total variable cost of rice production (Table 2).

Table 2. Average water requirement ofirrigated rice

Farm operation/ process	Consumptive use of water (mm)
Land preparation	150-200
Evapo-transpiration	500-1200
Seepage and percolation	200-700
Mid-season drainage	50-100
Total	**900- 2250**

There is growing awareness about the need to optimize water use in rice production which will have far reaching effects. At constant level of fresh water availability, per capita supply of water is decreasing progressively with time. Besides, competing demands for water from industrial and urban sectors, and the predicted climate changes are likely to further accentuate the impending water crisis more so for rice production which warrant change in the practices adopted for rice cultivation. Water is going to be most critical input in the future for agriculture, in general and rice cultivation, in particular. Per capita water availability has dwindled from 5.3 x 10^3 m^3 year^{-1} in 1955 to 2.5 x 10^3 m^3 year^{-1} in 1990 and is expected to further shrink to 1.5 x 10^3 m^3 year^{-1} by 2025 (Fig. 2). Share of water for agriculture is likely to drastically go down from 90% to less than 60%. Rice cultivation has traditionally been in water impounded paddies and hence rice has come to be known as water loving crop. The ability of rice to survive and grow under water submerged soil and effective weed management through standing water have further given credence to this view. Hence, water productivity in rice cultivation has been the lowest. Fortunately, this aspect of rice cultivation is undergoing radical changes, and technologies are being aggressively developed for more water productive cultivation practices. System of Rice Intensification (SRI), direct seeding under puddled soil, and alternate wetting and drying are some of these practices. Reducing crop duration without affecting productivity is another approach.

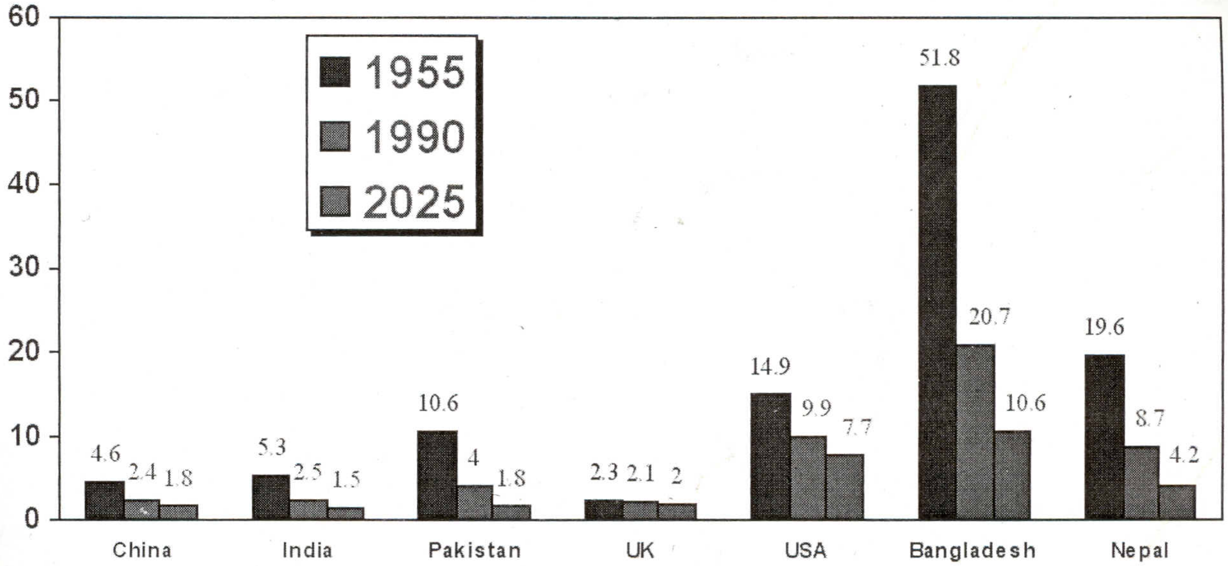

Fig.2. Per capita water availability in selected countries ('000 m^3)

There is a paradigm shift towards maximizing output per unit of water instead of per unit of land as water is going to be serious constraint in irrigated ecology. Can we come out with technologies that convince farmers to use less water in rice production without compromising on returns? This is yet another challenge before the scientists, technologists and all rice workers to increase water productivity in rice cultivation.

For improving productivity of irrigation water in wetland rice cultivation, the following three approaches are suggested :

1) Enhancing the water supply;
2) Conservation of water; and
3) Increasing crop and water productivity.

About the System of Rice Intensification (SRI) :

Future rice production in India will depend heavily on developing and adopting strategies and practices that use irrigation water efficiently at the farm level. System of Rice Intensification (SRI) is such a methodology (water saving and productivity enhancing) which has the potential to produce more rice with less water. Until 1990, the impression was that rice yields better only under flooded conditions. Recent reports from the International Water Management Institute, Colombo, however, suggest that continuous submergence is not essential for obtaining higher rice yields. Further, experiences from studies on SRI in China and Sri Lanka in the last decade have conclusively demonstrated that unflooded soil is ideal for rice plant to grow well and yield better than under conventional method of continuous shallow submergence.

According to Dr. Norman Uphoff, Professor of the Cornell University, USA and leading campaigner of SRI, this revolutionary innovative methodology was borne out of personal experience of Fr. Henry de Laulanie at Madagascar, and not as a development of scientific research (Stoop *et al.*, 2002; Uphoff, 2001 and 2005; Adhikari *et al.*, 2010). The method has spread to more than 45 countries and replete with many success stories and now efforts are on to generate and establish the scientific mechanisms responsible for the observed crop responses under SRI. In view of several advantages with this method, it has caught attention of major rice growing countries and is presently being tried as an innovative practice in several Indian states *viz.* Bihar, Tamil Nadu, Tripura, Orissa, Punjab Chattishgarh, Andhra Pradesh and West Bengal. The area under SRI is reaching to an extent of 1 m ha with bulk of the area covered in Bihar during last two years.

What is SRI?

The System of Rice Intensification, known by its acronym 'SRI', is gaining popularity among paddy farmers in several states. This method has the potential to improve productivity of land, capital, water and labour simultaneously. SRI is a system of growing rice which involves principles that are at times radically different from the traditional ways of growing rice. It involves planting of single and young seedlings with care instead of conventional method of multiple and mature seedlings from the nursery. SRI spaces rice plants more widely and does not depend on continuous flooding of rice fields. It uses lesser seed, chemical inputs and promotes soil biotic activities in and around the root zone, due to liberal applications of compost and weeding with a rotating hoe that aerates the soil. These changed practices with lower inputs lead to enhanced yields with considerable savings of inputs, especially the water, which is becoming scarce over the years.

What are the principles of SRI?

SRI, which is relatively a new methodology, involves a set of practices for plant, soil, water and nutrient management. It is revolutionary in the sense that it tries to change traditional practices especially with respect to water management that existed for thousands of years. SRI principles that underlie SRI practices are more important than the practices themselves.

- Rice is not an aquatic plant. Although rice can survive when growing under flooded (hypoxic) conditions, it does not really thrive in such a soil environment. Under continuous submergence, most of the rice plants' roots remain in the top 6 cm of soil, and most of the roots degenerate by the start of the plants' reproductive phase.
- Rice seedlings lose much of their growth potential when transplanted beyond about 15 days of age. This potential is preserved by early transplanting in conjunction with other SRI practices.

- It is important to avoid trauma to seedlings, and especially to their roots, during transplanting. Stresses such as from seedlings' roots drying out will delay the resumption of plant growth after transplanting and reduce total tillering and root development.
- Wider spacing of plants leads to greater root growth and accompanying tillering, provided that other favorable conditions for growth such as soil aeration are provided. With intact root systems, there is a positive correlation between tillering and grain filling.
- Soil aeration and organic matter create beneficial conditions for plant root growth and for consequent plant vigor and health. This results from having greater abundance and diversity of microbial life in the soil, helping plants to resist pest (weed, insect and disease) damage.

The greatest potential of SRI is seen when six important practices are adopted together. These include: (1) Transplanting young (8-12 day old) seedlings singly; (2) Careful transplanting at shallow depth; (3) Adoption of wider spacing (25 cm x 25 cm); (4) Water management to keep soil moist by alternate flooding and wetting; (5) Inter-row weeding using rotary weeder; and (6) Use organics such as FYM / compost. However, some desirable and best practices of SRI for harnessing higher productivity are given in Table 3.

What are the effects of SRI practices on plant growth and soil?

- Young seedlings (less than 15-day old) grown from a garden like raised bed nursery are stronger and keep the soil particles intact when removed. This not only avoids transplanting shock but also aids in quick establishment and retains the potential for profuse tillering and strong root growth. Further, young rice seedlings of less than 15-day old with four phyllochrons are reported to put forth a large number of tillers and dense root system.
- Transplanting at a wider spacing (16 hills m^{-2}) provides ample light intensity and soil volume which encourages luxurious growth of roots and tillers, supporting synergistically. For example, about 60% of photosynthates formed in the shoots are translocated to roots for its growth which pervasively explore soil for water and nutrient to supply to the aerial parts. Wider spacing also creates favorable microclimatic conditions for plant growth similar to that as 'border / edge' effect. But, the uniqueness of SRI is that such phenominal growth is seen uniformly all through the field which more than compensates for low plant density.
- Rice plants grown without the use of inorganic fertilizers and biocides are vigorous, strong and less susceptible to pest incidence, and are slow in senescence.
- Accumulation of nitrogen and dry matter production is greater in vegetative organs of rice plants grown under SRI as compared to those which are grown under traditional method.

Sl. No.	Principles	Rationale for the principle	Best practices	Desirable
1.	Utilise young seedlings (if transplant)	More prolonged and profuse tillering	Young seedlings (8-12 d) quickly and carefully transplanted	Up to 3-leaf stage; less than 15-day old.
2.	Wider spacing: Less competition among plants for light and nutrients	More extensive and efficient use of sunlight and nutrients	Optimally wide spacing; one plant $hill^{-1}$ in square pattern; single seedlings, reduced irrigation (AWD)	25 cm x 25 cm to begin, but wider if soil is more fertile.
3.	Reduce reliance on external inputs (new seeds, water, fertiliser, pesticides) and enhance soil organic matter	Realise biological potential of rice plant and living soil system using optimal resources in a sustained way; feed the soil so that it can feed the plants	Less chemical inputs; addition of *in situ / ex situ* organic matter as much as possible	Single seedling $hill^{-1}$; seed rate of 5.0-7.5 kg ha^{-1}; not more than 2.5 cm depth.
4.	Maintain mostly aerobic soil conditions and maintain AWD	Prevent negative effects of submergence (hypoxia), suppressing roots and aerobic soil organisms; exit of toxic gases	Intercultivation for actively aerating soil with weeder; small quantity of water as per requirement of the crop	Using weeder at 10-day intervals for 2-4 times, with 1st use at 10-12 DAT; provide irrigation after hairline cracks develop in soil.
5.	Promote healthy root growth	Reverse the inhibition of root growth caused by current normal paddy cultivation practices	Transplanting that does not invert the seedling root tip upwards (like J)	Careful transplanting is crucial to start the process, keeping soil and seed sac attached to roots; provide irrigation after hairline cracks develop in soil.
6.	Increase soil microbial activity	Realise biological potential of soils for better plant growth	Apply lot of organics and bio-products	Green manure crops / use of green manure / Azolla / incorporation of crop residues / compost / FYM / bio-fertiliser, etc.

AWD: Alternate wetting and drying; DAT: Days after transplanting

- Remobilization / partitioning of stored photosynthates from the vegetative organs is 1.4-3.0 times (66.9%) more with SRI practices.
- Uptake of nutrients as well as their use efficiencies is also favoured by SRI cultivation.
- Good water management practice of keeping the rice soil moist but not continuously flooded contributes immensely to the growth of larger roots in aerobic soil environment while hypoxic conditions prevalent under continuously submerged condition inhibit and degenerate root growth. Nearly 78% roots are known to degenerate by flowering stage in flooded soil which is almost prevented under SRI. Healthy and vigorous root system is the magical effect of SRI.
- The aerenchyma tissues formed in response to prevailing hypoxic conditions impair the capacity of the plants for nutrient uptake. In contrast, rice grown under SRI does not form aerenchyma and avoids root degeneration.
- SRI conditions permit more oxygen and nitrogen fluxes to reach rhizosphere which favours higher microbial activity and N-fixation.
- Soil aeration under SRI prevents intense soil reduction and reduces the build up of toxic concentrations of ferrous iron which is a major problem in acid soils.
- Rotary weeding churns up the surface soil, removes and incorporates weeds while aerating the top 10 cm of soil layer. This ideally benefits biological N fixation (BNF) and N mineralization.
- Addition of organic manures such as FYM and compost, besides including weed biomass, enriches soils with carbon which triggers biological processes by diverse microflora in the soil and also promotes plant growth promoting rhizoflora (PGPR).

Introduction of SRI in India :

SRI was introduced in India in 2000 when researchers at the Tamil Nadu Agricultural University (TNAU) initiated experiments involving SRI principles in a collaborative project on growing rice with less water. The results of the experiments during 2000-02 were followed by evaluations in farmers' fields. In 2003, a package of SRI practices was evolved and tested in about 200 farmers' fields through a state government initiative to compare the performance of SRI and conventional cultivation in the Cauvery and Tamiraparani river basins. The results showed an average increase in grain yield by 1.5 t ha^{-1} in both basins with reduced input requirements, and even an 8% reduction in labor needed per hectare. This evaluation provided a basis for officially recommending SRI adoption to farmers in 2004.

Concurrently, the State Agricultural University in Andhra Pradesh, Acharya N. G. Ranga Agricultural University (ANGRAU), introduced SRI in farmers' fields during *kharif* season of 2003, after ANGRAU scientists saw SRI being implemented in Sri Lanka. Comparison trials were conducted in all districts of the state. These results generated nationwide interest as they showed average yield increases of 2.5 t ha^{-1}, being 50% over conventional irrigated rice cultivation (Table 4).

Of late, Bihar has taken up SRI promotion as single point agenda to promote it in a large scale and covered around 7.5 lakh ha during 2011-12. It was reflected in the enhanced rice production of the state during the year.

Table 4. Grain yields in SRI as recorded in experiments across India

Location	Grain yield (t ha^{-1})		
	Conventional	SRI	% increase /decrease
Tamil Nadu Rice Research Institute, TNAU, Aduthurai, Tamil Nadu	4.7	**7.1**	+ 48.9
14 Research stations, ANGRAU, Andhra Pradesh	4.9	**5.7**	+16.6
Indira Gandhi Agricultural University, Raipur, Chattisgarh	5.9 (2006) 4.3 (2007)	6.6 5.1	+ 12.0 +17.8
Agricultural Research Institute, Patna, Bihar	3.9	6.1	+55.1
Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puduchery	2.2	3.7	+68.3
ICAR Research Complex, Umiam, Meghalaya	4.0 (2005) 4.7 (2006)	4.4 5.2	+9.3 +10.2
Central Rice Research Institute, Cuttack, Orissa	4.9 (2005) 5.6 (2006)	5.9 7.0	+20.4 +25.0
Regional Agricultural Research Station, Shillongani, Assam	3.1	4.5	+45.2
Agricultural Research Station, UAS, Kathalagere, Karnataka	8.8 (2005) 9.1 (2006)	10.2 10.5	+15.9 +15.4
Main Rice Research Station, AAU, Bawagam, Gujrat	4.0 (2006) 4.7 (2007)	6.3 7.5	+35.9 +37.1
Birsa Agricultural University, Ranchi, Jharakhand	4.3	5.0	+16.3

Research Experiences of SRI across the Country :

Response of SRI method on grain yield across the locations : The results of multi location trials (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 integrated crop management (ICM) and standard transplanting (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 to 20%, irrespective of soil and locations across the years (Fig. 3). The mean grain yield increase in SRI was 6-65% in 13 locations where SRI performed consistently superior across 4 years (Table 5). This increase in grain yield under SRI could be 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).

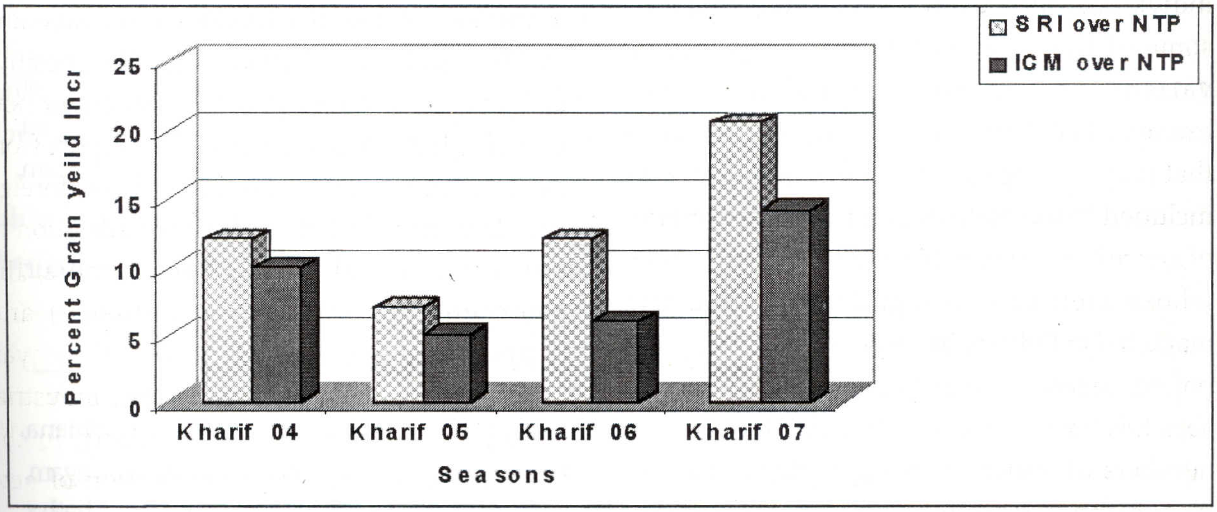

Fig. 3. Grain yield increase with SRI and ICM over normal transplanting (NTP) across the locations (*Kharif*, 2004-07)

Varietal response to SRI : Contrary to the perception that SRI is genotype-neutral, significant differences were observed among 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 like KRH 2, HRI 126 and PHB 71 and DRRH 2 performed better as compared to the varieties. Since seed requirement is quite low in SRI, it would be the best method for cultivating hybrids whose seed cost is relatively higher, compared to inbreds. Most of the varieties generally perform better although there are reports that some varieties perform much better than others. Therefore, to identify the response of different genotypes to SRI at different locations, locally popular varieties of

Table 5. Performance of SRI in different locations across India

Sl. No.	Item	Yield advantage	Locations	
			No.	Name
1.	SRI superior over ST	50% or more	19	Aduthurai, ARI-R'Nagar, Arundhatinagar, 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 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%	5	Karaikal, Karjat, Chiplima, Sabour, Kapurthala
5.	ST over SRI	5-10%	3	Kapurthala, Karaikal, Sabour
6.	ST over ICM	5-27%	15	Wangbal, Arudhatinagar, Ludhiana, Puducherry, ARI-R'Nagar, Patna, Nawagam, Coimbatore, Almora, Jagdalpur, Chatha, Kota, Raipur, Siriguppa, Upper Shillong

ICM: Integrated crop management; ST: Standard transplanting; SRI: System of Rice Intensification

different duration groups were tested at 16 locations. Results indicated that there was a significant differential response of genotypes to SRI. Based on the mean over the locations and among the groups 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 due to wider spacing under SRI, 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 single seedling hill^{-1} at a spacing of 25 cm x 25 cm, there would be only 16 hills m^{-2} as against 44 hills 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^{-1} under ST. In case of hybrids, 66% seed cost could be saved by adopting SRI. 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 is just 100 m^2 ha^{-1}, which is one-tenth of area required for ST. There will be reduction in the cost of nursery preparation, labour and 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 the Directorate of Rice Research (DRR), Rajendranagar, Hyderabad by using digital water meters during wet and dry seasons of 2006 and 2007 revealed that water saving in SRI could be up to 32%. SRI required only 8906 m^3 of water which is 32% less than that of ST (13055 m^3 ha^{-1}). Total water productivity of SRI was 53% higher as compared to conventional method (Table 6). SRI saved nearly 25% irrigation water without any penalty on yield compared to conventional transplanting. 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.

Table 6. Water productivity as influenced by conventional *vs.* SRI method (mean of *kharif* and *rabi*)

Parameter	Method	Quantity	Variation (%)
Water applied ($m^3 ha^{-1}$)	ST	13055	-
	SRI	8906	32.0 (Reduction)
Water productivity (kg m^{-3})	ST	0.32	-
	SRI	0.48	53.0 (Increase)
Unit water requirement (l kg^{-1})	ST	3125	-
	SRI	2083	-

ST: Standard transplanting; SRI: System of Rice Intensification

Root and shoot dry mass : Of the three cultivation methods *viz.* ST, SRI and SRI with organic inputs (Eco-SRI), the plots of SRI rice had the highest shoot mass, root mass and root length density. For the root length density, DRRH 2 had the biggest density with SRI and the lowest in control while Shanthi had the highest values in ST and the lowest in Eco-SRI (Table 7). Similar results were reported by Barison (2002). The root system was much larger in SRI and root pulling resistance (RPR) clump^{-1} 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^{-1}, per plant resistance is at least 6 times greater in SRI.

Table 7. Shoot and root dry weight, and root length density in top 30 cm soil profile at vegetative growth stage

Treatment	Shoot weight (g m^{-3})				Root weight (g m^{-3})				Root length density (m m^{-3})			
	MTU 1010	Shanthi	DRRH 2	Mean	MTU 1010	Shanthi	DRRH 2	Mean	MTU 1010	Shanthi	DRRH 2	Mean
Eco-SRI	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	
SEm±	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; Eco-SRI: SRI with organic inputs; SRI: System of Rice Intensification; ST : Standard transplanting

Nutrient use efficiency and status of soil available nutrients : The study conducted at the 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 *kharif* and *rabi* seasons. Though the nutrient 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. 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 with ST, even after two seasons (Table 8).

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. The study indicated that the dehydrogenase activity did not differ at sowing. However, at vegetative growth stages, dehydrogenase activity was significantly higher in SRI over ST as well as Eco-SRI (Table 9). 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. Magdoff and Bouldin (1970) reported that BNF activity is greatly increased when aerobic and unaerobic soil horizons are mixed together. Water management practices and weeding with cono weeder in SRI 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 (Microbial biomass carbon or MBC, Microbial biomass nitrogen or MBN and dehydrogenase activity) in rainy season, mainly due 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 was practiced only during post-rainy season (Kranthi *et al.*, 2005).

Table 8. Soil properties after two seasons as influenced by different crop cultivation methods

Treatments	pH	EC (dS m^{-1})	SOC (%)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
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. (P=0.05)	NS	NS	NS	NS	26	34

Eco-SRI: SRI with organic inputs; NS: Not significant; SOC: Soil organic carbon; ST: Standard transplanting; SRI: System of Rice Intensification.

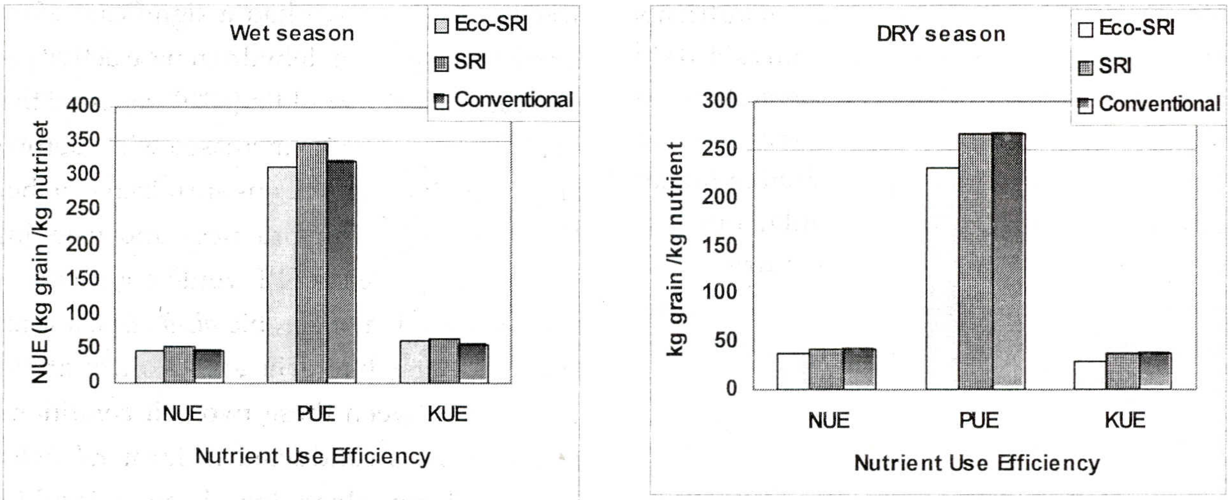

Fig. 4. Nutrient use efficiency as influenced by methods of crop establishment

Table 9. Dehydrogenase activity (µg TPF g^{-1} soil day^{-1}) during sowing and vegetative growth in the experiment

Treatment	At Sowing				At vegetative growth			
	MTU 1010	Shanthi	DRRH 2	Mean	MTU 1010	Shanthi	DRRH 2	Mean
Eco-SRI	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	-
SEm±	7.4^{NS}				45.7^{NS}			
C.V. (%)		25				26		

Eco-SRI: SRI with organic inputs; NS: Not significant; ST: Standard transplanting; SRI: System of Rice Intensification; SEm± in parentheses are to compare means within same treatment.

Influence of SRI on incidence of insect pests : Field experiments were conducted in dry and wet seasons of 2005 and 2006 at the DRR Farm, Ramachandrapuram. The pest incidence data indicated that yellow stem borer damage was high at all stages of crop growth period and its damage (dead heart) was low in Shanti grown under SRI (7.0%) as compared to ST (11.4%). At reproductive stage, the damage (white ear head) 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 were reported by Gasparillo (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.

Reduction of the duration of the crop : Field experiments were conducted for assessing the potential benefit of SRI especially in terms of reducing the crop duration. Three methods of crop establishment (SRI, Eco-SRI and ST) were compared with three promising varieties (two high-yielding varieties and one hybrid) and the results indicated that a mean reduction of days to 50% flowering was 11 days across seasons, varieties and also maturity of the crop. Furthermore, SRI recorded higher grain yield in both the seasons (1.4 t ha^{-1}) with reduced crop duration and helped to cultivate succeeding crop timely. Due to reduction in duration and increase in yields, SRI recorded a higher per day productivity (PDP) to an extent of 9.4 kg ha^{-1} day^{-1} and 21.7 kg ha^{-1} day^{-1} over ST during wet seasons of 2006 and 2007, respectively (Table 10). Similar trend of reduction in growth duration and increase in PDP under SRI was also reported earlier (Ramesh Babu, 2007 and Subba Rao *et al.*, 2007). This would also help to reduce the water requirement and facilitate to avoid water stress, especially for rice grown in tail end areas. Also, this shorter growing cycle can free upland for other uses, and crop diversification can itself buffer losses from climatic stresses (Mishra and Uphoff, 2011).

Table 10. Rice productivity as influenced by methods of cultivation in *kharif*, 2006 and 2007

Treatments	2006			2007		
	DFF	GY	PDP	DFF	GY	PDP
Methods						
Eco-SRI	95	4783	39.0	95	3189	25.8
SRI	104	5267	39.2	104	5604	41.8
ST	115	4284	29.8	115	4874	33.7
C.D. (P=0.05)	2	321	NS	3	481	3.2
C.V. (%)	3	12	13.2	3	10	9.1
Varieties						
BPT 5204	114	4320	30.1	114	4812	33.3
DRRH 2* / Krishna Hamsa**	94	4678	37.6	94	4390	35.4
Swarna* / KRH 2**	106	5336	40.1	106	4466	32.6
C.D. (P=0.05)	2	148	3.6	3	258	2.1
C.V. (%)	2.0	11.0	11.5	3.0	6.0	6.0

*2006; **2007; DFF: Days to 50% flowering; GY: Grain yield (kg ha^{-1}): PDP: Per day productivity (kg ha^{-1} day^{-1})

Role of SRI in Seed Production :

Studies on quality parameters of the seeds collected from three methods of crop establishment showed that differences due to varieties and methods were significant for germination %, seedling length, seedling dry weight and seedling vigour index (SVI). It may be noted that seeds obtained from Eco-SRI exhibited the highest seed quality, followed by SRI and conventional method (Ravindra Babu *et al.*, 2006).

Further, SRI helps breeders to produce large quantities of breeders' seed in short time as the quantity of nucleus (basic) seed of a new variety available is always less and seed requirement for SRI is only 2 kg acre^{-1}. Therefore, seed multiplication through SRI will be an added advantage for the breeders to popularize new cultures quickly. However, adoption of SRI poses problems of (i) preparing suitable nursery bed; (ii) transplanting of young seedlings along with soil to the main field; (iii) water management and (iv) use of cono weeder etc. when it is to be practiced on large scale by farmers. Further studies are being undertaken to assess the performance of breeder seed produced through SRI in seed multiplication chain from foundation to certified seed. There will be higher multiplication rate of seeds and easier availability to the farmers.

Comparative Economics :

A study was conducted to compare the economics of rice cultivation in five major rice growing states of India *viz.* Chhattisgarh, Uttarakhand, Punjab, Madhya Pradesh and Tripura, where SRI is in vogue. The results indicated the following trends :

The grain yield was 1724 kg acre^{-1} for conventional method whereas it was 2466 kg acre^{-1} in SRI. Even though the total cost of cultivation was comparatively more in case of SRI, net income was more when compared to conventional method and hence, the cost : benefit ratio was also more in SRI (1 : 2.21) than conventional method (1: 1.94). Further, the cost : benefit analysis of individual components of SRI and conventional transplanting (Fig. 5) clearly indicated the superiority of SRI (Table 11). In general, SRI is relatively cost-effective as compared to conventional method due to reduced inputs coupled with higher grain yield.

Table 11. Comparative economics of SRI *vs.* Conventional method of rice cultivation (average of 5 states)

Particulars	SRI	Conventional
Grain yield (kg acre^{-1})	2466	1724
Straw yield (kg acre^{-1})	3320	2960
Grain value (Rs. acre^{-1})	19899	13600
Straw value (Rs. acre^{-1})	2130	1964
Total cost of cultivation (Rs. acre^{-1})	9962.23	8004.46
Gross income (Rs. acre^{-1})	22029	15564
Net income (Rs. acre^{-1})	12066.77	7559.53
Cost : Benefit ratio	1 : 2.21	1 : 1.94

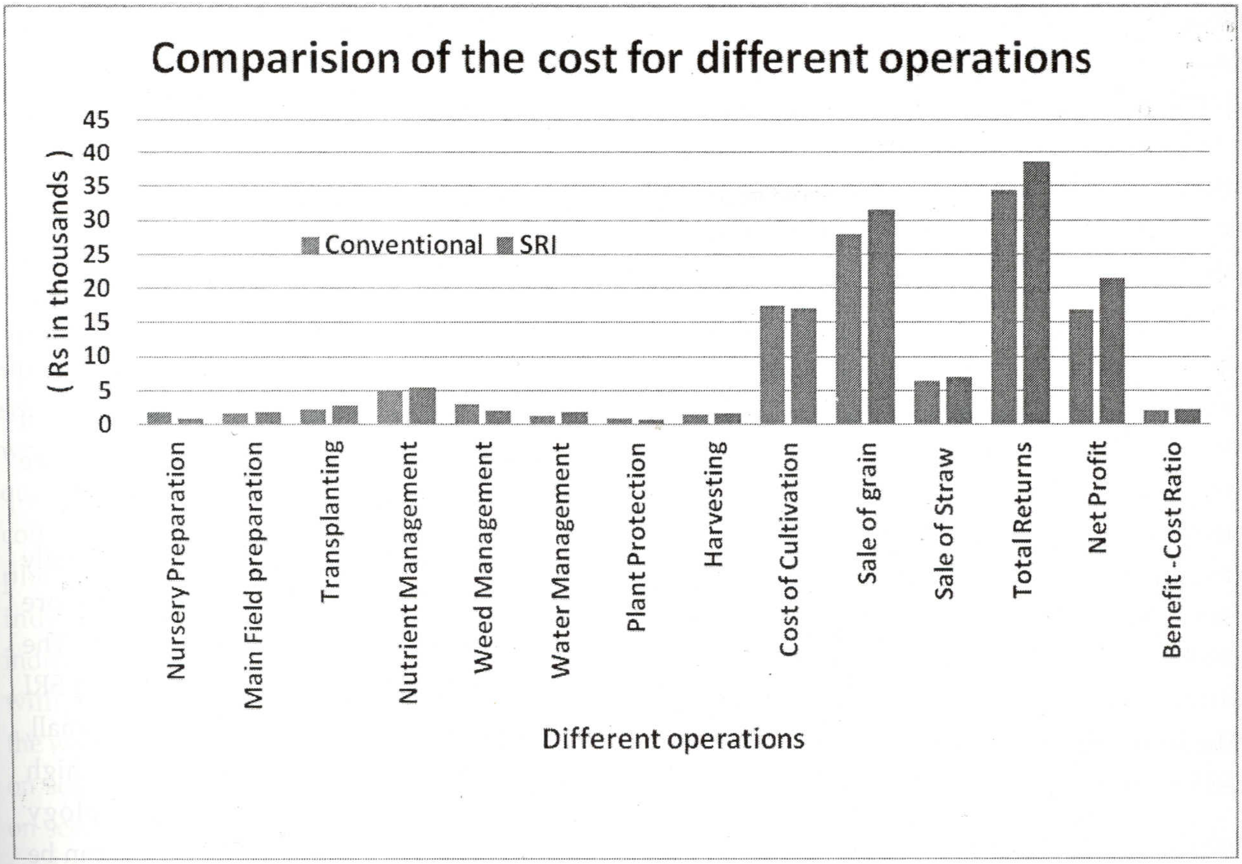

Fig. 5. Comparison of individual components of SRI and conventional transplanting

Present Status of SRI in India :

SRI is getting popularity in some states in India. It can be adopted in all those areas where there is water scarcity. Although Andhra Pradesh started in a big way during 2004-05, Tamil Nadu and Tripura have made good progress in adoption of SRI. Nearly 50% of rice area in Tripura and about 7.5 lakh ha of area in Tamil Nadu is reported to be covered with SRI. Bihar had also taken lead and implemented SRI in an area of 3.5 lakh ha in *kharif*, 2011 with a target to cover about 7.5 lakh ha in 2012. In India, nearly 10% of the rice area can be easily covered (4 m ha) with SRI which can create greater impact in terms of resource conservation and enhancing the productivity.

It has been proved beyond doubt that SRI does not work everywhere. It is difficult to adopt SRI in canal irrigation areas (unless the water is regulated as per the requirement and adoption in large scale area) with high rainfall, poor drainage and saline alkaline soils. Tank and tube well irrigated areas are most suitable. It may be possible to cover about 10% irrigated area of rice under SRI.

Socio-economic studies and frontline demonstrations 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.

Problems in Adoption of SRI :

Feedback from farmers indicated certain problems which need to be addressed for improving the efficiency of SRI and for its wider acceptance. Some of these are as follows :

- While appreciating the multiple roles of cono weeder in SRI, farmers felt the need for mechanized multi row weeders (that can be repaired /fabricated locally) to reduce drudgery and cover more area per unit time.
- The adoption level of various practices of SRI differed.
- Similarly use of organic manure (FYM / compost) was also not strictly adhered to uniformly, perhaps due to non-availability of the material which suggests for educating and encouraging the farmers to prepare organic manures on farm from the wastes to overcome such constraints.
- It was also observed that even with partial adoption of some of the SRI practices, there was improvement in grain yield by about 25%. The take home lesson borne out from observation is that farmers can still improve rice productivity substantially if all the recommended SRI practices are adopted in full.
- As rice cultivation with SRI is generally cost-effective, it is thought to be more suited for small and marginal farmers. The present study, however, showed that SRI has the potential to be practiced by small, marginal and larger farmers with high economic returns. The methodology appears to be scale-neutral, which can be adopted by all the farmers with equal success.

Conclusion :

The basic principle of SRI is that rice plants do best when their roots become vigourous, young seedlings are transplanted at shallow depth and wider spacing, soil is kept well aerated and rich with diverse microorganisms. SRI differs from normal flooded rice in: (i) transplanting of 8-10 day old seedlings, (ii) wider spacing, (iii) reduced use of water by avoiding continuous submergence, and (iv) use of more compost and organic manures. SRI has been claimed to result in phenomenal increase in grain yield by as much as 2- to 4-fold and save water by 50% or more, besides saving on seed and fertilizer cost using only fraction of the quantity otherwise recommended. SRI is also claimed as variety-independent system. While enthusiastic proponents of SRI have unsubstantiated overblown claims, cynical conservatives have turned down these claims without even seriously testing them.

One of the critical claim of SRI is water saving. Though in DRR studies, irrigation schedule was strictly followed as prescribed which led to considerable saving in water, quantitative data on this parameter were not collected. Studies are now in progress and planned to generate these data. Other independent studies at DRR in clay soil indicated a saving of 20-29% in irrigation water with intermittent flooding which improved the water use efficiency by 13-28%, depending on season and nutrient management. Saving on seed cost was evident from the fact that a seed rate of only 5 kg seed ha^{-1} was used for SRI as against 30-40 kg ha^{-1} for normal transplanting.

Preliminary studies on soil samples from farmers' fields showed substantial differences in soil microbiological, soil biological and soil chemical parameters under SRI as compared with normal submerged cultivation. How critical are these factors in yield enhancement are being studied in collaborative studies with the ICRISAT at Hyderabad.

Based on the experience, SRI appears to be more promising in terms of higher grain yield and better and faster seed production although gains observed were genotype- and location-specific. Further studies are required to confirm these issues and more collaborative efforts are essential to make SRI an efficient methodology for future rice production.

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