Climate-smart rice cultivation system to mitigate climate change impacts in India

Chapter · January 2016

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11 System of rice intensification

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Introduction

Rice is one of the most important staple crops for Indian society. India has the world's -largest area of rice cultivation (44 million ha) and it is the second largest rice producing country in the world after China (Thiyagarajan and Gujja, 2013). The country will need to produce at least 130 million tons of milled rice per year by 2030 in order to feed its growing population (Gujja and Thiyagarajan, 2009). However, there is not much scope to expand the current area under rice cultivation to increase rice production due to rapid urbanization on one hand, and water constraints and shortage of suitable soils on the other hand. Enhancing the productivity per unit area is another possible way to increase rice production under the existing cultivated areas. However, the challenge is not only increasing food production, but also adapting to the changing climatic conditions that impose water scarcity and mitigating Green House Gases (GHG) emissions from the rice fields.

To maximize agricultural production, mitigate GHG emissions, and enhance food security, fundamental changes are needed in rice production systems. One alternative option is to apply the System of Rice Intensification (SRI) which requires less agricultural inputs (land, seeds, fertilizers, pesticides) and less water compared to conventional rice cultivation (Stoop *et al.,* 2002; Uphoff, 2002; Thakur, 2010; Geethalakshmi *et al.,* 2011; Jain *et al.,* 2013). Assembled in Madagascar in the 1980s by the French agronomist Father Henri de Laulanié, SRI has been adopted by rice farmers in more than 50 countries worldwide. SRI was introduced to India in 2000 in Tamil Nadu, Puduchery, and Tripura (Thiyagarajan and Gujja, 2013). SRI is a package of agronomic practices which exploits the genetic potential of rice plants, creates a better growing environment (both above and below ground), enhances soil health, reduces inputs such as seeds, fertilizers, water, and labour requirements for planting (Gujja and

Thiyagarajan, 2009), and reduces fuel consumption for pumping water by 30 litres/ha (Siopongco *et al.,* 2013). On the other hand, the continuous flooding system (i.e. paddy rice) consumes more water, seeds and inorganic fertilisers than SRI (Lakshmanan *et al.,* 2012). Moreover, paddy rice is one of the major contributors to GHG emissions particularly methane and, to lesser extent, nitrous oxide.

Fields with SRI could reduce CH_4 production by about 30–60 percent and lower the Global Warming Potential significantly (Jain *et al.,* 2013; Rajkishore *et al.,* 2013). This supports previous work by several researchers (Uphoff, 2003; Barah 2009; Thakur *et al.,* 2010; Uphoff *et al.,* 2011). In addition, SRI can reduce water consumption by 22 to 25 percent, compared to paddy rice (Lakshmanan *et al.,* 2012). The water saved by practicing SRI could be used to grow other food crops or may be reallocated and used for domestic and/or industrial purposes.

Despite these favourable reports, SRI is highly criticized and is still a controversial issue among scholars, researchers, farmers and policy makers when it comes to its performance as a water-saving technology, increasing yield and reducing GHG emissions. Dobermann (2004) reported that SRI does not show any significant increase in yields. He argued that the performance of SRI largely depends on soil and other environmental conditions in the locality, efficiency in management and farmers' knowledge and experience. Further, Sheehy *et al.* (2004) evaluated SRI and conventional rice production in three locations in China, concluding that SRI has no inherent advantage over the conventional system and that the original reports of extraordinary high yields are likely to be the consequence of error. McDonald *et al.* (2008) reviewed different research publications on SRI performance against recommended management practice (RMP) and concluded that SRI yields were not higher than RMP. In fact, in 35 site-years of data compiled from nine different Asian countries, they found no evidence of a yield advantage except for one set of experiments in Madagascar, where SRI more than doubled rice grain productivity with respect to best management practices (BMPs). These publications have spurred considerable debate (Glover, 2011).

The objectives of this chapter are (i) to review and describe evidence-based SRI performance regarding climate change impacts, adaptation, mitigation of GHG emissions, and increasing agricultural productivity in comparison with the conventional rice cultivation methods practiced by small-holder farmers in Asia and Sub-Saharan Africa, and (ii) to present and discuss case study results from SRI activities carried out in Kalingarayan canal basin (KB) and Ponnaiyar reservoir basin (PB) in Tamil Nadu state of India.

Review of literature

Climate-smart agriculture is defined as an approach that 'sustainably increases productivity, enhances resilience ("adaptation"), reduces greenhouse gas emissions ("mitigation"), promotes carbon sequestration, and increases food security and development goals' (FAO, 2010). Climate-smart agriculture addresses the synergistic effects of climate change mitigation, adaptation and food security, and minimizes their potential negative trade-offs by bringing about 'win-win' opportunities. To demonstrate that SRI technology fulfils the principles of CSA as mentioned above, we have reviewed and discussed the performance of SRI (in relation to CSA principles) in comparison with the conventional practice by small-holder farmers in some selected rice growing countries in Asia and sub-Saharan Africa (SSA) in the following section. The terms paddy and conventional rice cultivation are interchangeable in this chapter.

SRI as an adaptation measure to water scarcity

The contribution of SRI in saving water in some of the rice growing countries are presented in Table 11.1. According to Zheng *et al.* (2013), irrigation water was reduced by 1,933.5 m^3/ha (a water saving of 22 percent compared with conventional flooded paddy) with SRI practices in Sichuan province in south-western China. Water productivity was 1.12 kg of grain per m^3, with an increase of 0.30 kg/m^3 (36 percent), and irrigation water use efficiency was 1.34 kg of grain/m^3, an increase of 0.37 kg/m^3 (38 percent). Reports from other countries also similarly showed that irrigation water requirements under SRI was lower compared to flooded paddy cultivation (Table 11.1).

Table 11.1 SRI performance in climate change adaptation in some rice growing countries.

Country (site)	*Water used by paddy (mm)*	*Water used by SRI (mm)*	*Water saved by SRI (%)*	*References*
China (Sichuan province)	2,377	1,933	19	Zheng *et al*. (2013)
India (Andhra Pradesh)	1,012	651	36	Satyanaryana *et al*. (2007)
India (Tamil Nadu)	1,077	938	13	This study
Vietnam (Mekong region)	n.a.	n.a.	33	Dung *et al*. (2008)
Indonesia (eastern region)	n.a.	n.a.	40	Sato and Uphoff (2007)
Kenya (Mwea)*	4,626	3,510	24	Ndiri *et al*. (2012); Nyamai *et al*. (2012)
Tanzania (Mkindo)	2,882	1,026	64	Katambara *et al*. (2013)
Mali (Timbuktu region)	n.a.	n.a.	10	Styger *et al*. (2011)

n.a.: not available. * converted into ha from 240 m^2 plot

Source: Authors' own compilation

Table 11.2 Examples of SRI's role in mitigating CH_4- C emissions in some Asian countries

Country (site)	*unit*	*SRI*	*Paddy*	*% change*	*References*
China (Thaihu lake basin)	kg C/ha	22.0*	39.0	44	Yang *et al*. (2012)
India (New Delhi)	kg C/ha	19.9	32.3	38	Suryavanshi *et al*. (2012)
India (New Delhi)	kg C/ha	8.2	22.5	64	Jain *et al*., (2013)
Thailand (irrigated)**	kg C/ha	302.7	473.0	36	Sass (1996); Kroeze (1996); Shin *et al*. (1996)
Thailand (rainfed)**	kg C/ha	129.3	202.1	36	Sass (1996); Kroeze (1996); Shin *et al*. (1996)
Thailand (clay soil)**	kg C/ha	301.8	471.6	36	Sass (1996); Kroeze (1996); Shin *et al*. (1996)
Thailand (sandy loam soil)**	kg C/ha	172.4	269.4	36	Sass (1996); Kroeze (1996) Shin *et al*. (1996)

* Partial SRI practices. ** CH_4-C emissions rate are total per season

Source: Authors' own compilation

SRI as a mitigation measure to GHG emissions

Very limited work has been done to quantify the GHG emissions from SRI and conventional methods of rice cultivation. The role of SRI in reducing GHG emissions from the experiments conducted in China, India and Thailand are presented in Table 11.2. For instance in a two-year field experiment in China, total N_2O emissions from intermittent irrigation (which is one of the components of SRI) during the rice-growing period was 107 mg N_2O-N/m^2 that is an increment by 10 percent from paddy cultivation (data not shown). In other words, SRI increase N_2O emissions by 10 percent. Whereas, total CH_4-C emissions were 2.5 g C/m^2 under intermittent irrigation (II) and 3.9 g C/m^2 under paddy cultivation (i.e. a reduction by 44 percent, on average, with II). Carbon dioxide equivalents of both CH_4-C and N_2O-N emissions from the paddy field during the rice-growing period under intermittent irrigation were 788 kg CO_2-C/ha, which is a reduction of 61 percent compared with those from continuous flooded irrigation (Yang *et al.,* 2012). The reduction in CH_4 emissions by SRI was, on average, 36 percent in Thailand under clay soils, sandy loam, rainfed, and irrigated systems but, in the case of India and China, the CH_4 reduction was 38 percent and 44 percent, respectively.

Table 11.3 Comparative performance of rice (average grain yield in t/ha) under SRI and paddy in some Asian and African countries

Country	*SRI*	*Paddy*	*% increase*	*References*
China	6.2	5.0	24	Zhao *et al*., (2010)
India	8.7	6.3	38	Satyanaryana *et al*. (2007)
Philippines	7.3	3.7	97	Thakar (2005)
Vietnam	6.8	5.6	21	Dung *et al*. (2008)
Indonesia	7.2	3.9	85	Sato and Uphoff (2007)
Bangladesh	6.0	4.0	50	Latif *et al*. (2005)
Myanmar	4.4*	2.1	110	Kabir and Uphoff (2007)
Kenya	6.6	5.0	32	Ndiri *et al*. (2012); Nyamai *et al*. (2012)
Tanzania	9.9	3.8	161	Katambara *et al*. (2013)
Madagascar	8.0	2.0	300	http://sri.ciifad.cornell.edu/countries
Mali	9.0	6.7	34	Styger *et al*. (2011)

* Rainfed SRI

Source: Authors' own compilation

SRI's role in increasing productivity and food security

The role of SRI in increasing crop yields in some rice growing countries are presented in Table 11.3. The average rice grain yields with SRI varied from 4.4 t/ha in Myanmar to 9.9 t/ha in Tanzania. However, the yields were lower with paddy cultivation, varying from 2.0 t/ha in Madagascar to 6.7 t/ha in Mali. In China, Zhao *et al* (2010) conducted field experiments in the northern part of Zhejiang where they compared rice production under SRI with traditional flooding. Grain yields ranged between 5.6 and 6.9 t/ha with SRI and between 4.0 and 6.1 t/ha under traditional flooded management. On average, grain yields under SRI were 24 percent higher than traditional flooding in China. However, the variability in yield increment was as low as 21 percent in Vietnam and as high as 300 percent in Madagascar (Table 11.3). The low increase in Vietnam may be partly explained by inadequate capacity of farmers to control water and infection by root-feeding nematodes (pers. comm. Norman Uphoof, 2015). It is important to acknowledge that SRI does not always enhance rice yields compared with traditional flooded production. For example, in 35 site-years of data compiled from nine different Asian countries, McDonald *et al.* (2008) found no evidence of a yield advantage of SRI over recommended management practices, except for one set of experiments in Madagascar where SRI more than doubled rice grain productivity.

Case study from India

In India, a number of studies have been carried out on SRI performance targeted at water saving, yield productivity (Abraham *et al.,* 2014; Bhuvaneswari *et al.,* 2014; Gathorne-Hardy *et al.,* 2013; Ndiiri *et al.,* 2013; Thiyagarajan and Biksham, 2013) and mitigating GHG emissions (Jain *et al.,* 2013; Rajkishore *et al.,* 2013). However, studies on the synergistic effects of SRI in building adaptation capacity of farmers to climate change and mitigating GHG gases while sustaining rice production are very few. The objective of the present case study is to assess the performance of SRI practices (various combinations of SRI components) in relation to increasing productivity, mitigating CH_4 and N_2O emissions, and adaptation to climate change impacts in two ClimaAdapt project sites namely, Kalingarayan and Ponnaiyar canal basins of Tamil Nadu (India).

Site description

Field trials were conducted in Kalingarayan basin (11° 58 N, 77° 58 E; 163 m a.s.l.), and Ponnaiyar canal basin (10° 57 N, 78° 25 E; 259 m, a.s.l.). In Kalingarayan basin, the climate is mostly dry with an average maximum temperature of 29°C to 38°C. The average annual rainfall is 714 mm with dry weather throughout the year except during the monsoons. The Ponnaiyar basin experiences a moderate climate with average maximum temperature ranging between 29°C to 37°C. The average annual rainfall is about 850 mm with maximum rainfall (323 mm) during the North-East monsoon season (October-December) and also a moderate rainfall (213 mm) during South-West Monsoon from June to September. There is also some rainfall (154 mm) during the hot season from March to May, but no rainfall during the winter months of January and February. The major soil types in the Kalingarayan basin area are red loamy, red sandy and lateritic soils of which red-loamy soils cover a larger area in the irrigated fields. The agricultural lands in Ponnaiyar basin are dominated by red loamy soil and clay loam soils.

SRI trial 2013

Field measurements were carried out on up to six components of SRI in selected farmers' fields (n = 26) in five villages located at Kalingarayan basin and six villages (n = 22) located in Ponnaiyar basin during *rabi* 2013. The SRI components were land levelling (LL); planting less than 14 days old young single seedling (YS); square planting at 25 x 25 cm spacing (SP); green manure application (GM); alternate wetting & drying (AWD); and cono weeding (CW). Cono weeding is practised by cono weeder which are made up of plastic materials that uproot weeds and bury them in the mud as result of the push and pull operations. The application of SRI components by the farmers in those villages varied from 17 percent (where only one component of SRI was applied) to 100 percent (where six components of SRI were fully implemented). To

Table 11.4 SRI components applied (in number and %) in each treatments at farmers' fields during *rabi* 2013

Treatments	*LL*	*YS*	*SP*	*GM*	*AWD*	*CW*	*No. of SRI components*	*SRI applied (%)*
T1	×	×	×	×	×	×	6	100
T2	×	–	×	×	×	×	5	83
T3	×	–	×	–	×	×	4	67
T4	–	–	×	×	–	–	2	33
T5	–	–	×	×	–	×	3	50
T6	–	–	×	–	–	×	2	33
T7	×	×	–	×	–	–	3	50
T8	–	–	×	×	×	–	3	50
T9	–	–	–	–	×	–	1	17
T10	–	–	×	–	–	–	1	17
T11	–	–	–	–	–	–	0	0
Total	4	2	8	6	5	5	-	-

Note that the symbol x indicates which SRI component has been in the corresponding treatment

Source: Based on data from ClimaAdapt project (www.climaadapt.org)

accommodate the variability among farmers' adoption levels, 11 treatments with various components of SRI practices including the control were formulated (Table 11.4).

The conventional method of cultivation (T11) was treated as a control and all the other treatments (T1 to T10) were modifications based on the adaptation of SRI principles, either singly or in combinations. Conventional transplanting (CT: control treatment) is characterized by: a) puddling the soils to keep them anaerobic and oversaturated; b) seedlings transplanted normally from 22 days; c) spacing is 10 cm by 15 cm; d) no green manure application but inorganic fertiliser application; e) continuous flooding; and f) use of herbicides to control weeds. Only two treatments (T1 and T7) had less than 14 day old YS planted, but the rest had 25 to 30 days old seedlings planted. Square planting (at 25 x 25 cm spacing) was the most common SRI component, applied in eight of the 11 treatments. The rice variety CO 48 in Kalingarayan basin and ADT 45 in Ponnaiyar basin were planted during *kharif* season (August 2013) and the seedlings were transplanted at a spacing of 15 x 10 cm in T7, T9, and T11. Cono weeding was practised four times at an interval of 10 to 15 days after transplanting (DAT) in T1, T2, T3, T5, and T6. Seven replications were maintained for each of the treatments to analyse some plant growth and yield parameters. Number of plants, number of productive tillers, number of grains per panicle, filled grains (in %), 1,000 grains weight (g), and grain yields were monitored.

Irrigation water was supplied to the SRI fields by open channel. In total, 11 to 14 irrigations were delivered during the whole crop growing season. The SRI fields were irrigated using the AWD method: water was re-applied after disappearance of ponded water and formation of hairline cracks on the soil surface to a depth of 2.5 cm. T1, T2, T3, T8, T9 followed the AWD method of irrigation, but the other treatments applied the normal conventional flood irrigation system. Recommended dose fertilizers (RDF) were applied at the rate of 100: 50: 50 kg for N: P: K per ha, respectively for all treatments. The P and K fertilizers were applied basally at once, but the N fertilizer application was split into three equal dosages, i.e. first application before transplanting, second and third applications at 25 and 45 DAT, respectively.

SRI trial 2014

In 2014, SRI was up-scaled in clusters assuming that each cluster has a similar soil type and uniform management practices were applied, except for the treatments tested. Clusters were defined based on geographical location. SRI treatment composed of 6 components, namely LL, YS, SP, GM, AWD and CW were tested in all SRI clusters in KB and PB basins, in addition to the conventional method used as a control. Each farmer's field was considered as one replication. A total of 14 replications in KB, 11 replications in Ponnaiyar dam and 9 replications in Manpathai village of PB were monitored for each of the clusters (Table 11.5). The total number of farmers' fields were 56 with a total area of 60 ha in KB. In the case of PB, they were 40 farmers' fields with a total area of 13.8 ha. In PB, due to shortage of water, a farmer's field was as small as 0.2 ha under paddy rice.

Table 11.5 Field trials conducted in clusters in Kalingarayan and Ponnaiyar basins during *rabi* 2014

Site	*Cluster*	*Treatment**	*Village*	*No. of farmers' fields*
Kalingarayan (KB)	SRI 1 & CT 1	ASD 16	B.S. Agraharam and S.S. Agraharam	14 & 14
	SRI 2 & CT 2	BPT 5204	Vairapalayam,	14 & 14
	SRI 3 & CT 3		B.P.Agraharam	14 & 14
Ponnaniyar (PB)	SRI 1 & CT 1	ADT 39	Ponnaniyar dam	11 & 11
	SRI 2 & CT 2	ADT 45	Manpathai	9 & 9

* Note that the treatments names refer to rice genotypes

Source: Based on data from ClimaAdapt project (www.climaadapt.org)

Agronomic data collection

The rice genotype BPT 5204 was transplanted on 07 October 2014 in the main field in both conventional and SRI plots. The date of sowing was 15 September 2014 in the conventional plot and 24 October 2014 in the SRI plot. In the SRI plot, 14 days old seedling were planted at a spacing of 25 cm x 25 cm, and in the conventional plot, 22 days old seedlings were planted at a spacing of 15 cm x 10 cm. In the conventional plot, hand weeding was performed twice i.e. 25 and 45 DAT but in the SRI plot, cono weeding was done at 15, 30 and 45 DAT. Five plant samples were collected from a 0.2 ha plot where grain yields were measured. The grain moisture was determined by moisture meter and the grain yield was corrected for difference in moisture content. Agronomic parameters such as number of plants/m^2, number of productive tillers per plant at maturity, number of grains per panicle, filled grains (%), 1,000 grains weight (g), and grain yield (t/ha) were recorded. In addition, cost of seeds, fertilizers, herbicides, pesticides and labour cost were also registered.

Water flow measurements

Water flow measurements were carried out in farmers' field from 0.2 ha where SRI and conventional method of cultivation were applied. The total water flow from PB canal was measured using a cut-throat flume. The water was channelled to SRI and conventional cultivation plots and measured using a water meter (WALTEX M-Horizontal Woltmann meter, Indian make) in the delivery pipe. In the SRI plots, field water tubes were also installed to observe the water level and assist in determining when to irrigate. The plot under conventional cultivation was always under water, ponded to a height of 2.5 to 5 cm. The following measurements were calculated:

$$\text{Total water use (mm)} = \text{irrigation water use (mm)} + \text{rainfall (mm)}$$

$$\text{Water productivity (kg/ha mm)} = \text{grain yield (kg/ha)} \div \text{total water consumed (mm)}$$

$$\text{Water saving (\%)} = [(\text{water used in CT} - \text{water used in SRI}) \times 100] \div \text{water used in CT}$$

Soil sampling, analysis and treatments

Soil samples were drawn from the fields of all participating farmers in the top 15 cm by making a 'V' shaped cut and collecting the soil samples from the sides of the cut. At least five samples were collected from each of the farmer's fields, and a representative sample was taken by thoroughly mixing the collected soil samples. Soil samples were analysed for physical and chemical properties before planting the rice seedlings, and at crop harvest. Organic carbon was analysed by the Walkley and Black method (Gelman *et al.,* 2011). The available N was determined by the alkaline permanganate method (Subbiah and Asija, 1956), available P by 0.5 M $NaHCO_3$ (pH 8.5) (Olsen *et al.,* 1954), and available K by neutral normal ammonium acetate method (Stanford and English, 1949). Dissolved oxygen was determined by the Azide modification of iodimetric method. In SRI and CT plots, four treatments were applied to investigate the effect of organic and inorganic fertilizers on CH_4 and N_2O fluxes from the plots, and also effects on grain yield. These treatments were: T1 (recommended dose of fertilizer, RDF); T2 (RDF + azolla); T3: (RDF + blue green algae, BGA); and T4: (RDF +azolla + BGA).

CH_4 & N_2O sampling and analysis

The closed chamber technique was used to measure direct N_2O-N and CH_4-C fluxes from soils treated with SRI and conventional rice cultivation (e.g. Jain *et al.,* 2013). The chambers were fabricated as recommended by studies on trace gas measurements under field conditions (Denmead, 2008). Open-bottom perplex chambers using 4 mm acrylic sheets with a dimension of 50 cm x 50 cm x 100 cm were fabricated. A battery (12V) operated fan was fixed to the chamber for air circulation in order to avoid plant suffocation, to mix the air inside the chamber and to draw the air samples into air-sampling bags (Tedlar®). Gas sampling was carried out in farmers' fields in PB basin from two different rice cultivation methods. These cultivation methods were SRI and CT. The chamber was inserted 5 cm into the soil. Four gas samples were withdrawn from each chamber at 15 minutes intervals (0, 15, 30 and 45 minutes) using a syringe and one way valve pump immediately after closure, from a surface area of 0.30 m^2. The gas samples were often collected in the morning (09:00–10:00) and in the evening (14:00–15:00). The average of morning and evening fluxes were used as the flux rate for the day (Jayadeva *et al.,* 2009). The gas samples were collected three times a week during the active tillering, panicle initiation, flowering and maturity stages. The average of the seven days was reported as the average daily CH_4 and CO_2 emission rate for the respective stage. The CH_4 and N_2O flux assessment was continued until the maturity stage to detect the trends of emissions from the rice soils. In total, 192 gas samples were collected on 12 events between 12 June to 14 September 2013 (total 70 days).

The CH_4-C and N_2O-N concentrations were analysed using a gas chromatograph (GC, Shimadzu GC-2014) equipped with a flame ionization detector. The GC was calibrated before and after each set of measurements using 1ppm, 2.3 ppm and 5 ppm of standards (Chemtron® science laboratories Pvt. Ltd., Mumbai) to develop a primary standard curve over the concentration ranges. The CH_4-C and N_2O-N concentrations were then determined by peak area and flux was calculated based the equation proposed by Rolston (1986) to estimate CH_4 and N_2O emissions as follows:

$$F = (V/A)(\Delta C/\Delta t)$$

where F is CH_4 (mg/ m^2/hr), or N_2O (μg/m^2/hr) flux rate, V is volume of the chamber above the soil (m^3), A is cross-section of chamber (m^2), C is concentration difference between zero and *t* times (mg/cm^3), and *t* is time duration between two sampling periods (hour).

Statistical analysis

The results in this study were statistically analysed using the Analysis of Variance (ANOVA) technique (Panse and Sukhatme, 1985).The critical significance difference (CD) of the means of the treatments were worked out at 0.05 and 0.01 probability levels.

Results and discussion

SRI growth parameters and yield: rabi *2013*

Figure 11.1 depicts some of the agronomic parameters of rice grown under the SRI (T1) and conventional cultivation systems at the KB and PB sites. At both sites, SRI outperformed conventional plots in the number of productive tillers and in grain number per panicle, although there was no difference in the percentage of filled grains or 1,000 grain weight. In both basins, the highest number of plants/m^2 were recorded in T11 (i.e. the conventional plot) and lowest in T1, T2, T3, T4 and T5 where more than 50% of the SRI components were applied. The wider plant spacing (25 cm ´ 25 cm) used in SRI plots compared with the closer spacing (15 cm ´ 15 cm) applied in the conventional rice cultivation system has contributed to the large difference in the number of plants/m^2 between SRI and non SRI plots, particularly in the early stage of the rice plant (Figure 11.1).

The average number of productive tillers per plant in the conventional plot were 14 and 13 in KB and PB, respectively, which were significantly lower ($p < 0.05$) than all the rest of SRI plots (data not shown). In the SRI plots, the number of productive tillers ranged from 27 (T10) to 43 (T1), where all the SRI components are implemented. This may be due to the roots under SRI having good air circulation and water movement in the soils, enabling them to absorb the nutrients effectively, thereby developing more productive tillers than the paddy rice plants (Krishna *et al*., 2008). The average number of grains per panicle in the conventional plot was 109 and 90 for KB and PB, respectively, and these were significantly lower ($p < 0.05$) than those recorded in most of the SRI plots in both basins (data not shown). However, the percentage of grain filling measured in SRI was slightly higher than the conventional plots. The rice grain yields under SRI plot (T1) in both basins were greater than the conventional plot (T11). At the PB site, the rice grain yield is lower than KB site in all the treatments.

Table 11.6 presents mean grain yield of rice and harvest index in Kalingarayan and Ponnaniyar basins during *rabi* 2013. The mean data for the growth and yield parameters for all treatments showed a statistical difference at the 5 percent level. The difference in means for SRI and conventional plots in all parameters

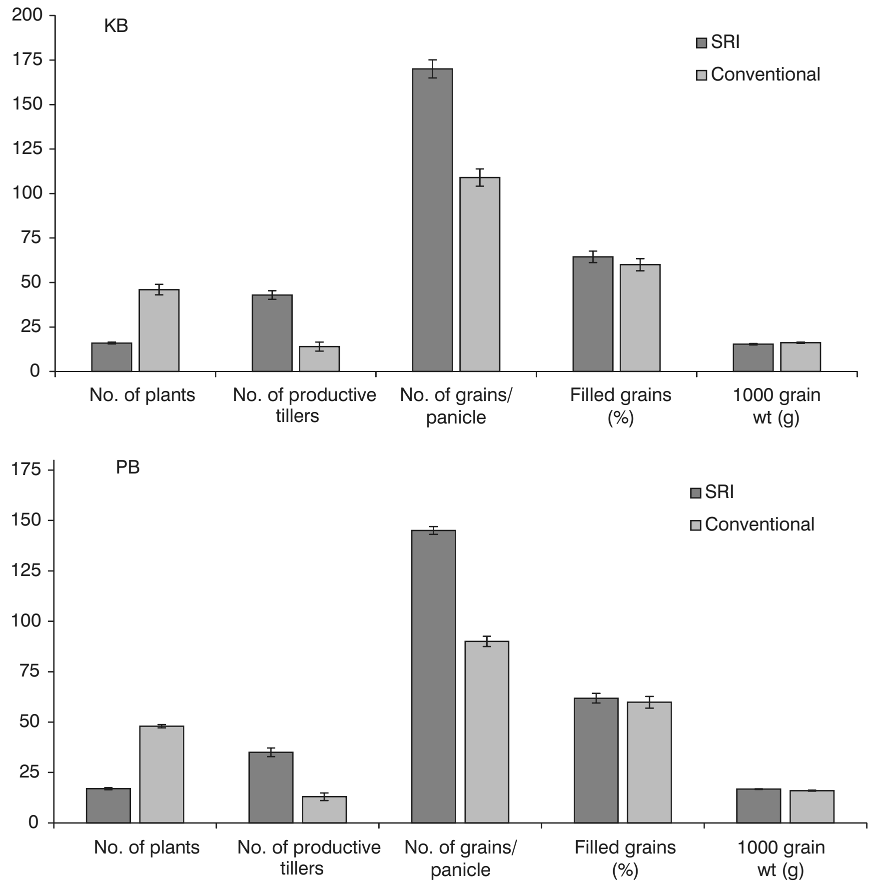

Figure 11.1 Mean values of some growth and yield parameters of rice grown under SRI and conventional in Kalingarayan basin (A) and Ponnaiyar basin (B): *Rabi* 2013.The error bars correspond to the standard errors. Note that the SRI bars represent only T1 which contains all 6 components of SRI

Source: Authors' own analysis, based on data from ClimaAdapt project (www.climaadapt.org)

was significant both at 5 percent and 1 percent levels (Table 11.6). There was no significant difference observed for mean yield between T7 and T9 (where three and one component of SRI was implemented, respectively) at 5 percent level in KB and PB sites. The standard deviation among the treatments was higher for the number of grains per panicle (data not shown) and lower for grain yield in KB, as well as PB sites (Table 11.6).

The highest grain yield was produced in T1 (containing all six components of SRI), averaging 8.74 t/ha across the two sites. In contrast, the conventional flooded system (T11) yielded only 67 percent of T1. Although the experiment was not a factorial design, analysis of certain combinations of components allows the value of particular components to be assessed. For example, adding the square

Table 11.6 Mean yield parameters of rice in Kalingarayan basin and Ponnaiyar basins, *rabi* 2013

Treatments	*SRI practices applied*	*Grain yield (t/ha)*		*% as of T1 (mean)*
		KB	*PB*	
T1	LL, YS, SP, GM, AWD, CW	9.72	7.76	100.0
T2	LL, SP, GM, AWD, CW	8.69	7.06	90.1
T3	LL, SP, AWD, CW	8.04	6.31	82.1
T4	SP, GM	7.58	5.81	76.6
T5	SP, GM, CW	8.38	6.66	86.0
T6	SP, CW	7.28	5.69	74.2
T7	LL, YS, GM	7.11	5.53	72.3
T8	SP, GM, AWD	7.63	6.12	78.7
T9	AWD	7.12	5.44	71.9
T10	SP	6.87	5.33	69.8
T11	–	6.56	5.11	66.8
SEd	–	0.0895	0.0720	–
CD (0.05)	–	0.1791	0.1440	–
CD (0.01)	–	*0.2382*	*0.1915*	–

SEd: Standard error deviation (±); CD: Critical Difference at 0.05 and 0.01 significance levels

Source: Based on data from ClimaAdapt project (www.climaadapt.org)

planting (SP) component alone to the conventional system (T11) increased the grain yield (relative to T1) from 67 percent to 70 percent. Further adding cono-weeding (CW) to SP increased the relative grain yield by another 4 percent to 74 percent. Alternatively, adding green manure (GM) to SP increased the relative grain yield even more to 77 percent. However, adding both CW and GM to SP resulted in a further significant increase in relative yield to 86 percent, indicating the synergistic interactions of SP, CW and GM. This demonstrates the stepwise increases resulting from particular components. Another useful comparison would be to remove particular components from T1 and see the extent to which yield is reduced. For example, T2 contains all components of SRI except YS, highlighting that the removal of this single component reduced yield by 10 percent. Removing GM in addition to YS reduced yield by another 8 percent (to 82 percent of T1).

SRI growth and yield parameters: rabi *2014*

Figure 11.2 shows the mean values of selected agronomic parameters for the ASD 16 and BPT 5204 rice varieties grown under SRI and conventional practices in KB, and ADT 39 and ADT 45 rice varieties in PB. In general, performance of the rice varieties grown under SRI was better than under conventional flooded production at both sites, particularly in relation to the number of productive tillers and the number of grains per panicle. The rice production system (SRI vs CT) had little impact on percentage of grain filling or 1,000 grain weight

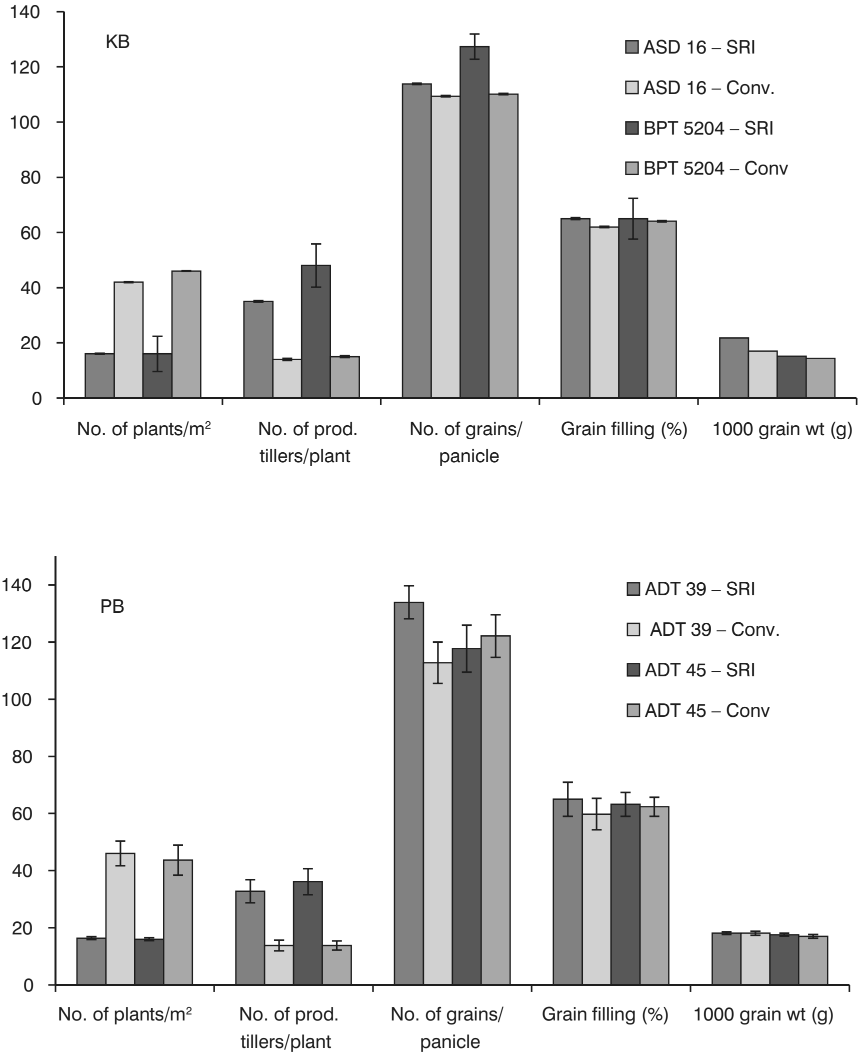

Figure 11.2 Mean values of some growth and yield parameters of rice grown under SRI (with ADT 39 and ADT 45) and CT (with ADT 39 and ADT 45) in KB (A) and PB (B) 2014 *rabi*

The error bars correspond to the standard errors

Source: Authors' own analysis, based on data from ClimaAdapt project (www.climaadapt.org)

Table 11.7 Mean grain yields of rice (t/ha) cultivated under SRI and CT in KB and PB: *rabi* 2014

KB	*Grain yield (t/ha)*	*PB*	*Grain yield (t/ha)*
SRI ASD 16	6.9	SRI ADT 39	7.2
CT ASD 16	5.8	CT ADT 39	5.3
SRI BPT 5204	8.4	SRI ADT 45	6.7
CT BPT 5204	5.4	CT ADT 45	5.5
Variety			
ASD 16	6.4	ASD 16 ADT 39	6.2
BPT 5204	6.9	BPT 5204 ADT 45	6.1
SEd	0.09	SEd	0.10
CD (0.05)	0.21	CD (0.05)	n.s.
CD (0.01)	0.30	CD (0.01)	n.s.
Cultivation method			
SRI	7.6	SRI	6.9
CT	5.6	CT	5.4
SEd	0.07	SEd	0.07
CD (0.05)	0.15	CD (0.05)	0.15
CD (0.01)	0.19	CD (0.01)	0.19
Variety X Cultivation method			
SEd	0.12	SEd	0.13
CD (0.05)	0.26	CD (0.05)	0.27
CD (0.01)	0.35	CD (0.01)	0.37
Cultivation method X Variety			
SEd	0.10	SEd	0.10
CD (0.05)	0.21	CD (0.05)	0.21
CD (0.01)	0.28	CD (0.01)	0.28

SEd: Standard error deviation (±); CD: Critical Difference at 5 % and at 1% levels. (n.s.: not significant)

Source: Based on data from ClimaAdapt project (www.climaadapt.org) at either location or in either variety. This was a similar result to the *rabi* 2013 season.

The effect of varieties, cultivation methods and interaction between variety and cultivation method and vice versa on grain yields are shown in Table 11.7 for the KB and PB sites.

Higher grain yield were recorded from SRI plots than CT plots in both KB and PB sites (Table 11.7). The mean critical differences for SRI and CT cultivation methods for all growth parameters were significant both at 0.05 and 0.01 levels, except for grain filling at 0.01 level and 1,000 grain weight for PB sites only. There was a significant difference in number of plants and tillers at the 0.05 level, but no significant difference observed at 0.01 level for all growth parameters except for 1,000 grain weight (data not shown). A significant difference was detected in grain yield between the rice varieties in the KB site at 0.05 and 0.01 levels, but no significant difference was observed at the PB site. The CD between the cultivation methods was significant in grain yields at KB, as well as PB sites (Table 11.7).

Water savings by SRI

The amount of water used under SRI and CT planting methods is shown in Figure 11.3. The water consumed in SRI was lower than for CT in all crop growth stages except in the 46–60 days after transplanting (DAT) period, when water consumption was equivalent between planting methods (Figure 11.3). In total, 491 and 630 mm were used by SRI and CT, respectively. There was no additional water applied in the SRI and CT plots after 1–15 DAT because the soils were saturated after more than 200 mm water was applied during the field preparation.

Table 11.8 presents the total water used and water productivity under SRI and CT plots. The SRI plots used less water and produced higher yield compared to CT plots. SRI saved about 22 percent of total water applied. The water productivity in SRI was about 1.5 times greater than CT. In other words, the difference between the two methods was about 55 percent which corresponds to the result found by Jagannath *et al.* (2013).

Cost-benefits of SRI

A cost-benefit analysis was carried out for the crops cultivated during the 2013 and 2014 *rabi* and *kharif* seasons in both the KB and PB sites (Table 11.9). In 2013 *rabi*, the rice varieties ADT 45 in PB and CO-48 in KB site were planted in SRI and CT plots. In *rabi* 2014, however, the SRI and CT plots were planted with BPT 5204 in KB site and ADT 39 in PB site. In both production seasons and sites, the total rice production costs were slightly lower in SRI than CT treatment. The main difference between SRI and CT was that total returns were substantially higher in SRI due to higher grain yields (Table 11.9). Calculation of the benefit-cost ratio shows that SRI compared to (CT) gave a significantly

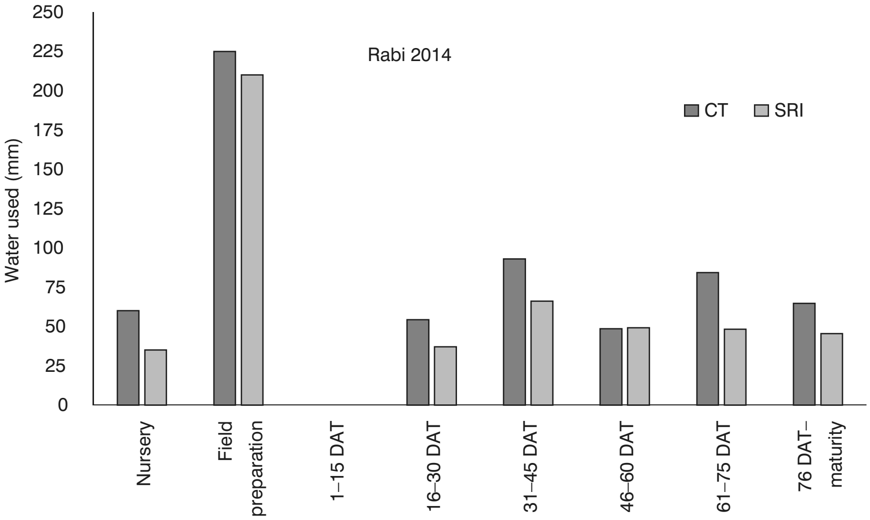

Figure 11.3 Water used by SRI and CT from nursery, field preparation and DAT until maturity stages of rice, *rabi* 2014

Source: Authors' own analysis, based on data from ClimaAdapt project (www.climaadapt.org)

Table 11.8 Water used in SRI and CT plots with grain yield and water productivity in PB during *rabi* 2014

	CT	*SRI*
Total irrigations (no.)	22	18
Water applied (mm)	630	491
Total rainfall (mm)	447	447
Total water applied (mm)	1,077	938
Water saving (%)	–	22
Grain yield (kg/ha)	5,146	6,951
Water productivity (kg/ha mm)	4.77	7.40

Source: Based on data from ClimaAdapt project (www.climaadapt.org)

higher benefit-cost ratio in the range of 1.67 (1.14) in *rabi* 2013 and 1.61 (1.16) in *kharif* 2014 at the PB site. However at the KB site, the benefit-cost ratio was even higher, ranging from 1.90 (1.38) in *rabi* 2013 to 1.71 (1.12) in *kharif* 2014.

Soil nutrients and dissolved O2 contents: **rabi** *2014*

The organic C, available N, P, K and dissolved O_2 contents of the soils treated with SRI and CT, amended with four types of fertilizer are shown in Table 11.10. The combined application of inorganic fertilisers with organic fertilisers

Table 11.9 Economics analysis of SRI and CT cultivation during *rabi* 2013 and 2014 in the PB and KB sites

Particulars	*Rabi 2013*				*Rabi 2014*			
	PB (ADT 45)		*KB (CO-48)*		*PB (ADT 39)*		*KB (BPT 5204)*	
	SRI	*CT*	*SRI*	*CT*	*SRI*	*CT*	*SRI*	*CT*
Land fLease rate)	7,000	7,000	8,000	8,000	7,000	7,000	8,200	8,200
Labour (family)	3,000	3,000	3,000	3,000	3,000	3,000	3,100	3,100
Seed (variety)	150	850	180	950	120	800	160	780
Land preparation and transplanting	12,100	8,700	12,300	9,100	12,700	9,200	13,700	9,600
Herbicides	0	1,450	0	1,400	0	1,500	0	1,350
Fertilisers	2,800	3,200	3,000	3,200	2,100	3,300	2,800	3,300
Organic manures	3,400	4,100	3,500	4,300	1,500	900	1,400	1,200
Pesticides	350	800	300	600	400	985	350	780
Manual weeding	2,200	3,000	2,400	3,300	2,600	3,100	2,750	3,200
Irrigation	1,150	2,600	1,350	2,650	1,300	2,300	1,450	2,600
Harvesting	11,100	11,700	11,400	12,000	11,100	11,700	11,400	11,900
Total cost	43,250	46,400	45,430	48,500	41,820	43,785	45,310	46,010
Yields – paddy (kg/ha)	7,760	5,110	9,200	6,560	7,200	5,300	8,400	5,400
Yields – byproducts (kg/ha)	2,510	3,730	3,230	4,510	2,400	2,300	2,500	2,300
Returns on paddy	65,960	43,435	78,200	55,760	61,200	45,050	71,400	45,900
Returns on straw	6,275	9,325	8,075	11,275	6,000	5,750	6,250	5,750
Total returns	72,235	52,760	86,275	67,035	67,200	50,800	77,650	51,650
Profit	28,985	6,360	40,845	18,535	25,380	7,015	32,340	5,640
Benefit cost ratio	1.67	1.14	1.90	1.38	1.61	1.16	1.71	1.12

All costs are expressed in Indian Rupees/ha, currently, 1 Indian Rupee is equivalent to 0.0157 US \$ (or 1 US \$ ~63.7Rs). n.a. not available

Source: Based on data from ClimaAdapt project (www.climaadapt.org)

Table 11.10 Organic C, available N, P, K and dissolved O_2 contents under SRI and CT cultivation methods

Treatments		*Org C (%)*	*Ava. N (kg/ha)*	*Ava. P (kg/ha)*	*Ava. K (kg/ha)*	*Dis. O2 (mg/L)*	*Grain yield (kg/ha)*
SRI	RDF	0.52	221.1	34.5	434	3.23	6,827
	RDF+ azolla	0.59	231.0	36.0	442	3.42	6,902
	RDF + BGA	0.56	239.8	37.2	452	3.55	6,987
	RDF + azolla + BGA	0.60	249.3	37.6	464	3.69	7,182
CT	RDF	0.52	199.5	33.5	421	1.75	4,814
	RDF+ azolla	0.57	206.5	33.6	431	2.11	4,889
	RDF + BGA	0.55	214.3	36.7	439	2.25	5,339
	RDF + azolla + BGA	0.59	226.5	36.6	448	2.35	5,156

RDF: recommended dose fertilizer; azolla; BGA: blue green algae. Note: results are the outcome of the soil sample analysis drawn on 45 DAT. ADT 39

Source: Based on data from ClimaAdapt project (www.climaadapt.org)

consisting of both azolla + BGA showed higher organic C, available N, P and K, and dissolved O_2 contents in both SRI and CT. The SRI plots (with RDF + azolla + BGA treatment) contained higher nutrients and dissolved oxygen than the rest of the treatments. This indicates that SRI soils were efficient in taking up the soil nutrients and were well aerated and drained. As a result, the SRI plots render higher grain yield than CT. The CT soils were deficient in oxygen and thus were poorly aerated and drained due to the continuous flooding of the rice fields. The soils under RDF contained the lowest organic C, available N, P, K, and dissolved O_2 in SRI as well as CT. The dissolved O_2 content of the CT soils amended with only RDF (1.75 mg/L), was less than the SRI plot treated with combined organic and inorganic fertilisers by over 50 percent.

CH_4 and N_2O fluxes

Among the different systems of rice cultivation, SRI recorded lower methane fluxes than conventional systems (Figure 11.4). SRI cultivation consists of components such as organic fertilisers, square planting, cono weeding, alternate wetting and drying, and enhance aeration in the soils. This has resulted in higher dissolved oxygen contents and higher storage of carbon in the soil (Table 11.10), and lower methane emissions than CT treatments from active tillering to crop

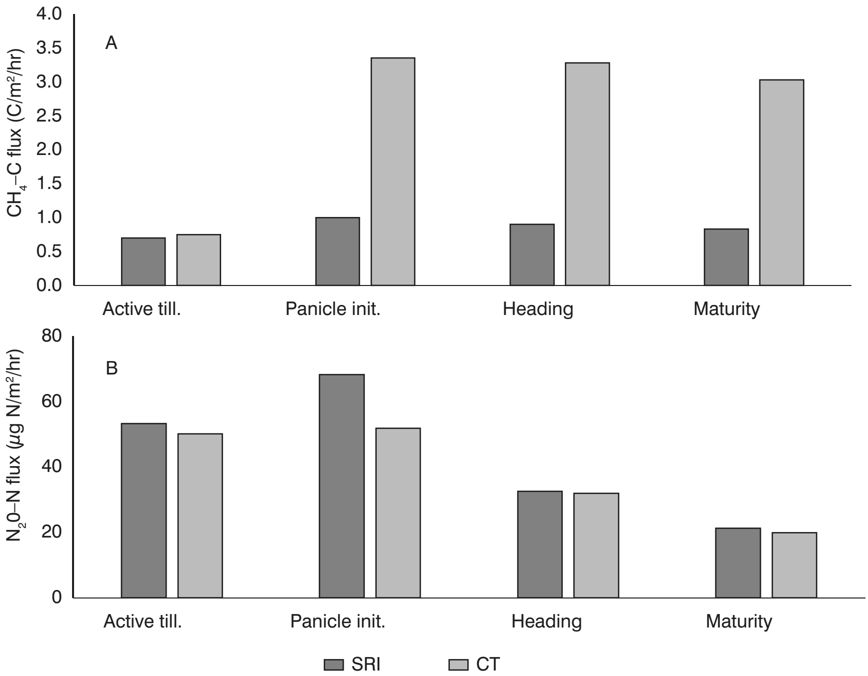

Figure 11.4 Influence of SRI and CT cultivation systems on (A) methane and (B) nitrous oxide fluxes along the growth stages of rice during *rabi* 2014

Source: Authors' own analysis, based on data from ClimaAdapt project (www.climaadapt.org)

maturity stages (Figure 11.4A). Cono-weeding stirs the soil, facilitating aeration and increasing the soil's redox potential (Eh) (Rajkishore *et al.,* 2013).

Methane flux increased progressively with the advancement of crop stage, reaching the highest value at panicle initiation and slighly declining towards maturity. It is likely that more intense reducing conditions at the panicle initiation stage that might have favoured the activities of methanogenic bacteria, contributing to highest methane emissions at this stage. However, the N_2O emissions from SRI plots were higher than CT at tillering and panicle initiation stages, but similar at heading and maturity stages. Hence, there is a trade-off between enhanced N_2O emissions and reduced CH_4 emissions from rice soils in SRI, as opposed to the conventional flooded fields which normally favour complete denitrification of nitrates and/or ammonium to gaseous nitrogen (N_2) thereby reducing N_2O emissions (Fig. 11.4B).

Adoption and upscaling SRI: opportunities and constraints

Some of the available opportunities that could be used to disseminate and upscale SRI to many farmers on a wider area are discussed below:

Opportunities to adoption and up-scaling SRI

1 *Adaptation to climate change:* The soils under SRI plots were well aerated and drained since the dissolved oxygen content (3.2 to 3.7 mg O_2/L) was greater than the soils under the conventional plots (1.8 to 2.4 mg O_2/L). This has contributed to increase water use efficiency. The SRI plots used 22 percent less irrigation water in the *rabi* 2014 season, on average, compared with traditional flooded production (see Table 11.8). Studies carried out in others countries showed that the irrigation water savings varied from 10 to 40 percent (Table 11.1). Water savings also translated into reduced production costs in terms of labour and power. The cost-benefit analysis in Table 11.9 shows that the cost-benefit ratio (CBR) under SRI was about 1.5 times greater than CT. Other researchers found similar results on CBR (Adusumilli and Laxmi, 2011). The water savings resulting from SRI could be used to grow other food crops or could be reallocated and used for domestic and/or industrial purposes. Moreover, the time savings compared with CT could be shifted to other livelihood activities such as off-farm work, which gives additional income for the household. Hence, adopting SRI practices in rice-based cropping systems could be a part of the solution to water scarcity related to climate change. Moreover, SRI builds up farmers resilience to the changing climatic conditions by producing 'more from less' while reducing GHG emissions.

2 *Mitigation to GHGs emissions:* One of the benefits of SRI is mitigation of net CH_4 emissions from flooded rice soils as shown in Table 11.2, and this has been confirmed by this case study. The methane emissions from SRI plots were lower than CT plots (Figure 11.4a) but the cumulative N_2O emissions from SRI were higher than CT plots (Figure 11.4b). This highlights the trade-off effects of SRI in mitigating GHG emissions. Higher losses of N_20-N indicate that the aerobic/anaerobic changes in SRI are probably associated with less efficient use of N fertilizers. However, proper nitrogen management such as applying need-based N fertilizer applications, use of slow release urea fertilizers and deep placement of N may curtail the increments of N_2O emissions, increase N use efficiency, and contribute to reduced Global Warming Potential (GWP). Field measurements by Jain *et al.* (2013) have shown that GWP was reduced by 28 percent in SRI over flooded paddy cultivation. Moreover, mitigating the net CH_4 emissions from rice fields increases carbon storage in soils and the organic matter content which, in turn, improves soil properties. In general, mitigating GHGs through SRI could help farmers earn carbon credits if policy mechanisms are developed.

3 *Increasing productivity and food security:* SRI increased the number of productive tillers and grains per panicle compared with CT (Figures 11.1 and 11.2). Moreover, the grain yields from SRI plots plus the harvest indexes were higher than CT plots (Tables 11.6 and 11.7). Similar results have also been found for grain yield under SRI and paddy in other rice growing

countries (see Table 11.3). The water productivity from SRI was 1.5 times greater than CT (Table 11.8). The higher water productivity gives more crop per drop and reduces the irrigation water requirement (Figure 11.3) with higher labour productivity. The benefit-cost ratio under SRI (1.6 to 1.90) was higher than CT (1.1–1.4) due to higher yields obtained from less production costs. The summed effects of SRI enhances the multi-dimensional aspects of food security i.e. food production, food availability, access to food, food utilization and stability.

Constraints to adoption and up-scaling SRI

The aforementioned benefits of SRI fulfil the core principles of CSA. These benefits can be achieved if all the components of SRI (see Table 11.4) are implemented in a given rice field. Otherwise, partial implementation of the components of SRI will at least achieve some benefits aligned to CSA principles. Under changing climate conditions, the conventional method of rice cultivation does not offer as many opportunities for farmers as SRI. Despite these facts, the implementation and adoption of SRI by many rice farmers in different parts of the world remains either low, or the rate of adoption is slow. This situation also applies for the Indian rice farmers. For instance, the adoption rate of SRI by farmers was 5 percent in the Kalingarayan basin (n = 502) and 10 percent in the Ponnaiyar basin (n = 384) in Tamil Nadu (ClimaAdapt, 2013).

Although rice farmers in India have seen the advantages of applying SRI in the neighbouring farmers' fields or demonstration sites, they are reluctant to implement all six components of SRI listed in Table 11.4. Rather, farmers practice one, or a few of the SRI components in combination, or follow the conventional way of rice cultivation unless situations force them otherwise. One notable example is the 2012 summer and winter seasons, when the monsoon rainfall was low, forcing many farmers to apply SRI because they faced severe water shortages. This has resulted in a 30 percent increase in farmers' productivity (ClimaAdapt, 2013). There are several reasons why farmers are reluctant to apply all of the SRI components.

1. *Changing farmers' perceptions towards SRI:* Planting more than one seedling has been practiced by farmers for many decades under conventional rice cultivation. Farmers are concerned about the survival of a single seedling if they adopt the YS component of SRI, fearing that this practice will lead to crop failure. Moreover, farmers believe that the yield from conventional rice cultivation is reasonable considering the cost of production. Therefore, it remains a challenge to change farmers' mind-set to a new method of rice cultivation such as SRI. Farmers also assume that SRI is not suitable to their soils. Wider spacing is perceived as waste of land area (SP, another SRI component).
2. *Shortage of inputs:* Although farmers show a willingness to practice components of SRI such as field levelling (LL) and cono weeding, they

encounter a shortage of farm implements such as cono weeders and levelling implements. These implements are also unaffordable to small-holders due to a lack of capital. Moreover, there is a shortage of good quality water for irrigation, especially for those fields that are near urban centres, as toxic substances are discharged into the irrigation canals.

3 *Supply of irrigation water and power:* As most of the irrigation schemes in the lowland rice areas are dependent on a power supply, irrigating at the right time is constrained by frequent power cuts in the irrigation areas. This deters farmers from applying AWD (a component of SRI), since they are not sure when the next power will come, and for how long it will last.

4 *High labour cost:* There is a shortage of skilled labour for transplanting at the right time. The labour costs are high for weeding and for applying green manures (an SRI component). Close follow-up and monitoring of crop growth is required while implementing SRI compared with CT, and this increases the cost of labour to farmers.

5 *Inadequate extension and CC awareness:* The local farmers lack knowledge on SRI principles, applications, and climate change impacts because of weak extension services and the lack of training. For instance, about 45 percent of the farmers interviewed in KB are not aware of the change in climatic conditions (ClimaAdapt, 2013). Farmers face problems in maintaining nurseries (e.g., the rice seedlings were scorched due to intense sunlight when plastic sheets were used). Farmers' in Tamil Nadu have some difficulty in using cono weeders in clayey soils. Demonstration through in-field trials and training farmers on SRI practices should be promoted in order to enhance adoption and upscaling SRI.

6 *National policy frameworks*: There are no national policy frameworks supporting the dissemination and uptake of water-saving technologies such as SRI in the rice growing countries of SSA and Asia, including India (Reddy and Venkatanarayana, 2013). Although SRI was introduced to India 15 years ago, there are still controversial issues raised by farmers, researchers and policy makers with regard to SRI's performance in increasing adaptation to CC impacts, reducing GHG emissions, and increasing yields and food security. Recently, some of the recommendations from the Climarice I and II projects (i.e. introducing modified cultivation methods such as SRI) are now being included in the final draft of State Climate Change Action Plan for the Tamil Nadu state of India.

Conclusions and recommendations

The performance of SRI in relation to the three core principles of CSA (i.e. increasing adaptation to CC, mitigation of GHG emissions, and increasing productivity and food security) have been reviewed by analysing research results in different rice growing countries of Asia and SSA. According to these publications, SRI has outperformed conventional rice cultivation with respect to increasing adaptation to CC impacts (Table 11.1), reducing GHG emissions, particularly CH_4 (Table 11.2), and increasing yield (Table 11.3). These results are also consistent with the case study from Tamil Nadu state (India) which demonstrated the superiority of SRI compared to the conventional planting method in the various plant growth and yield parameters (Tables 11.6 and 11.7), adaptation to water scarcity (Table 11.8), economic advantages in terms of the benefit-cost ratio (Table 11.9), and mitigation of CH_4 emissions (Figure 11.4a). However, potential trade-off effects have been observed by SRI (Figure 11.4b) in terms of increased N_2O emissions from soils, posing a concern to the implementation and adoption of SRI. Furthermore, some studies on SRI do not demonstrate increases in grain yield compared with conventional flooded rice production.

The beneficial effects of SRI suggest that this water-saving technology could be up-scaled. Farmers will only adopt the full components of SRI on a large scale if they actually benefit from using the technology. The interactions among researchers, policy-makers and stakeholders, including farmers, should be strengthened to increase our science-based knowledge of SRI, enabling us to develop policy guidelines targeting SRI adoption and, if appropriate, up-scaling activities. The following measures could help to promote the adoption and up-scaling of SRI at the local level:

- demonstrating SRI performance in relation to CSA principles to farmers and other key stakeholders;
- raising awareness campaigns and training on principles and applications of SRI and climate change impacts on rice production;
- providing low-cost levelling equipment and markers from local suppliers;
- promoting hand-held motorized cono weeders; and
- developing policy guidelines on water use for agriculture and law enforcement procedures.

Notes

1 Rhe *rabi* cropping season (in India) is from October-March (winter).
2 The *kharif* cropping season in India is from July –October during the south-west monsoon.
3 http://www.indiaenvironmentportal.org.in/files/file/tamil%20nadu%20climate%20change%20action%20plan.pdf

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