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Foreword

Rice, the most widely grown and consumed cereal crop, is the lifeline for more than half of the world's population. The introduction of high-yielding varieties, fertilizers, pesticides and irrigation has improved rice yields significantly and expanded the area under which rice is cultivated. However, two of the challenges to sustained rice production are the lack of adequate water for irrigation and the increased costs of cultivation. Traditionally cultivated paddy crop takes about 3,000 5,000 liters of water to produce 1 kg of rice. While the burgeoning population is escalating the demand for more rice thereby seriously threatening has started playing havoc with the periodicity and intensity of rainfall rice cultivation across regions. Despite this challenge, rice production will need to increase dramatically in the next decades to meet the demands of a growing population. This increase has to be accomplished with less per capita land, less reliable water supplies, less degradation of the environment, and less drain on the resources of smallholder farmers, who constitute the majority of the world's poor. Finding local solutions to food production is essential to eliminating hunger and providing insurance against rising food prices. The System of Rice Intensification (SRI) is perhaps the best current example of options available to farmers and nations to promote community-led agricultural growth, while managing soil and water resources more sustainably and even enhancing their future productive capacity. The SRI, a knowledge-based low-external input technology, developed in the 1980s in Madagascar to benefit farmers with small landholdings, promises higher yields with no deleterious impact on natural resources at affordable costs for poor smallholder farmers. It offers rice farmers yield increases and other benefits whilst using less water, provided this is done in conjunction with other changes in how they manage the plants, soil and nutrients. Some researchers also criticized by saying that eventually, SRI will go the way of other non-science and disappear into murkiness. No doubt the admirers of SRI will continue in their advocacy and some funding agencies will waste money by diverting it from hypotheses developed with logical consideration of the relevant theory and substantive preliminary experiments. The lesson of this exchange is how tenuous, and special, is the role of scientists in helping societies to invest wisely in the pursuit of knowledge and technological advances.

Through an extensive search of the literature, the authors have compiled comprehensive details of scientific basis and truths of SRI. I am confident that this publication may serve as an important document for the researchers, teachers and students.

(A.K. Nayak)
Director

Preface

The System of Rice Intensification (SRI) is not a new technology, not a fixed package of practices. Rather it is a set of ideas and insights, some old and some new, all focused on how to get more benefit from available resources. The SRI story is more than agriculture; it is equally about people, their needs, their capabilities, their limitations, their altruism, and their creativity. It is about social, economic, cultural and other relational phenomena as much as it is about physical and material relationships. In many respects, SRI is about potentials – socio-cultural and bio-physical – and about the expression of potentials within plant seeds, within soil systems and within human minds and spirits. SRI concepts and methods show how to create better growing environments for rice and other plants; thereby, raising the productivity of the resources - land, labor, water, seeds, and capital - that are already controlled by farmers. More than two decades ago, the SRI was developed in Madagascar based on certain insights into how to improve the growing environment for rice plants by changing certain long-standing cultural practices. Application of SRI principles has helped small farmers in that country to greatly increase their grain yields, from 2 t ha^{-1} to 8 t ha^{-1} and sometimes more on soils that were evaluated as poor or very poor. The main one is bringing down the irrigation water requirement by nearly 30-40%. This alone should be attractive to water managers and to decision-makers who are responsible for ensuring adequate water supplies for agricultural, industrial and domestic uses.

SRI has faced the criticism of a number of sceptics, despite growing popularity among farmers all over the world. Most farmers likewise, no understanding how "less can produce more" have found it difficult to believe that SRI methods, using a seed rate only 10% of what they presently use, can give them doubled yield, yet it does. SRI has been found to have a number of advantages beyond the most obvious one of increasing rice productivity. According to critics the SRI has no major role in improving rice production generally. Intrinsic yield limits are set by the combination of genes in the rice plant and the environments in which rice is grown. Raising those limits will require fundamental changes in the efficiency with which natural resources can be used by the rice plant and in the management systems which enable the crop to fully exploit its genetic potential. It can be said that the model predictions presented the extraordinarily high yields obtained using the SRI in Madagascar are probably the consequence of some form of measurement error.

This research bulletin provides scientific basis of SRI principles, myths and truths of SRI and its impact in India. We believe that this publication would serve as a useful document to researchers, students, teachers and extension workers.

Authors

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System of rice intensification, its origin and spread

Rice feeds more than half of the people in the world; but not well and not for much longer. As the population rises, so does the demand for rice, yet the yields of the crop are leveling out. The existing system of paddy production, particularly green revolution technology is input intensive and favors cash rich farmers. Increasing prices of agricultural inputs prevent poor farmers from completely adopting modern production technologies (Stoop et al., 2002). Among the constraints, water scarcity appears to be a major challenge affecting rice production across the globe. More than 80% of the fresh water resources in Asia are used for agriculture of which about half of the total irrigation water is used for rice production (Dawe et al., 2003). Therefore, future rice production depends on how we improve the water use efficiency of the rice crop. Production of "more rice crop from every drop of water" will have to be the guiding principle for the future.

There are several options to improve the water use efficiency in rice production. Zero tillage, Alternate Wetting and Drying (AWD), Aerobic rice, Integrated Crop Management (ICM) and System of Rice Intensification (SRI) are some of the alternative technologies to combat water scarcity (Bouman and Tuong, 2001). SRI method has an edge over the former methods as water-saving does not have penalty on yields in this system. Therefore, efforts are being made in many countries to popularize SRI to overcome the challenges of water shortages.

During the last decade, the SRI as an alternative method of rice cultivation has received considerable attention both in print as well as from farming communities. System of rice intensification is not a technology, but rather a set of ideas and insights. It is a whole package of agronomic approaches which together exploit the genetic potential of rice plants; creates a better growing environment (both above and below ground); enhance soil health; and reduce inputs (seeds, water, labour). SRI can increase farmers' rice yields, while using less water and lowering production costs (WWF, 2007).

The SRI methodology was synthesized in the early 1980s by Fr. Henri De Laulanié, S.J., who came to Madagascar from France in 1961 and spent the next (and last) 34 years of his life from 1961 until his death in 1995 working with Malagasy farmers to improve their rice production. In conventional rice agriculture, the plants spend most of the season partially submerged. During a 1983 drought, which prevented many farmers from flooding their paddies, de Laulanié noticed that the rice plants - particularly their roots - showed unusually vigorous growth. He noticed that two innovative farmer practices - transplanting single seedlings and keeping the soil moist rather than continuously saturated were more productive. He added two practices, planting single seedlings in a square pattern and using a rotary-hoe perpendicularly in two directions. With the use of 15 day-old seedlings, along with the other practices that he had assembled, Fr. Laulanié recorded a remarkable difference in plant growth. He named this the system of rice intensification (Uphoff, 2005), but it took another two decades for SRI to become known to the rest of the rice world.

Though SRI was discovered in 1983, benefiting from some serendipity, it took some years to gain confidence that these methods could consistently raise production so substantially. Since 2001, the SRI experience was initiated by Metta Development Foundation, in Myanmar to improve the basic food security status of farmers (Kabir, 2008). Positive results from SRI methods have been reported from the Philippines, Cambodia, Myanmar, Laos, Sri Lanka, Bangladesh, Gambia, Sierra Leone, China, India, Indonesia, Iraq, Iran, Nepal, Vietnam and Cuba. Yield increases of 50 % to 100 % are common, with sometimes even a tripling of yield (Yamah, 2002). On the basis of field experiences from some Asian and African countries reported that the average rice yield with SRI was to be double the current average yield (Uphoff, 2002; 2003).

Principles of SRI

According to proponents, SRI encompasses a set of five principles, each of them fairly simple, but working synergistically with the others in order to achieve higher grain yield (Uphoff, 2000).

1. Early transplanting

The growing conditions under SRI facilitate an optimum environment for tillering expression (de Laulanié, 1993). The basic key principle of SRI is transplanting of young seedlings around 8-15 days old, *i.e.* prior to the start of the 4th phyllochron of growth. Phyllochron, is the interval of leaf emergence (Nemoto et al., 1995), it varies in a function of temperature, day length, nutrition, light intensity, planting density and humidity (Nemoto et al., 1995). The first tiller off the main stem appears at the fourth phyllochron, whereas, De Laulanié had already found that if the rice seedling is transplanted later than the third phyllochron, the resulting plant will lose all of the incoming tillers from this first row of tillers which represents about 40% of the total tillers, and that any further delay of transplantation leads to a bigger loss of tillers (Association Tefy Saina, 1992). Hence, the proponents of SRI recommended transplanting of seedlings during the

Table 1. The relationship between phyllochrons, the potential development of new tillers in each phyllochron, and the cumulative number of tillers that can be produced during the vegetative growth phase

Phyllochron	Number of new tillers	Number of cumulative tillers
1	1 (Main stem)	1
2	0	1
3	0	1
4	1	2
5	1	3
6	2	5
7	3	8
8	5	13
9	8	21
10	13[a]	34[a]
11	21[a]	55[a]
12	34[a]	89[a]
13	55	144
14	89?	233?

[a] Laulanie (1993) observed that the maximum number of tillers possible was not likely to be achieved beyond the ninth phyllochron, possibly because of "crowding". The numbers he reports as being added in the 10th, 11th and 12th phyllochrons are 12, 20 and 31, for a total of 84 at the end of the 12th phyllochron. Farmers in Madagascar using SRI methods most skilfully can produce plants with more than 100 fertile tillers; the highest number reported is 140. This implies that the plant has reached its 13th or even 14th phyllochron of growth.

(Source: Stoop et al., 2002)

third phyllochron, *i.e.* when the plant has still only two leaves (Laulanié, 1993). The use of younger seedlings with SRI contributes to better root and shoots characteristics with greater uptake of N and Mn compared to older seedlings (Mishra and Salokhe, 2008).

2. Transplanting of a single seedling per hill and wider spacing

Conventional methods are characterized by transplanting of more than 3 or more seedlings per hill. Planting more seedlings per clump in closer spacing is thought to provide farmers assurance that if one plant dies, others can still grow and therefore a lower percentage of hills will be missing. In contrast, SRI recommends transplanting of one seedling per hill under wider spacing (Association Tefy Saina, 1992). Recommendation of transplanting single, young seedlings at wide spacing has many advantages, San-oh et al. (2004) confirms that hills containing single plants had a greater number of crown roots compared to hills produced from three plants. Laulanie emphasized the need to handle the young seedlings very carefully when removing them from the nursery, not separating the seed still attached to the root. The time between uprooting and transplanting should be minimal (15–30 min), and seedling roots should be kept moist during this time. Seedlings should be transplanted only 1–2 cm deep in the mud, ensuring that the roots are laid in a horizontal position so that the root tips can easily resume their downward growth.

Researchers reported that a single rice plant could express its tillering potential better than a larger number of plants in a hill (Joelibarison, 1997). Transplanting three seedlings together in a close spacing impeded rice growth in that the adjacent plants had to compete for nutrients, space and light. This competition repressed root growth and proliferation. When root systems are poorly developed, the plant devotes its energy for developing the seedlings in height to the detriment of the production of tillers (Joelibarison, 1997).

Well-developed root systems of hills from single plants enhance the synthesis of cytokinins and also maintain higher cytokinin fluxes from roots to shoot during the ripening stage, which helps to maintain higher levels of Rubisco in the leaves and a greater photosynthesis rate compared with three plants in each hill (San-oh et al., 2006). Such physiological changes in SRI plants could be one of the reasons for the better grain filling and higher grain yield seen with SRI methods.

Contrary to the first principle, rice is a remarkably well-adapted, aerenchymous wetland plant. The aerenchyma tissue in leaves and culms enables oxygen to move rapidly to the roots (Armstrong et al., 1991; Raskin and Kende, 1985) and sufficient oxygen leaks through the roots into flooded soils to affect biochemical activity in the rhizosphere (Begg et al., 1994; Kirk, 2003). The suggestion that very wide spacing could somehow release underexploited growth potential largely rests on the assumption that mutual shading in dense crop canopies leads to low yields, which has long been an attractive from a spacing of 20 cm x 20 cm, yields declined as the spacing increased. The effect of the number of seedlings transplanted per hill has also been studied for nearly 100 years (Rodrigo, 1924; Zhong et al., 1999) and there is no evidence that transplanting a single seedling per hill would increase yield. Transplanting two or three seedlings per hill is a common practice undertaken to prevent the loss of hills caused by damage from pests.

3. Mechanical weeding

One of the main purposes for flooding rice paddies with some controlled drainage is for weed control (Sahid and Hossain, 1995). Rice fields are kept flooded until aquatic weeds develop. Once they start to invade the rice field, the field is drained in order to kill the aquatic weeds. Thereafter, rice field is re-flooded with standing water again when terrestrial weeds start to dominate. This is the traditional way for managing weeds in conventional flooded rice systems.

With SRI, weeds are controlled by the use of mechanical weeding initially with rotary pushed weeder and now-a-days with cono weeder. The system relies on early and frequent weeding which varies from 3 to 4 times throughout the cultivation period. The first series of weedings are done about 10 days after transplantation and the others in a frequency of 10-20 days (Association Tefy Saina, 1992).

Cono weeder has several other advantages apart from weed control:

- Weed biomass is incorporated into the soil, adding organic carbon
- The nutrients taken up by the weeds return to the soil
- The churning up of the soil activates microbial, physical and chemical processes which are beneficial to crop growth
- If fertilizer top dressing precedes weeder operation, fertilizers are incorporated and nutrient loss by leaching is reduced
- Some earthing up takes place when the weeder is used. This makes the plants produce new roots which increases root activity.

4. Maintaining moist soil under non-saturated conditions during the vegetative phase

Irrigated rice plants are grown under standing water throughout the season because most farmers and scientists believe that rice performs well under flooded conditions. Rice and water are all linked together from the field to the pots.

Under flooding, rice roots alter their root cortical cells by the creation of air pockets (aerenchyma) to facilitate oxygen transport to roots since the concentration of soluble oxygen in the water/soil interface is very low and the diffusive transport of oxygen is about 10^4 times lower in water than in air. Such cell lysis leads to the formation of gas-filled cavities or lacunae (Vartapetian, 1993; Drew, 1997; Puard et al., 1999). These lacunae enhance the transport of oxygen from the shoot to the root tip. Puard et al. (1999) noticed the same mechanism when he planted an upland rice variety in a lowland condition with standing water. The lack of oxygen leads to more aerenchymatous spaces in the root systems. Flooded conditions have been, however, found to lower yield.

Rice plants, when grown under saturated condition, develop more hairy, fine and branched secondary adventitious and surficial roots near the root-soil interface in order to absorb the dissolved oxygen in the oxidized layer close to the water-soil interface (Obermueller and Mikkelsen, 1974). The elongation of the root system for nutrient uptake is repressed. Whereas, when rice is grown under intermittent dry and flooded conditions, the same condition as that of the SRI system, there are fewer surficial roots and more tap roots and primary roots. Such rooting pattern is apparently the result of the soil aeration brought about by the intermittent drainage.

5. Compost application

Proponents of SRI recommend the use of organic fertilization (compost) instead of chemical fertilizer. The idea is to capitalize on the biological resources and organic matter in the compost and to maintain optimum biological activity of the soil. Organic fertilization is thought to improve the soil structure and the continual release of nutrients. Organic nutrient sources are important components of the nutrient cycle in agroecosystems and should be utilized where they are cost-efficient and available. Effects of organic matter applications on soil quality and crop yields generally become clearer after several years of continuous applications. However, numerous long-term experiments, conducted in upland and lowland cropping systems in different climatic regions, have demonstrated that the continuous use of organic amendments, at affordable rates, does not lead to significant yield advantages compared to systems that are managed with judicious and balanced use of mineral fertilizers (Dawe et al., 2003; Edmeades, 2003).

Previously published comparisons of SRI with traditional management practices (Fernandes and Uphoff, 2002) tend to be confounded because the conventional management treatments often do not represent current best practice in modern rice production. Dobermann (2004) hypothesized that the benefits of SRI over conventional rice management are likely to be small in well-managed rice crops grown on fertile rice soils with no specific constraints such as potential Fe-toxicity. Results from Sheehy et al. (2004) provide experimental and theoretical evidence to support this hypothesis. Achieving critical concentrations of nutrients in the biomass throughout growth is essential for high yields in most crops (Greenwood et al., 1990) and in rice it is crucial to do so during reproductive growth (Horie, 2001).

Success of SRI depends on the location and resources available, SRI principles were modified by people of different parts of the country according to their convenience as it is not always possible to implement all the SRI components at the same time in the fields. Some critiques have explicitly accepted that SRI practices have substantial advantages over farmers' practices in rice production, but then deflected the discussion by invoking vaguely-defined BMPs as a standard of comparison that has little relevance to the majority of the world's rice farmers (McDonald et al., 2006). The insights and principles for attaining higher yield gathered under the rubric of SRI methodology deserve more and continuing attention by researchers to fill in fundamental knowledge gaps and to address the synergies of individual SRI components for diverse rice ecologies and production systems (Dobermann, 2004). It is quite convincing that there are no shortcuts to achieving increased, sustainable crop yield. Hence comprehending the complexity of plant growth and yield under SRI management needs further critical appraisal through detailed research (Sinclair, 2004).

Myths and truths of SRI

SRI has been characterized as 'voodoo science,' said to be based on unconfirmed field observations (UFOs), with the high yields reported being described as a 'consequence of measurement error' (Sheehy et al., 2004). On the other hand, significantly large contributions to the literature have documented enhanced rice productivity, water saving and higher returns with SRI management. There has been enough farmer satisfaction with SRI that it has emerged as an alternative rice production system, showing benefits now in 39 countries around the world.

In the literature available on SRI, on one side there are reports of rapid acceptance and significant benefits among farmers, while on the other side there is controversy among rice scientists regarding its reported superiority over standard rice cultivation practices. These attractive claims have been hotly disputed in the pages of scientific journals. At best, the critics have been prepared to concede that SRI might be suitable for some poor and marginal farmers and/or for certain rice-producing areas with poor soils, like the poor upland districts of Madagascar where it was first developed, but these are relatively atypical. The critics suggest that the dramatic results reported for SRI could be an artefact of simple good agronomy, since any intensification of farming practice – e.g. the improvement of soil fertility – would inevitably have a big impact in any context where a farmer's existing methods deviate substantially from recommended best management practices (BMPs). One claim that has annoyed some rice scientists is the suggestion that SRI methods unlock a hitherto unsuspected genetic potential within the rice plant itself. They argue that the methods and conditions for achieving the maximum potential yield from rice are already well known and that the yield ceiling is determined by strict physiological limits that are well understood both conceptually and experimentally. They argue that overcoming these biological limits is the urgent task for plant breeders and genetic engineers, in order to transform the very yield potential of rice (Sheehy et al., 2004).

According to Sheehy et al. (2005), the advocates of the system of rice intensification (SRI) have claimed both the world record for rice yield and the highest yields (by a substantial margin!) for any grain crop (Rafaralahy, 2002). This is curious because none of the usual information expected in support of these 'fantastic yields' was presented to support the claim. Data were lacking of concerning cultivar, experimental design, statistical errors, dates of planting and harvesting, soil types, fertilizer inputs, weed control, disease control, insect control, water management and the weather? Was the information withheld because they wanted to repeat the experiments and publish their incredible results in Nature or Science, before others beat them to it? Did they pause and wonder if they had discovered 'super' rice with a yield potential beyond that of any known grain crop? Oddly, the answer to both of those questions is no. Perhaps it escaped their notice that the energy required to achieve such a yield is well beyond the thermodynamic capabilities of plant photosynthesis and crop use of solar energy. Their carelessness with 'discovery', the pinnacle of scientific achievement, was matched only by their indifference to the commonly accepted protocols and principles of agronomic science (Sinclair and Cassman, 2004).

SRI advocates take a more applied view of agricultural science. They argue that research should be geared towards the development of crop management techniques and seed varieties that suit marginal conditions, where both the farmers' needs and the scope for agricultural improvement are great (Stoop et al., 2002; Uphoff et al., 2008). They argue that SRI allows poor farmers to apply the resources they have at their disposal, such as skill and labour, rather than expensive external inputs like chemical fertilizers and certified seeds. They argue that SRI is a ''civil society'' innovation' (Uphoff, 2007) that spreads spontaneously from farmer to farmer and country to country because farmers find it to be accessible and beneficial. In this respect, the SRI promoters' argument implicitly draws attention to the material power of corporations, which is inscribed in commercial agricultural technologies in the form of proprietary rights and reflected in pricing structures and distribution systems. SRI advocates complain that scientific critiques of SRI have been based on theoretical models of rice physiology, which they say can hardly refute the dramatically increased yields that have been observed in farmers' fields (Stoop and Kassam, 2005). Their critics object that few of these reports of success have been based on rigorous scientific analysis or published in peer-reviewed journals (Sheehy et al., 2005). In response, SRI's supporters stress its 'empirical and experiential' origins as crucial characteristics of the system. Their point echoes phrases that one often hears in discussions with SRI-promoting organizations and extensionists, such as 'the farmer (only) has to see it for him/herself'.

Sheehy et al. (2005) further claims that like most advocates of nonsense, Stoop and Kassam (2005) suggest that it is the role of scientists to seek verification and confirmation of the SRI. They seem unaware that every genuine test of a theory, or a hypothesis, is an attempt to falsify it (Popper, 1989). Their sole test of the validity of any investigative work concerning SRI is whether it confirms their ideas. Indeed, in their letter they focus on claims that the work critical of SRI (Dobermann, 2003; Sheehy et al., 2004; Moser and Barrett, 2003) is flawed for not including a long list of mysterious components or, worse, they suggest that the authors and the 'anonymous' referees are part of a conspiracy of ignorance or vested interests. Such claims are not unusual outside the community of genuine scientists. The criticisms of Stoop and Kassam are not new, and the same comments occur repeatedly when members of the general public are disappointed that scientists do not eagerly pursue unsubstantiated, miraculous observations (Park, 2000).

Initial criticisms of SRI came from many rice scientists and they rejected the validity of reported yield increases, arguing that the energy requirements for achieving such high yields with SRI management are beyond the thermodynamic capabilities of plant photosynthesis and the crop's use of solar energy. Researchers suggested that the reports of remarkable SRI performance reflected some misunderstanding of the processes of plant growth and yield. Some also state that scientifically accepted standards were not followed in the experimental work (Dobermann, 2004). These criticisms are based on past research carried out on agronomic practices that have no comparison with those of SRI. For example, the physiology of rice when it is grown under combined conditions of low plant density and shallow irrigation with alternate wetting-and-drying, plus soil-aerating inter cultivation with mechanical hand weeders has not been studied.

It is well documented that moist field conditions and AWD improves root development reduce crop lodging, and provide better soil aeration. Replacing conventional flooding of paddy fields with maintenance of moist soil conditions or irrigating by AWD methods under SRI practice can enhance rice yield due to the aforesaid advantages in addition to saving water. But, SRI cannot be compared with other water-saving technologies like alternate wetting and drying (AWD) unless all the other practices that make up SRI are also evaluated. Researchers have shown the positive effects on crop growth and yield from interactions among practices that cause simultaneous growth increases in both root systems and canopy (Randriamiharisoa and Uphoff, 2002). Changing water management practices alters many other parameters to do with crop growth and health because there are profound differences between non-flooded and flooded soil conditions.

For any system of rice cultivation to achieve higher grain yield, the relationship among plant density, tiller number, leaf area index, leaf angle and light interception need to be optimized. SRI practices through optimum spacing attempt to minimize competition among rice plants for the various growth factors. They are as a consequence associated with higher leaf area index at flowering, more favorable canopy architecture, and achievement of greater light interception, even with a reduced number of plants per sq. metre (Thakur, 2010).

Although SRI was developed with organic fertilizers but now-a-days it is well performed with chemical fertilizers. Some researchers also commented that SRI emphasizes organic nutrients to the exclusion of mineral fertilizer and thus faces serious challenges in obtaining enough mineral nutrients from organic sources to achieve high yields. This is also incorrect. Proponents of SRI do not claim it is possible only with organic manures. On the other hand, SRI does emphasize the importance of the soil organic matter content and of soil health. This is because the response of rice under SRI is more pronounced when organic manure is added along with mineral fertilizers. In fact, most farmers apply chemical fertilizers along with available organic manure (Sinclair, 2004; Sheehy et al., 2004; Gautam et al., 2013).

As a result of this imprecision, disagreements about what exactly determines maximum grain yield are commonplace, but several 'scientific rules of thumb' and well-established empirical models allow the credible to be separated from the incredible (Sinclair, 1993). The failure to understand the fundamental nature of what governs yield and what constitutes a yield barrier will seriously impede efforts to design the radically new plant types and management systems needed to meet the future demand for rice (Sheehy, 2001).

Benefits and impact claimed for SRI

It is quite widely accepted that SRI techniques promote visible changes in the growth patterns and morphology of individual rice plants, specifically a vigorous production of numerous tillers (shoots with the potential to produce grain bearing panicles). Some studies have confirmed that SRI methods produce physiological and morphological changes in rice plants that can lead to improved yields and higher factor productivity (Chen et al., 2006; Vijayakumar et al., 2006; Thakur et al., 2010). However, the relationship between tillering and grain production is not linear and vigorous tillering may not necessarily lead to high yields (Latif et al., 2009). SRI techniques are reported to give rise to three key benefits. First, grain yields are reported to increase, delivering a direct benefit to both subsistence and commercial farming households. Second, SRI methods are widely believed to increase the productivity of two key inputs, namely water and seed. Consequently the system is thought to be more accessible and affordable to poor and marginal communities and farmers facing water scarcity. A more controversial claim holds that the productivity of the system as a whole increases through positive synergetic interactions among the SRI practices; in other words the positive impacts of individual components of the system are multiplied when they are applied in concert (Stoop et al., 2002; Uphoff, 1999). Third, SRI is said to represent a more ecologically sustainable method of rice cultivation, primarily through water conservation but also (organic) soil husbandry and lower methane emissions (Uphoff, 2007).

According to some researchers, these beneficial effects are encouraging many rice farmers to adopt SRI methods but rigorous studies assessing diffusion and adoption are scarce. A handful of published studies provide only localized snapshots, consequently it is impossible to answer the question exactly how widely SRI or its components have been adopted worldwide, nor to provide a consistent picture of the factors shaping adoption patterns across time and space. These studies do, however, reveal that patterns of adoption of SRI components differ substantially between sites, which suggest that some components fit better with particular types of farmers, households, rice plots or other specific characteristics, and that productivity changes associated with SRI are heterogeneous.

Modifications in SRI

A study conducted in West Bengal compared SRI with farmer practices, where some of the SRI methods were not properly followed by the farmers, like precise water control (these farmers practiced a rainfed version of SRI), application of organic manure (some farmers applied only mineral fertilizers), and adopting mechanical weeding. Despite these deviations from best SRI practice, average yield benefits of 32% was achieved with SRI compared to farmers' present practices (and this was in one of the two village areas surveyed experiencing severe drought, which was better resisted by SRI-grown plants). Achieving benefits by using many if not all of the SRI-recommended practices should not be considered as a disqualification for the full set of recommendations. It is not always possible to implement all the SRI components at the same time in the fields (Sinha and Talati, 2007).

In any case, the academic debate is meaningless to those farmers who are able to appreciate the benefits of switching to SRI or any modified version of SRI. It is actual experience that sustains any new technology or practice and farmers are better judges than anybody else. That more and more farmers (about one million since 2003) are coming forward to adopt SRI is proof alone of its beneficial effects (Randriamiharisoa and Uphoff, 2002). Recommended package and practices of SRI cultivation has not been adopted fully by farmers in India.

Apart from different controversies regarding SRI, there are some critical observations under that SRI can out performed under certain circumstances:

- Performance of SRI is location specific
- Varieties respond differentially to this method.
- It can be a best option to promote hybrid rice as hybrids perform better under SRI and it helps to save significantly in seed cost.
- This technology could be well adopted in the coastal districts of Eastern India during dry season. However, in western parts of the state it can be practiced both in wet and dry seasons.

Table 2 Flexibility in adopting SRI practices

Practice	Flexibility in farmers' practice	Flexibility in SRI
Seedling age	25 – 45 days Sometimes seedlings of 60 days old are planted due to contingent situations	10 – 15 days Up to3-leaf stage If temperatures are cold, somewhat older seedlings can still be 'young' in biological terms
Spacing (cm)	Usually random	20-30 cm If soil is fertile, even wider spacing may give higher yield; spacing is to be optimized for local conditions and variety, so this requires farmer experimentation
Number of hills per sq.m	50 - 100	10 - 22
Number of seedlings per hill	3 - 6	1 is best if soil is reasonably fertile 2 seedlings when crop establishment is not certain or when soil is less fertile
Irrigation	Keep the field flooded when water is available	Keeping the soil just moist Where water control is difficult, draining is not feasible; so soil should be kept as aerobic as possible
Intercultivation	Not practiced	2–4 times depending upon availability of labour and mechanical weeders
Organic manures	Not applied at all Available sources utilized Unspecified quantity applied	No specified quantity is recommended, but emphasis is on applying more organic manure Gradual replacement of chemical fertilizers is expected, to improve soil structure and functioning

Table 3 Variations in adopting the principles of SRI

Principle	Recommended practice	Variations
Young seedlings	8-14 day-old seedlings, notbeyond the 3-leaf stage	Direct seeding Conventionally-raised older seedlings
Lower plant density andwider spacing	Single seedlings per hill in a square pattern at 25 x 25 cm spacing	More than 1 seedling Only wider row spacing but narrow within-row spacing
Keep the soil moist and not continuously flooded	Irrigate a thin layer of water (2 cm) after hairline cracks form on the soil, and no water stress after flowering	Flood irrigationNo possibility to drain
Intercultivation	Use weeder preferably at 10 12 day intervals after planting; 3-4 times in both directions	One-direction use only1 time onlyLate timing
More organic manures	Use of available cattle manures, green manures, and bio fertilizers	Only chemical fertilizers Minimum use of organic sources

Table4 Modification of SRI followed in Southern Indian states

	Andhra Pradesh	Tamilnadu	Karnataka
Seed rate and age of seeding	5 kg /ha 8-12 day old seedlings in problem areas seedlings	7 -8 kg for single seedling 5 kg /ha 12-15 kg for double 15 day old seedlings	5 kg /ha 15 day old seedlings
Nursery	Raised bed nurserywith sufficient quantity of well decomposed organicmanures	On shallow raised bed covered with polythene gunny bags (mat nursery) Community nursery at staggered time was promoted Application of 1.5 kg of phosphorus (DAP) 12 kg 17:17:17 NPK fertilizer	Seedling s raised onplastic sheet (matnursery)
Spacing (cm)	25x25	22.5x22.5	25x25 to 30x30
Fertilizer	Addition of organic manures over recommended NPK(100:60:40kgNPK/ha)	Recommended dose of fertilizers and additional green manure and FYM LCC based 'N' management for 'N' top dressing.	10 t/ha FYM inaddition to 50%RFD (100:50:50 NPK/ha)
Irrigation	Alternate wetting Drying	Irrigation to a depth of 2.5cm and allow to develop hair line cracks till next irrigation. SRI implementation wastargeted on the water scarcetail end areas of basins	Moist or saturated condition is maintained up toflowering and thin film of water after PI
Weeding	2-3 times of weedingby cono weeder starting 10 days after TP at 10 days	3-4 limes cono weeding Use of motorized weeder is also in practice	3-4 times of conoweeding with 10day interval

Table 5 Modification of SRI followed in Eastern Indian states

	Tripura	Orissa	Chhattisgarh	Meghalaya
Seed rate and seedling age	5 kg ha 8-12 day old 1-2 seedling /ha	5-8 kg/ha 8 -12 days old seedlings	5-8 kg/ha 8 -12 days old seedlings	5-8 kg/ha 15-20 day old seedling 2 seedling/hill
Nursery	Raised bednursery	Raised bednursery	Raised bednursery	Raised bednursery
Spacing (cm)	25x25	25x25	25x25	20x20
Fertilizer	Recommended m ore organic 50% of manures in addition to inorganic fertilizer	Recommended NPK (60:30:30 kg/ha in kharif 80:40:40 kg/ha in Rabi) 50% organic +50% inorganic fertilizer (FYM or compost @10t/ha)	Recommended dose of inorganic fertilizer 90:60:40 recommended to apply organics if available	INM (5 t/ha of FYM + 50% of NPK)
Irrigation	Alternate wetting and drying	Alternate wetting and drying	Alternate wetting and drying flooding 3 days after disappearance of water	Alternate wetting and drying
Weeding	Cono-weeding for 2-3 times during crop season at 10 day interval	Mandava weeder is recommended over cono weeder	2-3 times con-wedding at 10 day interval	Adoption of 2-3 times con-wedding at 10 day interval

Modification of SRI principles at NRRI

The yield potential of rice under SRI with different plant geometry and age of seedlings was studied at CRRI, Cuttack during dry season 2006 with the rice hybrid Ajay. Higher grain yield of 6.43 t/ha was recorded with 8 days old seedlings planted at 25 cm x 25 cm spacing which was 5.75% and 14.4% higher than 14 and 21 days old seedlings at same spacing.

To overcome the problem/ difficulties in planting young seedlings in SRI method of rice cultivation particularly during dry season an observation-cum-demonstration trial is conducted during dry season with three treatments i.e. M1- SRI (standard Package), M2- State Recommended Practice (SRP) and M3- Direct Wet Seeding (DWS) + SRI using medium duration rice variety Naveen. The crop is DWS/Transplanted on 25.01.2008. The DWS rice with SRI management gave grain yield of 7.24 t/h whereas the standard SRI and SRP methods gave a grain yield of 6.82 and 5.81 t/ ha respectively. This clearly shows adoption of crop establishing through Direct Wet Seeding and the rest management by SRI technology not only increase grain yield but also overcome the problems of using young seedling for establishing the crop under SRI.

Impact of SRI in India

India is a water stressed country; 45% of all available water is used for agriculture with ground water accounting for about 70% of water used. A World Bank study estimates that by 2020, India's demand for water will exceed all sources of supply (World Bank, 2008). It is imperative that India strengthens its irrigation structure and improves its agricultural practices. The recent *World Development Report* (UNDP, 2008) shows that India's agriculture sector faces major constraints due to low investment and dilapidated irrigation infrastructure. India's recent high economic growth, which is likely to increase the industrial demand for water, means that even less water will be available for agriculture. India needs to make significant and sustained investments in agricultural research, agriculture and general infrastructure in rural areas to face the challenge of decreased water availability for agriculture and to revive and sustain its agricultural productivity (World Bank, 2008). India's population is projected to reach around 1.59 billion by 2050. This is about 470 million people more than today. At this rate, India will be the world's most populous country by 2035. Yet, today there are about 200 million underfed people and 50 million on the brink of starvation. There are more hungry people than in 1997, when India was importing food at great expense. Therefore, the food situation is far from secure. There is some debate over the various rice demand projections for 2030 or 2050. However, one thing is clear: India needs to produce a lot more paddy than it is producing today to meet the growing demand, which is likely to be 130 million tonnes of milled rice in 2030. This target is achievable, being lower than the current average productivity in China and other countries. Therefore there is potential for India to increase its food grain production by concentrating on enhancing rice yields. SRI either with its all components or with some modification can improve productivity significantly. Besides increased paddy production, the enormous savings in water and seed resources are very appealing.

Field experiments conducted in many parts of India have shown the significant effect of SRI on root growth, tillering, yield, grain qualities, physiology, nutrient uptake, pest and disease interactions, water use efficiency, soil nutrient and microbial dynamics. Economics and the adoption pattern by farmers have also been studied. Higher grain and straw yields, coupled with lowered cultivation costs, leave farmers with

Table 6 Average grain yields in SRI and conventional cultivation observed in farmers' fields in several states.

			Grain yield (t ha^{-1})			
State	Year	Season	Conventional	SRI	Increase	% increase
Tamil Nadu	2003-04	Rabi	5.7	7.2	1.5	26.3
	2007-08	Rabi	4.4	5.7	1.3	29.5
Andhra Pradesh	2003-04	Kharif	4.9	8.4	2.5	51.0
	2003-04	Rabi	5.5	7.9	2.4	43.6
	2007-08	Kharif	5.0	6.2	1.2	24.0
	2007-08	Rabi	5.2	6.6	1.4	26.9
Tripura	2006-07	Kharif	4.5	7.0	2.5	55.0
Himachal Pradesh	2007-08	Kharif	2.8	5.5	2.7	96.4
Uttarakhand	2007-08	Kharif	2.9	5.3	2.4	82.7
Bihar	2004-06	Kharif	3.8	4.7	0.9	23.0
Kerala	2007-08	Late Rabi	3.0	3.4	0.4	12.0
Gujarat	2007-08	Kharif	2.9	5.4	2.4	82.8
Punjab	2007-08	Kharif	7.7	9.8	2.1	27.3

Source: Presentations in National Seminar on SRI, 2007 and 2008 higher net income (Stoop et al., 2002; Uphoff, 2002; Thiyagarajan et al., 2005; Rajendran et al., 2005). This experience with SRI has been repeated across many rice growing regions. Grain yields reported from field experiments carried out in different parts of India showed yield increases from SRI ranging from 9.3% to 68% when compared with conventional practice (ICRISAT-WWF, 2008). A number of on-farm evaluations in farmers' fields have been conducted by research institutions, extension departments and civil society organizations in Tamil Nadu, Andhra Pradesh, Tripura, Orissa, Jharkhand, Himachal Pradesh, Uttrakhand, and Punjab. One such evaluation was done with 100 farmers in Tamiraparani basin, Tamil Nadu. The average yield increase due to SRI was 1,570 kg/ha. The biggest yield advantage achieved by a farmer was 4,036 kg/ha. The farmers also reported lodging resistance and an absence of rat damage in SRI crops (Water Technology Centre, 2009).

Innovative crop establishment methods such as System of Rice Intensification (SRI) and Integrated Crop Management (ICM) were compared with Local Recommended Practice (LRP) with two rice varieties CRHR 7 (hybrid) and Lalat during dry season 2006. The SRI and ICM gave significantly higher grain yield than LRP. The mean grain yield under SRI (5.92 t/ha) and ICM (5.51 t/ha) was higher by 21 and 12 percent over LRP (4.90 t/ha). SRI gave about 7.5 per cent increase in grain yield over ICM. The SRI and ICM gave significantly higher grain yield than LRP. The effect of variety was not significant. Water use efficiency under the System of Rice Intensification (SRI), and traditional practice followed by local farmers was compared using Naveen as the test variety during dry season 2006 with 4 levels of irrigations (Irrigation with 2-5 cm standing water, irrigation at air crack stages, irrigation at soil saturation and irrigation at 8 days interval). Highest yield and Water Use Efficiency was recorded when irrigation was provided at saturation and the lowest was obtained when irrigation was given at 10 days interval.

In 2010-11, IWMI-Tata Program, in collaboration with local partners, undertook a study covering 2234 rice farmers in 13 major rice growing states to analyze the adoption level and impact of various SRI practices. The results confirm that SRI adopters, on the whole, displayed comparatively higher yield, higher gross margin and lower production costs. However, most 'SRI farmers' in the study sample did not adopt the full package of practices due to several constraints. In fact, only 20 percent could be classified as 'full adopters' while the rest were 'low adopters' or 'partial adopters'. This highlight argues that a targeted approach that offers farmers flexibility in adopting a sub-set of SRI practices in accordance with the local resources conditions can have a significant

Table 7 Grain yields in SRI recorded in experiments across India

	Grain yield (t ha^{-1})			
Location	Conventional	SRI	% increase/ decrease	Source
Tamil Nadu Rice Research Institute, TNAU, Aduthurai	4.70	7.10	+ 48.9	Rajendran et al., 2005
14 Research stations, ANGRAU, Andhra Pradesh	4 .90	5.70	+ 16.6	Mallikarjuna Reddy et al., 2007
Indira Gandhi Agricultural University, Raipur, Chhattisgarh	4.30 (2007)	5.10	+17.8	Chitale et al., 2007
Agricultural Research Institute, Patna, Bihar	3 .90	6.10	+ 55.1	Ajaykumar et al., 2007
Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal,Puduchery	2 .20	3.70	+ 68.3	Sridevi and Chellamuthu, 2007
ICAR Research Complex, Umiam, Meghalaya	4.00 (2005) 4 .70 (2006)	4.40 5.2	+9.3 +10.2	Munda et al. 2007
Central Rice Research Institute, Cuttack, Odisha	4.90 (2005) 5.60 (2006)	5.90 7.00	+ 20.4 + 25.0	Rao et al. 2007
Regional Agricultural Research Station, Shillongani, Assam	3.10	4.50	+ 45.2	Bora and Dutta, 2007
Agricultural Research Station, UAS, Kathalagere, Karnataka	8.80 (2005) 9.10 (2006)	10.20 10.50	+ 15.9 + 15.4	Jayadeva et al., 2008
Main Rice Research Station, AAU, Nawagam, Gujarat	4.00 (2006) 4.70 (2007)	6.30 7.50	+ 35.9 37.1	Chauhan et al., 2008
Birsa Agricultural University, Ranchi, Jharkhand	4.30	5.00	+ 16.3	Singh et al., 2009
Deras Farm, Mendhasal, Khurda District, Odisha	4 .40	6.50	+ 47.7	Thakur et al., 2011
DRR/ICRISAT Farm, Hyderabad	7.65	8.17	+ 6.8	Gujja and Thiyagarajan, 2011

Table 8 Water use in conventional and SRI cultivation and water saving in SRI

Water used		Water	
Conventional	SRI	saved (%)	Reference
16,634 (m^3 ha)	8,419 (m^3 ha)	49.4	Thiyagarajan et al. (2005)
13,055 (m^3 ha)	8,906 (m^3 ha)	32.0	Mahenderkumar et al. (2009)
1,223 x 104 (l/ha)	952 x 104 (l/ha)	22.2	Thakur et al. (2011)
1,774 mm	1,298 mm	26.8	Zhao et al. (2011)
34,500 (m^3 ha)	21,600 (m^3 ha)	37.4	Hameed et al. (2011)

impact on paddy productivity (Palanisami et al., 2012).

Generally, SRI Fields have significantly higher yields, but with different patterns across most states. Average yield in SRI in all states is 8.5 q/ha (0.85 t/ha) or 22 % higher than the non-SRI fields. Madhya Pradesh, Gujarat and Orissa have significantly higher yield in SRI in percentage terms (52, 54 and 33 % respectively). Maharashtra, Chhattisgarh, Andhra Pradesh and Karnataka have the next highest: 27, 24, 23 and 25 % yield increments with SRI. Among the other major rice growing states, only Rajasthan and Assam have low absolute yield increases, but they still recorded more than 12% yield increment compared to the non-SRI. Kerala, Tamil Nadu and West Bengal have recorded only moderate yield increase. Overall, only 6 states have experienced higher yield increase above the national average due to SRI (Palanisami et al., 2012).

The difference between the average gross margins (gross income minus variable costs) due to SRI and non-SRI was Rs. 6971/ha with the highest in the Central region (Rs. 11184/ha) and the lowest in the North Eastern region (Rs. 3504/ha). Assam, Chhattisgarh, Maharashtra and Rajasthan had the lowest income possibly due to high operating costs. The cost of production (COP) per quintal of rice indicates the real profitability of the rice cultivation. Overall, COP of SRI over non-SRI was less by Rs. 178/quintal. Both Western and Southern regions were observed to have comparatively lower COP. Rajasthan has the highest COP due to the cultivation of basmati rice varieties with higher input costs and low yields (Palanisami and Karunakaran, 2012).

At present, mostly low adoption (41 %) and partial adoption (39 %) of SRI have been observed in all the regions. However, the yield increase under full adoption (incorporating all 4 core SRI components) is significantly higher (31 %) than the yield increase under partial (25 %) or low adoption (15 %). SRI/modified SRI practices have a higher gross margin (Rs. 7000/ha) and

Table 9 Differences of yield, cost and gross margin between SRI and non-SRI fields

Region and State	Non-SRI fields	Difference (SRI-non SRI) Total	%	Non-SRI fields	Difference (SRI-non SRI) Total	%	Non-SRI fields	Difference (SRI-non SRI) Total	%
Southern region									
AP	56.8	13.0	22.9	54490	10094	19	560	-146	-26
Karnataka	56.7	14.1	24.8	56277	12885	23	370	56	15
Kerala	47.1	6.4	13.6	51613	7044	14	857	-244	-28
Tamil Nadu	45.5	6.8	14.9	41879	5786	14	675	-223	-33
Average	51.0	9.2	18.0	49552	8290	17	617	-168	-27
Western Region									
Gujarat	18.7	10.0	53.6	17274	8973	52	757	-234	-31
Maharashtra	27.9	7.5	26.9	26904	4266	16	527	-253	-48
Rajasthan	20.9	2.7	12.9	41145	5327	13	2068	-201	-10
Average	25.6	7.3	28.5	27597	6585	24	715	-220	-31
Eastern Region									
Chhattisgarh	48.7	11.9	24.5	53451	1257	2	581	-167	-29
Odisha	36.2	12.0	33.1	33929	12111	36	669	-151	-23
UP	54.5	8.5	15.5	53655	8334	16	655	-41	-6
WB	36.0	5.9	16.5	32885	5400	16	507	-14	-3
Average	40.9	9.0	22.0	38446	7474	19	585	-71	-12
Central Region									
MP	19.3	10.0	51.9	12530	11184	89	430	-56	-13
North Eastern Region									
Assam	34.1	4.1	12.0	32188	3504	11	674	-380	-56
All India	37.9	8.5	22.4	37845	6971	18	621	-178	-29

Source: Palanisami et al., 2012.

Table 10 Adoption levels of SRI in different regions

Region	Percentage of farmers at different adoption level			Yeld in non-SRI prcels at different adoption level (q/ha)			Yield increase in SRI parcels over non-SRI yield at different adoption level (percent)		
	Low	Partial	Full	Low	Partial	Full	Low	Partial	Full
Southern	55	17	27	45.5	54.4	51.6	15.2	24.3	19.5
Western	43	43	14	22.7	17.6	19.3	15.8	53.9	65.0
Eastern	6	89	6	46.3	40.6	39.7	25.4	21.2	31.4
Central	10	48	42	15.4	21.6	17.8	24.7	44.1	68.0
North Eastern	100			34.1			12		
All India	41	39	20	38.2	38.3	36.2	15.0	24.8	30.9

Source: Palanisami et al., 2012.

lower production cost (Rs. 178/q) compared to non-SRI parcels. Major constraints in the adoption of SRI for modified SRI practices are lack of timely and skilled manpower for planting operations, poor water control in the fields and unsuitable soils. Farmers felt that the transaction (managerial) cost, though insignificant is also constraining the full adoption of SRI due to difficulties in mobilizing the resources for SRI or modified SRI. Hence, necessary interventions are needed to address these constraints. The key message is that whether it is SRI or modified SRI, there is an increase in yield compared to conventional practices. But the question to be addressed is where and how the SRI should be looked into. Given the current rice area of about 42 million ha in the country, using the difference in yield due to SRI as observed from the results of the study, it is possible to get an additional rice production of about 30 mt where the Eastern region alone could account for about 56 % increase followed by the Southern region (27 %). Hence region specific focus can be given to boost rice production using SRI or modified SRI practices. In this context, the following are suggested:

1. Selective SRI components: As most of the farmers are low and partial adopters, in order to get maximum yield under SRI, focus should be on the selective components of SRI to suit the regions.
2. Doing it differently: Farmers can be encouraged to do SRI in their own way instead of forcing them to adopt the defined SRI core

components. This way, these modified SRI or improved management practices will enhance the rice yield compared to the conventional practices.

3. SRI target regions (hot spots): Using GIS mapping, areas suitable for SRI - locations with suitable soils, crop seasons (*kharif* or *rabi*) and irrigation sources (surface, groundwater or rainfed) - can be marked and attention can be given for popularizing SRI only in those regions.
4. Machine transplantation: Machine transplanting can be introduced in all regions using the concept of wider spacing, young seedling and one to two seedlings.
5. Capacity building programs: Focused field based training to farmers on those SRI components which are important to their regions is important.
6. Long term field experimentation: As the yield varies across regions as well as under different soil and irrigation sources, long term field experimentation with different SRI practices is important so that concrete recommendations about the sustainability of SRI practices can be drawn.
7. The 12th Five Year Plan approach paper highlights the importance of SRI practices in improving the crop productivity (GoI, 2011). The drivers of SRI adoptions can be examined and incorporated in the agricultural development programs such as *Rashtriya Krishi Vikas Yojana* (RKVY) etc.

Strategies for up scaling the adoption of SRI in India

The System of Rice Intensification (SRI) is showing an unprecedented promise of 'more with less'. Government is generally positive and has extended its support in the promotion of SRI. The process of up scaling SRI is relatively slow owing to multiple constraints in its promotion and management intensity being one of the important factors. Integrated nature of SRI also throws multiple challenges in the areas of research, extension and policy support and there is a need to achieve coherence in these areas. The promotion of SRI in Tamil Nadu is the typical example of convergence of the different organizations in promoting SRI in a big way.

Research Approaches

Due to increasing fertilizer costs that farmers in India are facing irrigation water shortage and ever growing pollution / environmental problems that are foreseeable in future decades, there is a need to intensify research on SRI practices.

- Adoption of SRI principles to specific eco-regions including identification of suitable cultivars, spacing requirements for different crop durations and soil fertility, fertilizers and labour saving equipments (motorized weeder) is essential.

- Cropping system approaches for utilizing the benefits of SRI on long term basis. Fabrication and popularization of the motorized cono- weeders to overcome the serious problem of weeds and drudgery involved in weeding under SRI method.
- Studies on water balance, schedule of water application under different soil and climatic conditions along with the relationships among root systems, nutrient uptake and yield
- Long term studies under SRI as compared to conventional method on pest and disease dynamics, soil health and nutrient balance, green house gas emissions under SRI *vs* Conventional for its ability to mitigate climatic changes.
- Developing the suitable tools for SRI like row seeders and transplanter to incorporate SRI principles.
- Socio-economic impact studies on SRI in different situations and ecosystems

Extension Approaches

SRI is knowledge and experience based method of rice production than input centric technology. The extension systems in vogue are mostly designed around input driven technologies. Subsidized demonstrations with 'progressive' farmers are the only methods used for extension of knowledge, which is not so encouraging. Finding appropriate drivers for the extension of SRI is crucial. The knowledge based and labour oriented technical processes can best be extended on the farmers' institutional platforms.

Farmer Field Schools is another promising extension method that can be of great use in up scaling SRI.

Formal public sector extension agencies should evolve ways of working synergistically with these groups/farmer's platforms/ Institutions. Compact demonstrations at block level will be having more impact rather individual demonstrations. Training to all the stake holders including laborers will create the required impact for adoption.

Policy Support

The state level government support for SRI is limited to extending subsidies for weeders and markers, field demonstrations. Subsidies are extended at present for mechanical weeders. The labour for weeding is seen as a problem hence the support must be extended for engaging labour during initial seasons of adoption. A group/ area based approach to weeding may be considered rather than an individual farmer centric subsidy. Labour training in weeding, transplanting operations would be of immense relief to farmers. The designs of weeder should also be diversified and be made amenable to local production.

Staggered and community nurseries sown at different times at a village level can make available the required aged seedlings to farmers and coping with labour demand. State support must be extended to green manure crops and for production of organic manures such as vermicompost, biofertilizer.

Controlled irrigation in canal and tank systems for better management of water will lead to adoption of SRI in large scale. Convergence of different organizations working on SRI for large scale adoption.

Major Constraints Experienced by farmers at operational level

- Some practices of SRI like planting of young seedlings at shallow depth, raising specialized nursery needs skill and labour especially in the early stage of adoption.
- SRI cannot be adopted everywhere. It may not be suitable in command areas where water release is highly uncertain and in lowlands under uncontrolled water situation especially in kharif season
- Weeding is reported as one of the major constraints in adoption of SRI. Availability of soil specific cono weeder is still a problem and mechanized multi row weeder are yet to be develop to reduce the drudgery for farm labour (a person has to walk 16 km/acre for weeding with cono weeder in one direction).
- Organic manures (FYM, compost) are not available in sufficient quantities with good quality therefore; it is difficult for farmers to adopt this principle wholly.

Do's and Don'ts for SRI

Do's

- Use quality seeds of relevant variety/hybrid for healthy seedlings
- Favorable upland areas and areas with assured irrigation should be used for SRI
- Planning for SRI areas needs to be done at district level
- Young seedlings with intact soil roots to be shallow transplanted
- Use as much organic manures as possible
- Use cono-weeder for controlling weeds & creating aeration
- Care should be taken to control leaf folder & Nematodes
- Avoid flooding & adopt AWD to keep the soil at saturation

Don'ts

- Not to be promoted where the fields are not leveled
- Not to be promoted in saline soils, lowlands and high rainfall areas

Conclusions and knowledge gaps

Major findings

Despite an increase in the number of publications describing SRI adoption and impact, the discussion makes clear that our understanding of what drives a farmer to adopt SRI components, and how this affects his or her livelihood, remains limited (Berkhout et al., 2015). It is also evident that there is substantial diversity in SRI extension and practice across sites, making it very difficult to draw general conclusions about the impact of "SRI" as a singular technological package. From our discussion, several specific conclusions emerge:

1. The overall effect of SRI adoption on total factor productivity remains unclear. Although reported yields under SRI cultivation methods are often higher than reference practices, the cause(s) of these increases remain obscure. Adoption of SRI methods is associated with fairly substantial changes in the allocation of inputs, especially labour, water and fertilizer. No studies have assessed the changes in all relevant inputs simultaneously, while sufficiently controlling for observed and unobserved farmer characteristics. For the same reason, possible synergetic effects among SRI components have not been demonstrated.
2. It is clear that the adoption of SRI transplanting and weeding methods leads to significant changes in the organization of tasks, gender division of labour, and temporal distribution of labour demand, including the possibility of an increased labour requirement at harvest time. The available literature allows few firm conclusions regarding the impact of these changes, which theoretically may be positive or negative for different households or groups. There is a widely held view that SRI methods may increase labour demand in the short term, but that labour requirements can be reduced once the new methods have been mastered. Though this is plausible, need to be studied extensively.
3. The nature and exact cause of increases in land productivity remain obscure, although differences in land productivity between SRI plots and non-SRI plots (or farmers) are likely to be a partial cause or an effect of

improved results with SRI methods. Various studies suggest that a considerable part of higher yields under SRI management may be attributed to a preferential allocation of SRI to more fertile plots, and/or to a preferential allocation of fertilizer and labour to SRI plots.

4. Available evidence does indicate that SRI practices can substantially improve the partial productivity of seed and water. Increases in seed and water productivity follow logically from reductions in the seed rate and irrigation, which can be achieved without adverse effects on output, and sometimes with an increase in yield. However, water savings and improvements in water productivity can also be achieved by adopting water-saving management methods, without necessarily adopting the whole set of SRI practices.
5. Yield variability under SRI management is often reported to be larger in comparison with conventional practice. This difference may stem from either unobserved farm characteristics, or truly represent a source of elevated risk associated with SRI management, making SRI less attractive for the most vulnerable farmers. The literature does discuss some sources of increased risk under SRI management, such as the hazard of seedling loss when the seedlings are very small due to pests, flooding or soil salinity. These factors, together with the physical difficulty involved in handling tiny seedlings, may explain why some farmers and SRI-promoting organizations have opted not to use extremely young seedlings.

Knowledge gaps

While SRI may potentially offer advantages, several socioeconomic issues remain unresolved and deserve further research:

1. There is a vital need to generate more detailed and reliable information about the spread and levels of adoption of SRI methods. In particular, it is very important to study the patterns of adoption and partial adoption, including the range and degrees of variation in the ways SRI guidelines are specified and practiced by farmers.
2. (Partial) adoption of SRI methods by farmers will potentially lead to changes in output and input productivity. As a result, different types of farmers are likely to re-allocate scarce production factors across on-farm, off-farm and non-farm activities in different ways. In addition, labour demand changes in rice production may have a profound impact on the income and well-being of landless labourers. In all these cases SRI methods may have a measurable

impact on household income, food security status and health of household members. The magnitude and direction of this impact, and how it varies across different regions and types of households, has not yet been established, but can be addressed through the implementation of well-designed impact assessments, such as randomized controlled trials or natural experiments at farm household or village level.

3. Studies investigating both partial and total factor productivities should make it possible to investigate the presence of synergetic effects among the SRI components. Such studies should focus on whether interaction effects can be detected between some or all of the SRI components, how and when these occur, and how they affect total factor productivity.

4. An interesting question is whether the diversity in local and regional specifications of SRI is a systemic property, stemming from an inherent flexibility of the technical characteristics of the cultivation system, or simply a consequence of the natural diversity that characterizes smallholder farming across diverse landscapes, cultures and institutional settings. Investigating this question would be an important step towards creating training and extension systems that can support specific kinds of farmers and communities to improve their rice cultivation practices in appropriate and locally valued ways.

References

Armstrong, W., Justin, S.H.F.W., Beckett, P.M., Lythe, S., 1991. Root adaptation to soil waterlogging. Aquat. Bot. 39, 57–73.

Association Tefy Saina, 1992. Presentation technique du système de riziculture intesive basée sur le modèle de tallage de Katayama. Fanabeazana Fampandrosoana Ambanivohitra. 31 pp.

Begg, C.B.M., Kirk, G.J.D., Mackenzie, A.F., Neue, H.U., 1994. Root-induced iron oxidation and pH changes in the lowland rice rhizosphere. New Phytol. 128, 469–477.

Berkhout, E., Glover, D., Kuyvenhoven, A., 2015. On-farm impact of the System of Rice Intensification (SRI): Evidence and knowledge gaps. Agricultural Systems 132, 157–166.

Bora, P.K., Dutta, S., 2007. System of Rice Intensification – an experience in Central Brahmaputra Valley. *In*: Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 184 – 186.

Chauhan, N.P., Bhuva, N.P., Mehta, A.M., Pathak, A.R., 2008. Comparative performance of crop establishment methods in transplanted rice of the Gujarat State. *In*: Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 36 – 37.

Chen, H., Zhu, D., Rao, L., Lin, X., Zhang, Y., 2006. Effects of SRI technique on population quality after heading stage and yield formation in rice. Journal of Huazhong Agricultual University, 25, 483–487.

Chitale, S., Pandey, N., Chandrakar, B.L., 2007. Prospects of System of Rice Intensification in Chhatisgarh Plain. *In*: Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 47.

Dawe, D., Dobermann, A., Ladha, J.K., Yadav , R.L., Lin, B., Lal, P., Panaullah, G., Sariam, O., Singh, Y., Swarup, A., Zhen, Q.X., 2003. Does organic matter improve the suatainability and profitability of intensive rice systems?. Field Crops Research, 83, 191–213.

Dobermann, A., 2003. A critical assessment of the system of rice intensification (SRI). Agric. Syst. 79, 261–281.

Dobermann, A., 2004. A critical assessment of the System of Rice Intensification (SRI). Agricultural Systems, 79(3), 261–281.

Drew, M. C., 1997. Oxygen deficiency and root metabolism under hypoxia and anoxia. Annual Review Plant Physiol. Plant Mol. Biol. 48, 223–250.

Edmeades, D.C., 2003. The long-term effects of manures and fertilisers on soil productivity and quality: a review. Nutr. Cycl. Agroecosyst. 66, 165–180.

Fernandes, E.C.M., Uphoff, N., 2002. Summary from conference reports. In: Uphoff, N., Fernandes, E.C.M., Yuan, L.P., Peng, J.M., Rafaralahy, S., Rabenandrasana, J. (Eds.), Proceedings of an International Conference on Assessment of the System for Rice Intensification (SRI), Sanya, China, 1–4 April 2002. Cornell International Institute for Food, Agriculture and Development (CIIFAD), Ithaca, NY, pp. 33–39, http://ciifad.- cornell.edu/sri/proccontents.html (verified 21 April 2003).

Gautam, Priyanka, Sharma, G. D., Rana, Rachana, Lal, B., Joshi, Ekta, 2013. Evaluation of integrated nutrient management and plant density on productivity and profitability of rice (Oryza sativa) under system of rice intensification in mid-hills of Himachal Pradesh. Indian Journal of Agronomy, 58(3), 421–423.

GoI. 2011. Faster, sustainable and more inclusive growth: An approach to the Twelfth Five Year Plan. New Delhi: Planning Commission, Government of India (GoI).

Greenwood, D.J., Lemaire, G., Gosse, G., Cruz, P., Draycott, A., Neeteson, J.J., 1990. Decline in percentage N of C_3 and C_4 crops with increasing plant mass. Ann. Bot. 66, 425–436.

Gujja, B., Thiyagarajan, T.M., 2009. New Hope for Indian Food Security? The System of Rice Intensification. International Institute for Environment and Development, London, UK.

Hameed, K.A., Abdul-Kadhim Jawad Mosa, Jaber, F. A., 2011. Irrigation water reduction using System of Rice Intensification compared with conventional cultivation methods in Iraq. Paddy and Water Environment 9:121-127. doi:10.1007/s10333-010-0243-1.

Horie, T., 2001. Increasing yield potential in irrigated rice: breaking the yield barrier. In: Peng, S., Hardy, B. (Eds.), Proceedings of the International Rice Research Conference on Rice Research for Food Security and Poverty Alleviation, Los Banos, Philippines, 31 March–3 April 2000, pp. 3–25.

Jayadeva, H.M., T.K. Prabhakar, S., Bandi, A.G., 2008. Performance of SRI method of rice establishment under Bhada Command of Karnataka. *In*: Extended summaries of the Third

National Symposium on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 33 – 35.

Joelibarison, 1997. Perspective de développement de la region de Ranomafana: Les mécanismes physiologiques du riz sur sols de bas-fonds —Cas du SRI. Mémoire de fin d'etudes, ESSA, University of Antananarivo, 91 pp.

Kabir, H., 2008. Update of SRI in Myanmar. Available: http://ciifad.cornell.edu/sri/countries/Myanmar/my MDFrpt08.pdf

Kirk, G.J.D., 2003. Rice root properties for internal aeration and efficient nutrient acquisition in submerged soil. New Phytol. 159, 185–194.

Kumar, A., Sahai, V.N., Singh, V.K., 2007. Searching suitable space / time for System of Rice Intensification in Bihar. *In*: Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3–5, 2007. Agartala, Tripura, India. pp 48 – 50.

Latif, M.A., Ali, M.Y., Islam, M.R., Badshah, M.A., Hasan, M.S., 2009. Evaluation of management principles and performance of the System of Rice Intensification (SRI) in Bangladesh. Field Crops Research, 114, 255–262.

Laulanié, Henri de, 1993. Le système de riziculture intensive malgache. Tropicultura (Brussels) 11, 110–114.

Mahender Kumar. R, K. Surekha, Ch Padmavathi, L.v. Subba Rao, P.C. Latha, M. S. Prasad, V. Ravindra Babu, A.S.Ramprasad, O.P. Rupela, Vinod Goud, P.Muthu Raman 1, N .Somashekar, S.Ravichandran, S.P.Singh and B.CViraktamath. 2009. Research experiences on System of Rice Intensification and future directions. Journal of Rice Research, 2 (2), 61–74.

McDonald, A. J., Hobbs, P. R., Riha, S. J., 2006. Does the system of rice intensification outperform conventional best management? A synopsis of the empirical record. Field Crops Research, 96, 31– 36.

Mishra, A., Salokhe, V. M., 2008. Seedling characteristics and early growth of transplanted rice under different water regimes. Experimental Agriculture, 44, 1–19.

Moser, C.M., Barrett, C.B., 2003. The disappointing adoption dynamics of a yield-increasing, low external-input technology: the case of SRI in Madagascar. Agric. Syst. 76, 1085–1100.

Munda, G.C., Das, A., Patel, D.P., 2007. Performance of lowland rice as influenced by stand establishment methods and nutrient management practices at mid altitude of Meghalaya. *In*: Papers and extended Summaries. SRI India 2007-Second National

Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 92–93.

Nemoto, K., Morita, S., Baba, T., 1995. Shoot and root development in rice related to the phyllochron. Crop Science, 35 (1), 24–29.

Obermueller, A. J., Mikkelsen, D. S., 1974. Effects of water management and soil aggregation on the growth and nutrient uptake of rice. Agronomy Journal, 66, 627–632.

Palanisami, K., Karunakaran, K.R., 2012. Adoption levels of SRI in different regions of India. Hyderabad: IWMI-Tata Program, draft report.

Palanisami, K., Karunakaran, K.R., Amarsinghe, U., 2012. Impact of the System of Rice Intensification (SRI) Analysis of SRI Practices in 13 States of India. Hyderabad: IWMI-Tata Program, draft report.

Park, R., 2000. Vodoo Science: The Road from Foolishness to Fraud. Oxford University Press, Oxford, UK.

Popper, K., 1989. Conjectures and Refutations: The Growth of Scientific Knowledge. Routledge, London.

Puard, M., Lasceve G., Couchat P., 1989. Etude des mecanismes d'adaptation du riz (Oryza sativa L.) aux contrainted du milieu: II — Effets de la nutrition azotée sur la consommation d'oxygène par les racines et l'évolution de l'acidité. L'Agronomie Tropicale 44, 173–177.

Rafaralahy, S., 2002. An NGO perspective on SRI, its origins in Madagascar. In: Uphoff, N., Fernandes, E.C.M., Yuan, L.P., Peng, J.M., Rafaralahy, S., Rabenandrasana, J. (Eds.), Proceedings of an International Conference on Assessment of the System of Rice Intensification (SRI). Sanya, China, April 1–4, Cornell International Institute for Food, Agriculture and Development (CIIFAD), Ithaca, NY, http://ciifad.cornell.edu/sri/proccontents.html (verified April 21, 2003), pp. 17–22.

Rajendran, R., Ravi, V., Valliappan, K., Adanasabapathy, T. N., Jayaraj, T., Ramanathan, S., Balasubramanian, V., 2005. Early nursery for enhancing rice productivity and profit. Indian Journal of Agronomy, 50(2), 132–136.

Randriamiharisoa, R., Uphoff, N., 2002. Factorial trials evaluating the separate and combined effects of SRI practices. *In*: N. Uphoff *et al*. (eds.). Assessments of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1–4, 2002. Cornell International Institute for Food, Agriculture and Development, Ithaca (http://ciifad.cornell.edu/sri/proc1/sri_10.pdf).

Rao, K.S., Poonam, A., Ghosh, A., Mohapatra, P.C., Pandey, M.P., 2007. Present status of SRI research at CRRI, Cuttack, India. *In*: Papers and extended Summaries. SRI India 2007-Second National Symposium on

System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 35 – 37.

Raskin, I., Kende, H., 1985. Mechanism of aeration in rice. Science 228, 327–329.

Reddy, M., Reddy, C.V., Reddy, P.R., 2007. Status of SRI in Andhra Pradesh, problems and prospects. *In*: Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 44 – 46.

Rodrigo, P.A., 1924. The effect of spacing on tillering and production of three varieties of rice. Philippines Agric. 13, 5–28.

Sahid, I. B., Hossain, Md. S., 1995. The effects of flooding and sowing depth on the survival and growth of five rice-weeds species. Plant Protection Quarterly 10, 139–142.

San-oh, Y., Mano, Y., Ookawa, T. and Hirasawa, T., 2004. Comparison of dry matter production and associated characteristics between direct-sown and transplanted rice plants in a submerged paddy field and relationships to planting patterns. Field Crops Research, 87, 43–58.

San-oh, Y., Sugiyama, T., Yoshita, D., Ookawa, T. and Hirasawa, T., 2006. The effect of planting pattern on the rate of photosynthesis and related processes during ripening in rice plants. Field Crops Research, 96, 113–124.

Sheehy, J.E., 2001. Will yield barriers limit future rice production? In: No¨sberger, J., Geiger, H.H., Struik, P.C. (Eds.), Crop Science: Progress and Prospects. CABI Publishing, Wallingford, UK, pp. 281–305.

Sheehy, J.E., Peng, S., Dobermann, A., Mitchell, P.L., Ferrer, A., Yang, Jianchang, Zou, Yingbin, Zhong, Xuhua, Huang, J., 2004. Fantastic yields in the system of rice intensification: fact or fallacy? Field Crops Research 88, 1–8.

Sheehy, J.E., Sinclair, T.R., Cassman, K.G., 2005. Curiosities, nonsense, non-science and SRI. Field Crops Research, 91, 355–356.

Sinclair, T.R., 1993. Crop yield potential and fairy tales. In: Buxton, D.R., Shibles, R., Forsberg, R.A., Blad, B.L., Asay, K.H., Paulsen, G.M., Wilson, R. (Eds.), Proceedings of the International Crop Science Congress, International Crop Science I. Ames, IA, USA, 14–22 July 1992. Crop Science Society of America, Madison, WI, pp. 707–711.

Sinclair, T.R., 2004. Agronomic UFO waste valuable scientific resources. Rice Today, 3–43.

Sinclair, T.R., Cassman, K.G., 2004. Agronomic UFOs? Field Crops Res. 88, 9–10.

Singh, R.P., Singh, S.P., Agrawal, R.K., Singh, H.B., 2007. Response of combined application of trichoderma and azospirillum on rice production in System of Rice Intensification. *In*: Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3–5, 2007. Agartala, Tripura, India. p103–104.

Sinha, S.K., Talati, J., 2007. Productivity impacts of System of Rice Intensification (SRI): A case study in West Bengal, India. Agricultural Water Management, 87(1), 55–60.

Sridevi, V., Chellamuthu, V., 2007. Effect of System of Rice Intensification (SRI) practices on the yield and yield attributes of rice. *In*: Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 74 – 75.

Stoop, W., Kassam, A., 2005. The SRI controversy: a response. Field Crops Research, 91, 357–360.

Stoop, W., Uphoff, N., Kassam, A., 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource-poor farmers. Agricultural Systems, 71, 249–274.

Thakur, A. K., 2010. Critiquing SRI criticism: beyond scepticism with empiricism. Current Science, 98, 1294–1299.

Thakur, A.K., Rath, S., Patil D.U., Kumar, A., 2011. Effects of rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. Paddy and Water Environment, 9 (1), 13–24.

Thiyagarajan, T.M., Senthil kumar, K., Priyadarshini, R., Sundarsingh, J., Muthusankaranarayanan, A., Hengsdijk, H., and Bindraban, P.S., 2005. Evaluation of water saving irrigation and weeder use on the growth and yield of rice. *In*: Transitions in agriculture for enhancing water productivity. Proceedings of the International Symposium on Transitions in Agriculture for enhancing water productivity, 23-25 September, 2003, Killikulam, Tamil Nadu, India, 251 p.

UNDP. 2008. *World Development Report.* United Nations Development Programme, New York.

Uphoff, N., 1999. Agroecological implications of the System of Rice Intensification (SRI) in Madagascar. Environment Development Sustainable. 1, 297–313.

Uphoff, N., 2003. Higher yields with fewer external inputs? The System of Rice Intensification and potential contributions to agricultural sustainability. International Journal of Agricultural Sustainability, 1(1), 38–50.

Uphoff, N., 2005. Possible explanations for the productivity gains achieved with the System of Rice Intensification (SRI). *In*: Transitions in Agriculture for enhancing Water Productivity. Proceedings of an International Symposium held in Killikulam, Tamil Nadu, India during 23-25, September 2003.

Uphoff, N., 2007. Agroecological alternatives: capitalising on existing genetic potentials. Journal of Development Studies 43, 218–236.

Uphoff, N., Fernandes, E., 2002. System of Rice Intensification gains momentum. LEISA India. September 2002, pp. 22–27.

Uphoff, N., Kassam, A., Stoop, W., 2008. A critical assessment of a desk study comparing crop production systems: The example of the 'system of rice intensification' versus 'best management practice'. Field Crops Research, 108, 109–114.

Uphoff, N., Koma Y.S., Gypmantasiri, P., Prinz, K., Kabir, H., 2000. The System of Rice Intensification (SRI) and its relevance for food security and natural resource management in Southeast Asia. Paper for the International Symposium on Sustaining Food Security and Managing Natural Resources in Southeast Asia: Challenges for the 21st century, Chiangmai, Thailand, January.

Vartapetian, B. B., 1993. Flood-tolerant and flood-sensitive plants under primary and secondary anoxia. NATO ASI Series 116, 231–241.

Vijayakumar, M., Ramesh, S., Chandrasekaran, B., Thiyagarajan, G., 2006. Effect of System of Rice Intensification (SRI) practices on yield attributes, yield and water productivity of rice (Oryza Sativa L.). Research Journal of Agriculture and Biological Science, 2, 236– 242.

Water Technology Centre. 2009. *Report on the Implementation of SRI in Phase I and II Sub-basins under TN-IAMWARM Project*. Tamil Nadu Agricultural University, Coimbatore.

World Bank, 2008. *India, a New Way of Cultivating Rice.* Available online at: http://web. worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTPOVERTY/0,,contentMDK:21789689~m enuPK: 2643747~pagePK: 64020865~piPK: 149114~theSitePK: 336992, 00.html

WWF. 2007. *More Rice with Less Water - System of Rice Intensification*, World Wide Fund for Nature, Gland. Available at www.panda.org.

WWF-CRISAT, 2010. More Rice with Less Water - System of Rice Intensification second edition in draft. Joint Dialogue Project of Worldwide fund for Nature and International Crop Research Institute for the Semi-Arid Tropics on 'Food, Water and Environment,' Hyderabad.

Yamah, A., 2002. The practice of the system of rice intensification in Sierra Leone. *In* Uphoff N, Fernandes E, Long-Pin Y, Jiming P, Sebastien R, Rabenanadrasana J, editors. Assessments of the System of Rice Intensification (SRI): Proceedings of an international conference, Sanya, China, 1- 4 April 2002, Ithaca, NY(USA): CIIFAD, pp 23–25

Zhao, L., Wu, L., Li, Y. S., Lu, X. H., Zhu, D. F., Uphoff, N., 2009. Influence of the system of rice intensification on rice yield and nitrogen and water use efficiency with different application rates. Experimental Agriculture, 45, 275–286.

Zhong, X., Peng, S., Sheehy, J.E., Liu, H., Visperas, R.M., 1999. Parameterization, validation and comparison of three tillering models for irrigated rice in the tropics. Plant Prod. Sci. 2, 258–266.

Annexure-I

Package of Practices of System of Rice Intensification

1.Nursery management

- Prepare the land thoroughly when dry, apply FYM and puddle well. Level the seedbed and spread a thin layer of well-decomposed FYM/compost on the bed.
- Broadcast the sprouted seeds sparsely. See that 2 kg seed is sown on 40 Sq. m area.
- Apply another layer of FYM to cover the seeds.
- Mulch with paddy straw to prevent the seed to come in direct contact with sun, rain, birds etc.

- Irrigate carefully with rose can every morning and evening.
- Do not apply any agrochemicals to the nursery bed.
- In 8-14 days, vigorous & healthy nursery is ready for transplanting.

2.Land preparation for planting

- Plough the land thoroughly and puddle it as it is done with the conventional method.
- At every 3 m distance form 30 cm wide channels to facilitate drainage
- Level the field thoroughly so that water can be applied very evenly
- With the help of a marker draw lines both ways at 25 x 25 cm apart and transplant at the intersection
- There should not be standing water at the time of transplanting.

3.Transplanting

- Remove seedlings from nursery with seed, soil and roots intact carefully and plant it in the field without plunging too deep in to the soil.
- Transplant as soon as possible after being removed from the nursery, within half an hour and preferably within 15 minutes, to avoid desiccation and traumatirization of the plant.

- Care is to be taken to ensure that when the seedlings are transplanted their tips are not inverted.
- Do not thrust seedlings downward into the soil. Rather each seedling is slipped into the soil very gently and close to the surface, so that its roots lie horizontally in the moist soil.
- Plant single seedling at the intersection rather than in clumps of 2 or 3 or more in a square pattern at 25 x 25 cm apart.

4.Weeding and interculture

- Herbicides are not recommended under SRI method. Instead, weeds have to be incorporate into the soil.
- Use simple mechanical rotary weeder to churn the soil for weed control.
- Rotate the weeder at least 2-4 times. This incorporates the weeds into the soil.
- The 1st weeding should be done at 10-12 days after transplanting (DAT) to eliminate weeds when these were germinating rather than wait for them to grow.
- Subsequent weedings are done at 10 days interval.
- Working with rotary weeder helps in greater aeration, which results in more root growth, reduced weed competition, more oxygen and nitrogen to roots.

- Weeds incorporate into the soil with each weeding can add-up to 1 ton green manure per hectare per weeding and also helps build up of large and diverse microbial population in the soil.

5.Water management

- Water should not be allowed to stagnate under SRI method.
- Give regular irrigations to keep the soil moist.
- Alternate wetting and drying should be done which gives aerobic and anaerobic soil conditions for better nutrient mobilization by soil biota.
- Unflooded conditions, combined with mechanical weeding, result in more air in the soil and greater root growth.
- Higher root growth provides access to more nutrients.

6.Fertilizer management

- Soil test based fertilizer application especially for P and K is preferred over blanket dose.
- Apply NPK as per the conventional practices, N can be applied through customized leaf color chart for efficient use.
- For better soil health apply nitrogen in the form of both organics (green manure, FYM, Azolla etc.) and chemical fertilizer (Prilled urea) in 50:50 proportion.
- Apply $ZnSO_4$ @ 25 kg/ha in Zinc deficient soils.§ In highly fertile soils, instead of chemical fertilizers, application of FYM or compost @ 10t/ha is quite sufficient as source of nutrients. More plant growth is achieved because of better soil health and more balanced nutrient supply. Apply diverse organic manures. Organic manures act as food for microorganisms.

Annexure-II

Important National Initiatives

Meeting on System Of rice Intensification (SRI) held on 18th October, 2007 in ICAR Committee Room No. 1: Dr. P.L. Gautam, DDG (CS) has organized this meeting to understand prospects and problems of SRI in India which was chaired by Dr. Mangala Rai, DG, ICAR and attended by Mr. P.K. Mishra, Secretary, Agriculture and Senior Officials from ICAR & Ministry of Agriculture. Prof. Norman Uphoff, Cornell University, USA presented experiences on SRI in 25 centres and found its potential in India. Dr. Mangala Rai, DG. ICAR took a overview and opined to adopt SRI only where it is feasible. He also desired that PD, DRR and Director, CRRI should workout the Do's and Don'ts for implementing the SRI and should also help in identifying the areas where SRI has to be popularized.

1st, 2nd and 3rd National Symposium on SRI in India- Progress and Prospects: WWF-ICRISAT Project, together with a number of agencies, had organized three national level Symposia on SRI-Hyderabad 2006, Agartala 2007 and Coimbatore 2008. These symposiums achieved their main objective of involving many players in evaluating and promoting SRI to increase production and food security with positive consequences on the environment. Many major organizations such as SDTT, NABARD and NFSM are engaged in spreading the benefits of SRI innovation.

One day meeting on SRI Scaling Up-Future directions held on 3rd February 2009 at ICRISAT, Hyderabad: The meeting was mainly focused on current concerns on SRI and ways to widely promote it at the National Level. The concerns relating to SRI scaling up were circulated in advance after which a core group met to deliberate on them so as to share views with a wider audience including the state level policy actors, research agencies, farmers and civil society actors involved in SRI promotion.

Interactive policy dialogue on upscaling of SRI at ANGRAU campus, Hyderabad on 4th May 2009: An interactive policy dialogue on Upscaling SRI was held at ANGRAU auditorium, Hyderabad. Around 50 deligates including 2 members (Dr. Abhijit Sen & Prof. V.L. chopra) and 3 advisors (Shri L. Rynjah, Dr. V.V. Sadamate and Dr. Vandana Dwivedi) of Planning Commission, ICAR Senior Officials, Vice Chancellors, NGOs, Scientists from ICAR institutes, SAUs, Progressive farmers, WWF-ICRISAT and others participated in the meeting. The Objectives of the meeting is 1. To evolve a national framework for upscaling the SRI, 2. To identify the scientific and technical issues for further improving the SRI adoption which include design and production of tools, research issues on varietal response to SRI, suitability in different climsate jones, etc and 3. To draw timeline on national Poliy framework and instruments for up-scaling of SRI

Recommendations

- System of Rice Intensification (SRI) is a proven method which saves seed, water and other inputs and results in enhanced yields. This method has become popular in Tripura and Tamil Nadu and concerted efforts should be made to promote SRI in other states wherever there is a feasibility
- Areas most suitable for adoption of SRI need to be identified across the country and efforts to be focused to promote SRI in such areas.
- SRI has been already included as a component under NFSM. During the mid term evaluation, performance of SRI component may be critically reviewed and appropriate corrective measures and modifications if any, may be brought about to realize the expected goals.
- Rashtriya Krishi Vikas Yojana (RKVY) is one of the important programmes of Government of India with broader objectives which functions with bottom up approach involving district level planning. Efforts may be made to bring SRI under RKVY so that it becomes a strong program to realize the expectations.
- Capacity building at village level is quite critical for the success of SRI. Training programmes should be organized for the farmers, farm labourers and others who are involved in promoting SRI. Inter state farmers visits may also be organized to educate the farmers.
- Mechanization holds the key for successful adoption of SRI especially the weeders, transplanters, threshers etc. to overcome the labour shortage. Efforts should be made to develop appropriate machinery. The weeders (both manual and mechanized) developed so far by different agencies/farmers to be critically evaluated for their suitability and efficiency by CIAE Regional Centre, Coimbatore. This could be done at respective states.
- SRI promotion work should be taken up in close collaboration with the Irrigation Department which controls the flow of water. Unless this collaboration is established, it would be difficult to adopt SRI in command areas.
- Differential responses of varieties to SRI have been observed. Therefore, the existing high yielding varieties/hybrids may be

evaluated to identify the most suitable varieties for SRI cultivation so that farmers can get higher returns. However, for the time being, farmers can use any variety for growing under SRI.

- Multilocation trials on SRI under AICRIP may be intensified to study the specific effects of different components and to come out with location-specific recommendations. Further studies are needed to document the impact of SRI on pest and disease incidence, nutrient dynamics and eventual effects of climate change.
- For most practical purpose, seedling age at the time of planting could be 15 days. However, criteria of 2-3 leaves would be better as it is not influenced by location or the season. Integrated nutrient management (both organics + inorganics) could be followed in SRI. Those who can manage complete organic SRI are most welcome. However, the issue of controlling weeds through herbicides could not be resolved.
- Possibilities of direct seeding of sprouted seeds may be explored for SRI as this would avoid nursery raising and transplanting this leading to further saving in water
- Special efforts should be made to empower the farmers to produce their own organic matter (compost, vermicompost) and green manures. This should be built in the overall programme to assist the farmers.
- Land leveling is a critical component for the success of SRI. Custom hiring facility for such implements and the motorized weeders has to be created in villages.
- The Ministry of Rural Development may be approached to avail the incentives for labour for SRI under NREGA as labour shortage is becoming a serious problem in rural areas.
- Convergence of all the stakeholders such as State Governments, NFSM, RKVY, Researchers and Civil Society groups is desirable to implement the promotion of SRI. Such groups should meet at National, State and District levels to plan and implement the programme.

Review meeting on performance of System of Rice Intensification (SRI) held on 22nd June 2010 at TNUVAS, Chennai: The review meeting on performance of System of Rice Intensification was held at Chennai, on June 22nd 2010 under the Chairmanship of Dr. K. Kasturirangan, Member (Science), Planning Commission. Before start of the meeting the team visited SRI fields (from 08.30 to 10.30 hrs) and had discussion with farmers. This was followed by a SRI Review meeting in the Conference Hall, Madras Veterinary College Chennai. The following dignitaries were present in the meeting

- Dr. K. Kasturirangan, Member (Science), Planning Commission
- Shri L. Rynjah, Sr. Consultant (Agriculture), Planning Commission
- Smt. Vandan Dwivedi, Joint Adviser (Agri.), Planning Commission
- Commissioner of Agriculture, Govt. of Tamilnadu
- Director of Horticulture, Govt of Tamilnadu
- Vice Chacellors, TANUVAS, Chennai
- Assistant Direcor General (Seeds), ICAR, New Delhi
- State Government Functionaries

The Vice Chancellor, TANUVAS, Chennai welcomed the guests and the Commissioner of Agriculture, Govt. of Tamilnadu explained the objectives of the meeting. Brief presentation was made by the State Dept. of Agriculture Official on the status of SRI in the state. I was also given chance to present status of SRI research at CRRI, Cuttack upon the persuasion of Shri L. Rynjah, Sr. Consultant (Agriculture), Planning Commission. Afterwards through discussions were held on advantages and constraints in adoption of SRI.. The group felt that necessary steps should be initiated to popularize the SRI with the ultimate aim of increasing the production and productivity of rice.

National Workshop on "SRI: A decade in India- Lessons, experiences and Future Directions in the context of Food Security and Climate Change" in ICRISAT, Hyderabad on 21- 22, December 2010 : **Workshop on "SRI:** A decade in India- Lessons, experiences and Future Directions in the context of Food Security and Climate Change" was held at ICRISAT, Hyderabad on 21st December 2010 under the Chairmanship of Dr. N.K. Sanghi, Advisor, WASSAN. Dr. C.L. Gowda, Global Theme Leader, Crop Improvement, ICRISAT welcomed the guests. Dr. Biksham Gujja, WWF-ICRISAT Project explained the Objectives of the workshop and expected outcomes. Dr. Shambu Prasad, associate Professor, XIMB, Bhubaneswar gave National Overview of SRI and the Global Scenario was given by Dr. Norman Uphoff, Programme leader for Sustainable Rice systems, CIIFAD, Newyork via tele-conversation. The opening session was followed by panel discussions on the following topics.

1. What are the key lesions from the decade of experiences
2. What should be the key points for extension and research
3. What should be the shared vision for SRI for the next decade
4. What could be the main directions for a National SRI Consortium

5. What are the key policy changes required and from whom.

All the participants actively participated in the panel discussions and the outcomes were listed and distributed to the participants in due course. In the concluding session discussions were made on prioritizing/coordinating/integrating the actions/initiatives.

Sub-Group on "Upscaling Innovative technologies" for the 12th Five Year Plan: The Planning Commission has agreed to constitute a Sub-Group on "Upscaling Innovative technologies" for the 12th Five Year Plan. The subgroup members are Dr T M Thiyagarajan (Chairperson), Dr B C Barah (Member Secretary), Shri Biswanath Sinha, Narendranath and myself. TMT and Barah had a preliminary meeting with the rest of the working groups recently in Bengaluru UAS and the first meeting of the Sub Group will be hosted by the National Consortium in Delhi on the 4th this Saturday to take this forward. It is expected that there would be a report to be submitted to the PC by the end of this month. This effort is a culmination of several workshops and meetings with the National Food Security Mission (NFSM), the Planning Commission in May 2009 at Hyderabad and also a recent civil society consultation in December coordinated by WASSAN, apart from the three national symposiums and several state level alliances, workshops and symposia.

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