POLICY Brief

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System of Rice Intensification (SRI)

Benefits and Challenges in Technology Upscaling

Amod Kumar Thakur, Arjamadutta Sarangi

Key Messages

1. SRI is a climate-smart agriculture which offers numerous benefits and can make multiple contributions to achieving Sustainable Development Goals (SDGs).
2. Adoption of SRI practices on a large scale is limited at present despite SRI's multiple benefits.
3. Policy support from the government is essential to promote any new technology/ intervention like SRI.
4. Infrastructure development for irrigation, incentives to farmers, skill development, farm mechanization, and promotion of organic fertilizations are areas for government policy support.

ICAR-Indian Institute of Water Management
Bhubaneswar, Odisha-751023

Overview

The sustainability of rice production raises concerns due to increasing water scarcity, labour shortages, and climate change. Researchers have developed several water-saving technologies, such as alternate wetting and drying (AWD), soil saturation method, direct-seeded rice (DSR), aerobic rice, mulching, etc. These technologies save water and improve water productivity, but often at the expense of grain yield. To avoid endangering food security, innovations are needed that reduce agricultural constraints without diminishing yield.

The System of Rice Intensification (SRI) developed in Madagascar has been tested in 60-plus countries (SRI-Rice, 2023). It has been reported to reduce its water demand (Jagannath et al., 2013) accompanied by increased yield (Thakur et al., 2023). SRI makes several departures from conventional rice growing methods, relying more on knowledge and skill than capital expenditure.

For the transplanted version of SRI, young seedlings are planted singly in a square pattern with wide spacing instead of older seedlings planted in clumps; this reduces plant densities dramatically, by 80-90%, but with higher yield as each plant can better achieve its genetic potential for growing roots and tillers. Paddy fields are not continuously flooded; instead, can produce more with intermittent irrigation (alternate wetting and drying). Simple mechanical weeders are used to control weeds, aerating the soil at the same time and; can be motorized to reduce drudgery and labour time. Further, for enhancing soil fertility, organic materials are preferred to chemical fertilizers, although the latter can be used if the former are not in adequate supply. These changes promote more profuse plant root systems and multiply and diversify the soil biota, i.e., the life in the soil.

The practices of SRI provide optimal growing conditions for the crop, improve soil health, minimize water use, and ultimately improve crop performance and enhance resource productivity (Stoop et al. 2002). The Food and Agriculture Organization (FAO) has recognised SRI as a preferable rice production system (FAO, 2015), and the FAO-CGIAR Global Alliance for Climate-Smart Agriculture has reported SRI as ‘climate-smart agriculture’ (Styger and Uphoff, 2016; also, Thakur and Uphoff (2017). The World Bank Institute has produced a multi-media toolkit for SRI dissemination (WBI, 2016) and has supported the extensive spread of SRI in Bihar and Tamil Nadu States of India (Behera et al., 2016; TNA et al., 2021)

What does SRI offer? Scientific evidence

Higher Grain Yield

Altering rice plants’ growing conditions from the conventional flooded rice transplanting method, SRI induces more productive and robust plants (better phenotypes) from any given variety or cultivar (genotype) (Thakur et al., 2010; Uphoff et al., 2015). Larger and active root systems, higher leaf chlorophyll contents and rates of photosynthesis, and delayed senescence (ageing) of leaves and roots all contribute to a prolonged and faster grain-filling process, leading to higher grain yield under SRI management (Thakur et al., 2016). A recent study analysing 78 published studies from 27 countries plus several large-scale evaluations showed SRI method resulted in 24% higher grain yield than currently recommended practices and 56% more than

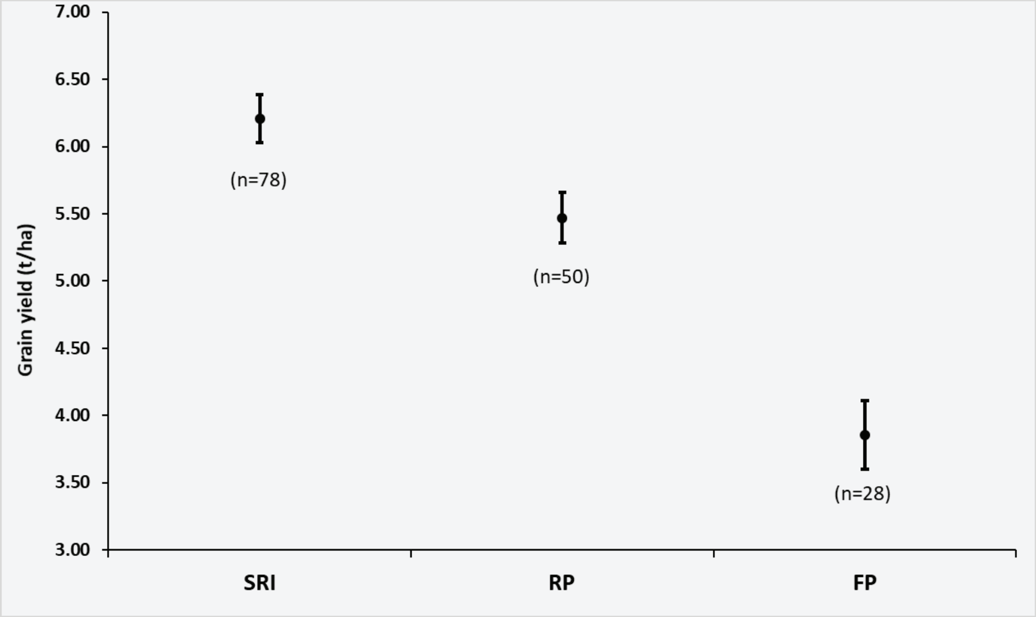

Fig. 1. Average rice grain yield (tonnes per hectare) under SRI, RP, and FP. The vertical bars represent the standard error of the mean value, which is represented by the dot in the centre of the range. (SRI: system of rice intensification; RP: recommended practices; FP: farmer practices)

Source: Thakur et al. (2023)

farmer's practices (Thakur et al., 2023; Fig. 1). Assessment of large-scale evaluations in eleven countries revealed an average increase of 54% in grain yield under SRI management compared with recommended and farmers' practices, with a reduction in production inputs resulting in higher net income (Thakur et al., 2023).

'Swarna' variety grown with SRI produced 84 Panicles in AP, India (Photo: A. Satyanarayana)

The pair of rice plants grown with the system of rice intensification (SRI) on the left vs. conventional methods on the right side (Photo: Amrik Singh)

Water Saving under SRI

Water constraints for agriculture are becoming more severe day by day, and using the current amounts of water to grow rice will not be possible in future. SRI recommends keeping paddy fields mostly unflooded, irrigating with either AWD or just maintaining the paddy soil at or near saturation, a departure from the conventional method of continuous flooding. Research has shown that SRI methods produce more grain using less water. Thakur et al. (2011) observed that grain yield enhanced by 48% under SRI using 22% less water than conventional flooded rice. A meta-analysis of 29 published articles from 8 countries reported that SRI produced higher crop yield with an average of 35% less irrigation water (Jagannath et al., 2013). In China's Sichuan Province, where SRI undertaken with provincial government support rose from 1,133 ha in 2004 to 400,000 ha by 2011 resulting in yield enhancement by 22% using SRI while irrigation was reduced by 25% (Zheng et al., 2013).

Higher yield with water saving and greater water productivity by adopting SRI practices has been documented in different countries *viz.*, Afghanistan (Thomas and Ramzi, 2011), China (Lin et al. 2009), India (Satyanarayana et al., 2007; Thakur et al., 2011), Indonesia (Sato and Uphoff, 2007), Iraq (Hameed et al., 2011), Kenya (Ndiiri et al., 2013), Sri Lanka (Namara et al., 2008), and Taiwan (Chang et al., 2016). FAO has also reported that SRI with widely-spaced plants in aerobic soil produced higher yields than conventional flooded rice production, noting soil health improvements, reduced irrigation requirements, and lower net greenhouse gas emissions (FAO, 2016).

SRI as Input-Saving Methodology

Originally, SRI was developed to improve irrigated production of rice, but the principles upon which it is based are agronomically corroborated with some adaptations of practices, for rainfed cultivation of rice, as seen in West Bengal (Sinha and Talati, 2007) and Karnataka (Balamatti and Uphoff, 2017), as well as for other crops like wheat (Dhar et al., 2015) and sugarcane (Gujja et al., 2017). The discussion here will deal with the irrigated version of SRI.

SRI practices include the use of single seedlings at wider spacing, about 20-25 cm in a square pattern, in contrast to the conventional method using 3-5 seedlings in clumps more closely spaced. This reduces seed requirements and plant density by 80-90%, with increased yield. Similarly, ending the continuous flooding of paddy fields saves an appreciable amount of water, as discussed in the preceding section. Using available organic matter as much as possible rather than relying on chemical fertilizers not only improves soil health but also reduces fertilizer use and its cost. Evaluations at the China National Rice Research Institute (CNRRI) found that rice yields with hybrid varieties were 2.5 t ha^{-1} higher when planting fewer plants (less seed), switching from flooding to AWD (less water), and providing half of the soil's nitrogen amendments in organic form (in this study, rapeseed cake, a by-product of oil pressing) rather than entirely with chemical fertilizer (Lin et al., 2009). These practices save money for both farmers and the Government while improving food production and food security.

Reduction in GHG Emissions

Reducing farmers' use of chemical fertilizers under SRI, as well as preventing continuous flooding of paddies also contributes to diminishing the net greenhouse gas (GHG) emissions from rice fields. This has been shown in studies from India (Rajkishore et al., 2013; Jain et al., 2014; Gathorne-Hardy et al., 2016) as well as Korea (Choi et al., 2015) and Vietnam (Dill et al., 2013).

- A study at ICAR-Indian Agricultural Research Institute (IARI), New Delhi, estimated that with SRI management, there was a 62% reduction in CH_4 emission, accompanied by a 23% increase in N_2O emission from rice fields, with a 28% net reduction in global warming potential from irrigated rice production (Jain et al., 2014). Reduced application of fertilizers also reduces chemical pollution in the runoff from paddy fields (Choi et al., 2015).
- Another evaluation of SRI in India (Andhra Pradesh) calculated in a thorough life-cycle analysis that SRI methods increased grain yield by 60%, accompanied by 40% lower net GHG emissions per hectare (60% lower GHG emissions per kg of rice produced) and 60% less groundwater depletion and 74% less fossil-energy use (Gathorne-Hardy et al., 2016)

Resistance to Insect Pests and Diseases

SRI crops exhibited reduced susceptibility to infestation and damage by insect pests and diseases. Numerous research evaluations have reported more robust and healthier crops resulting from SRI production management than the conventional flooded rice production system, which is less vulnerable to most, although not necessarily all, insect pests and disease attacks (Chapagain et al., 2011; Pathak et al., 2012; Visalakshmi et al., 2014). On-farm evaluations conducted in eight provinces of Vietnam documented a 55 to 70% reduction in the incidence of major rice pests and diseases under SRI (Dung, 2007). Resistance to damage by pests and diseases will become an increasingly important consideration for climate-stressed rice crops.

- A recently published 5-year study conducted across 8 locations in India by the ICAR-Indian Institute of Rice Research reported a lower incidence of pests in SRI-managed plots as well as greater numbers of natural enemies of pests. SRI was not more protective against all insect pests, but losses across all locations and for all pests ranged from 7 to 34% in SRI plots compared to 13-51% for conventional rice crop management, a reduction of 33 to 50% with no expenditure on chemical biocides (Chintalapati et al., 2023).

Tolerance of Climatic and Other Abiotic Stresses

SRI-grown rice plants are more robust and hardier, able to tolerate stresses like drought, flooding, wind and rain damage from storms, and extreme temperatures. These traits are attributable to their greater uptake and incorporation of silicon, which contributes also to their greater resistance to pest damage. Research has also shown that the plants resulting from SRI management practices have larger and deeper root systems which make them tolerant to water stress and other climatic hazards (Zheng et al., 2013; Thakur et al., 2015).

- **Resistance to drought stress** is likely to become more and more important in the years ahead. In the Sichuan province of China, it was observed that SRI had a yield advantage of 12% in two drought years (2006 and 2010) compared to the average provincial yield in non-drought years (Zheng et al., 2013). A study in Sri Lanka by the International Water Management Institute (IWMI) found that rice plants grown under drought conditions with the SRI method produced and stored more photosynthates and also had 30% more grain-bearing tillers per m^2, with more grains/panicle (Namara et al. 2008). This resulted in 38% higher grain yield with SRI compared to conventionally- grown crops under drought stress.

- SRI-grown plants are better able to **resist strong winds and rain** with less lodging (falling over). This is due to their growth of stronger and more prolific shoots, as well as to their better root systems (Chapagain and Yamaji, 2010). Wider spacing also enables the plants to avoid being blown or beaten down by letting the wind pass through the field.

Complete lodging of rice crop grown under conventional method after the storm on 30.10.2017 at ICAR-IIWM Research Farm, Khurda, Odisha

Only 7-9% of lodging in SRI after the storm

- SRI plants have been found also to **resist cold stress**. In Andhra Pradesh, ANGRAU researchers had their SRI vs. non-SRI trials hit by a 5-day cold snap (down to 9.2-9.8°C) in December 2006. This cold spell at a critical time in the crop growth cycle knocked the conventional yield down to 0.21 tons (just 210 kg) per hectare, while the SRI plots had a yield of 4.1 tons (4100 kg) per hectare (Sudhakar and Reddy, 2007).

- SRI rice crops have **shorter crop cycles** so the crop can usually be harvested 5-15 days earlier than with conventional management. This is due to the seedlings having minimal or no shock during their transplanting. Such reduction with greater production per day as well as per hectare has been documented in Bangladesh and Nepal (Uzzaman et al., 2015; Thakur and Uphoff, 2017). It also reduces crops' exposure time to the abiotic and biotic stresses that usually make them vulnerable to losses during the maturing stage.

In Addition to Being Climate-Smart, SRI Can Accelerate Achieving Sustainable Development Goals (SDGs)

The performance of different combinations of rice crop management and irrigation methods was assessed using indicators such as rice productivity, energy balance, soil health, profitability, and reduction in GWP (global warming potential) to calculate a Climate Smartness Index (CSI) (Mohapatra et al., 2023). Rice grown with SRI-AWD methods had a 55% higher CSI than farmer's practice with continuous flooding, and also had a CSI 25 to 28% higher than direct-seeded rice and transplanted methods. This indicates that SRI provides cleaner and more sustainable rice production, which can be promoted by the formulation of policy frameworks.

The System of Rice Intensification can contribute to achieving almost half of the Sustainable Development Goals (SDGs) promulgated by the United Nations to be attained by 2030, *viz*. No poverty (SDG #1), zero hunger (SDG #2), good health and well-being (SDG #3), gender equality (SDG #5), clean water and sanitation (SDG #6), decent work and economic growth (SDG #8), reduce inequality (SDG #10), and climate action (SDG #13) (Thakur et al., 2022).

To summarize, SRI methods have been observed to increase rice production by 25-50% or more, using 20-50% less water and lowering farmers' costs of production, thereby raising their income per hectare by more than the yield increase. Also, SRI practices reduce the net emission of GHGs from paddy fields, while reducing crops' vulnerability to the perils of climate change, both abiotic and biotic stresses (Dahlgreen and Parr, 2024). However, cooperation from governments, the private sector, civil society, and individual citizens is required to take advantage of these opportunities to improve life for present and future generations and to reach Sustainable Development Goals.

Taking Advantage of SRI Opportunities

SRI methods, although simple and scientifically validated, are counter-intuitive – fewer plants, less water, and more organic rather than more chemical fertilizer will improve yield and crop performance. Many farmers find it hard to accept these new practices in preference to their age-old methods of production – until they see how much more vigorous and productive SRI-grown rice plants can be. So, extension efforts need to be more than telling farmers **what** to do by conducting pilot field demonstrations of SRI techniques. Also, time should be taken to explain **why** SRI methods are more productive, not just what to do and how. Farmers satisfied with the technology should be involved in the extension work because this can be more persuasive, and such farmers can address very specific issues based on personal experience. The focus should be on adaptation and problem-solving to address any difficulties in the nursery and handling of young seedlings, availability of organic fertilisation, training and labour constraints, water management; and weed management, etc.

At first, researchers and extension personnel may be as sceptical or resistant as farmers because SRI departs substantially from the gene-centred, input-dependent strategies of the past. They too will need to engage in some new learning along with farmers. This makes farmer-field-school and farmer-participatory approaches more appropriate, where researchers, extension staff and farmers all participate in trials and evaluations. Rather than just transferring a set technology,

MODIFIED SRI

The modified SRI (var: Surendra) with 20 x 20 cm row and plant spacing, 3-DAD irrigation, and integrated nutrient management saved about 22-35% of water and gave 36-49% higher yield (about 6 t ha^{-1}) with 34-40% higher agronomic nitrogen use efficiency compared to the conventional transplanted rice crop.

for SRI there should be experimentation with variations in practice to find the timing, spacing, varieties, etc. that are most suitable for local conditions.

It is not suggested or claimed that SRI practices will be suitable for every farmer in the same way. It is also established that one variety is unlikely to be the best for all farmers and fields. Cultivation practices should similarly be adapted to make the most productive use of the available resources. SRI is not a 'silver bullet' for use in all situations, but rather an understanding of how to elicit the fullest expression of the genetic potentials of plants and the biological potentials of soil systems. There are no agricultural innovations that will be good for every farmer or good in the same way. Nonetheless, it is imperative to capitalize on the opportunities that SRI has already demonstrated in most States of India and several Countries.

Training

The foremost challenge in scaling up SRI is imparting appropriate and adequate training to farmers and trainers. Initially, the SRI method was understood as a technology involving certain fixed practices developed in Madagascar, and farmers were trained accordingly. This invited several problems as well as criticisms because SRI was better understood as a methodology based on certain principles that are agronomically valid. Some of the practices appear counter-intuitive as noted above. SRI principles for eliciting the greatest vigour and robustness from rice crops get manifested in specific practices that should be adapted to local conditions. For example, if soil fertilization cannot be fully organic because of cost or unavailability, the other SRI practices can be used beneficially with inorganic fertilizer; the principle is to apply as much organic material to the soil as possible, to improve soil structure and functioning and to nurture the life in the soil. If a regular schedule of alternate wetting and drying is not possible, managing irrigation to give the soil more intervals of aeration is desirable, such as mid-season drainage. This necessitates the development of protocols of modified SRI fitting to different agro-ecosystems.

Both trainers and farmers should know the principles of SRI, and why they enhance plant growth and health. Farmers should be encouraged to do some experimenting with the timing and spacing of transplants, or the number of plants per hill, to satisfy themselves and come out with the most productive and efficient best management practices in their circumstances. Famers should be given to understand how to create better growth-promoting conditions above- and below-ground. In the Mwea Irrigation Scheme in Kenya, it was found that SRI methods doubled the yield compared with farmers' practices, but there was a need for capacity-building and proper training on SRI to promote it on a large scale (Mati et al., 2011). Extension personnel are often more accustomed to promoting inputs and less confident and competent in conveying ideas. Hence, there is a need for capacity building of extension personnel and strategies to be more participatory and experimental rather than just 'delivering' a set package.

Labour

A frequent objection has been that SRI is 'too labour-intensive' for widespread adoption. It is reported in India and elsewhere that SRI adoption is constrained by the availability of skilled and committed labour, especially at the time of transplanting, and that farmers could not go for the SRI method in their entire paddy fields despite higher yield and economic return (Ly et al., 2012). At the same time, labourers are reluctant to leave familiar practices and adopt or learn new techniques which are initially more tedious. However, numerous studies have shown that SRI is either labour-*neutral* or even labour-*saving*, once the new practices have been learned. No studies have shown a decline in labour productivity as the SRI method produces more kg of rice per hour or day of labour. A study in Andhra Pradesh found that SRI methods reduced labour, and overall, payments for hired labourers were reduced by 50% (Gathorne-Hardy et al., 2016). Usually, once farmers gain skill and confidence with the new methods, their labour requirements decline with the subsequent adoption of the SRI method. Its labour requirements can also be lowered with technological innovations and mechanization, especially for transplanting, weeding, and harvesting for the sustainable adoption of SRI.

Controlled Water Management

The SRI crop management practices along with AWD will be most feasible as well as profitable where crops are irrigated with groundwater. The principle is to provide rice plants with sufficient water but not any surplus that causes asphyxiation of plant roots and aerobic soil organisms (earthworms, beneficial microorganisms, etc.) besides percolation of more water. All these depend upon physical infrastructure, water supply, and management capability. SRI methods as well as AWD will be more successful where there are reliable and controlled irrigation and drainage facilities, with timing and quantity of water delivery optimized under the operative constraints. AWD is difficult when farmers have no assured source of irrigation or where irrigation is free and abundant so there is no incentive to use less water. Generally, SRI is not recommended where controlled irrigation is not possible, for example, under rainfed conditions or within canal irrigation systems that have no fixed water delivery schedules. Still, all rice-growing farmers should be mindful of the adverse impacts of continuously standing water, which suffocates plant roots and most life in the paddy soil. Consuming less water for rice production is beneficial for communities (reducing water-borne disease vectors, and freeing up water for domestic and other uses) as well as for the Government (*viz*. less conflict over water besides reduced fiscal expenditure).

Nursery Management

A few farmers report that nursery management and handling of younger seedlings in SRI is difficult because roots get damaged while uprooting for transplanting. Under SRI, a dry nursery should be prepared rather than a conventional wet nursery. A dry, garden-like nursery for SRI should be top-layered with a mix of compost, sand, and soil so that the young seedlings can be uprooted without damage to their roots. Also, they should be transplanted within half an hour after uprooting for the best results, avoiding drying out (desiccation) of the roots.

Organic Fertilization

Initially, SRI was developed using chemical fertilizer, but when the subsidy was withdrawn by the Government, farmers had to switch to compost or manure, which was found to be superior and lower cost. Compost is generally made mostly or entirely from rice straw, leaves, and other vegetative matter, but animal manure is also considered to be a good material. SRI can be either fully organic or only partially or mostly organic. If no organic inputs are provided to enrich the soil along with other SRI practices, it will be a minimal version of SRI. There can be yield benefits from SRI practices just using chemical fertilizer. However, the full benefits of SRI management cannot be expected because such fertilizer does not improve soil health. Also, some SRI proponents prefer 'organic SRI' because of environmental and health benefits and economic gains.

Moreover, the use of high doses of chemical fertilizer can adversely affect the soil organisms that contribute to SRI rice plants' productivity. Adding sufficient organic amendments to the soil helps to sustain 'the life in the soil' -- a key to SRI success. On the

INTEGRATED SRI (ISRI) FOR RAINFED SITUATION

During the rainy season, there is no control over water for rainfed rice, and waterlogging in the rice field reduces the yield. It is also difficult to use any water-saving irrigation methods in the rice field during this season.

To enhance the land and water productivity of rainfed rice, 10% of the SRI rice field area was converted into a refuge for harvesting rainwater; the refuge pond was used for supplementary irrigation and short-duration fish culture. In this way, the SRI field was kept moist (not flooded) during the rainy season. Bund could be used for growing horticultural crops. This system is named as 'Integrated SRI (ISRI)'.

Grain yield enhanced (by 52%) under SRI as compared with conventional rainfed methods.

ISRI greatly raised the net income/unit of water compared with conventional rainfed rice. Water productivity was raised from ₹ 0.31 per m^3 of water to ₹ 18.91 per m^3 of water under the ISRI system compared to conventionally flooded rainfed rice.

Producing 'more crop per drop' and 'doubling incomes' for farming households can be accomplished in rainfed areas by integrating SRI rice production methods with aquaculture and horticulture.

other hand, the availability of large amounts of organic amendments is a problem for many rice farmers if they want to go for 'organic SRI'. Another problem for 'organic SRI' is that if farmers have been heavily reliant on chemical fertilizer, their rice production system may have become fertilizer-dependent, and conversion will involve a transition period (*viz.* one or a few seasons) during which their crop yields may be lower because the soil system needs to adjust to the new nutrient regime and the abundance and diversity of soil organisms is gradually increased or restored.

A plethora of studies have shown that some optimized combinations of organic and inorganic sources of nutrients -- integrated nutrient management -- can give the highest yield (Lin et al., 2011; Thakur et al., 2020). In Indonesia, two versions of SRI have been encouraged: (i) '*basic SRI*', in which farmers' reliance on chemical fertilizer is reduced by 50% while they increase the amount of compost added to their soils to support crop growth; and (ii) '*organic SRI*', in which only organic inputs are used (Sato and Uphoff, 2007) to qualify for a premium price in the market and to get higher profitability even with lower yield levels. As demand from consumers around the world for organic rice is increasing, so organic versions of SRI can be promoted, considering soil and human health, environmental benefits, and net economic returns, where the availability of organic materials is not a problem.

Weed Management

Rice fields are usually flooded particularly to control weeds. Under SRI practices, paddy fields are no longer kept flooded, weeds can be a menace for farmers if not controlled properly. For controlling weeds, SRI recommends the use of a simple mechanical hand weeder (e.g., cono-weeder, mandava weeder). This not only controls weeds, but has some other advantages, i.e., aerating the soil, incorporating weeds into the soil, and pruning surface roots to induce deeper root growth. Usually, women farmers are engaged in weeding by hand in paddy fields. During the initial stage of SRI promotion, some women farmers complained about using mechanical weeders, as they require more strength to operate them. However, women-friendly weeder designs have been developed to ameliorate the problem and subsequent use by women. A study undertaken at ANGRAU showed that mechanical weeding reduced women's labour time by 78% (Mrunalini and Ganesh, 2008).

Policy Interventions

SRI is particularly beneficial for the poor, resource-limited farmers having small landholdings and for farm labourers engaged in rice farming, although with mechanization its principles can be applied beneficially on a larger scale. The first large farmer in the Punjab province of Pakistan designed appropriate implements and applied SRI practices on a laser-levelled, 20-acre 'test plot,' with raised beds to conserve water. The mechanization with water control enabled to achieve an average yield of 12 tons per hectare, using 70% less water and 70% less labour (Sharif, 2011). So, there are options to promote capital-intensive as well as labour-intensive versions of SRI.

It has been seen that SRI has several benefits and constraints in its adoption, which could be easily addressed through policy interventions and changing the mindset of the farmers. It is realised that conventional flooding rice planting methods are unsustainable and there is a need to shift from this method to SRI and AWD methods which necessities these basic requirements:

- **Infrastructure** support from the Government is always essential to promote any new technology/interventions. For example, the Green Revolution could not have happened without the development of irrigation systems and the availability of subsidized fertilizers. Similarly in the present scenario of water scarcity, climate change, declining soil and human health, besides greater food requirements for the growing population, policy interventions are needed. Since judicious water management is the most challenging part of SRI adoption, investments in irrigation systems' hardware (physical structures) and software (administrative organization and farmer) will be required so that reduced but reliable quantities of irrigation water can be provided to the rice crop. A combination of public and private investments should be orchestrated to ensure that at least the crop's minimum water requirements can be fulfilled.
- **Training** is one of the most important constraints in the adoption of SRI methodology. Not only knowledge and skill are the basis of success in SRI but also an understanding of why certain age-old practices should be modified. This applies to line department trainers as well as to farmers. Fortunately, there is a lot of expertise in India for SRI training, especially in civil society and in farming communities. For this technology, a participatory and learning-by-doing approach in training is suitable for SRI expansion.
- **Remuneration of Labour:** When agricultural labourers are trained and engaged in SRI production, they are generating more value-added for their employers and more value for society (such as water saving and water quality). Labourers will be more inclined to learn new practices if this earns them more income. Those who have received SRI training and can raise productivity, both at the farm level and societal, should be given certificates by approved government and civil society training programs that would entitle them to a higher daily wage for SRI work such as transplanting and weeding. Besides this, the ecosystem service component of SRI needs to be evaluated properly and farmers need to be rewarded or incentivized for adopting SRI.
- **Marketing Channels:** The production of rice with SRI methods produces better grain quality that already is sometimes eliciting premium prices from traders and consumers. Studies in India have shown that SRI grains are richer in micronutrients, for example (Dass et al., 2017), with 20-70% higher concentrations of iron, zinc, copper and manganese, essential dietary elements that are deficient in millions of Indians' diets. SRI rice is also recognized by consumers for its taste, cooking and keeping qualities that make it more desirable. Developing distinct marketing channels for SRI-grown rice would enable consumers to purchase it at a higher price, and also give farmers a higher price for their produce. The Government need not enforce or subsidize a higher price for SRI rice, only facilitate its branding different than that of rice produced by other methods, letting the market reward farmers for higher-quality rice, and thereby giving them more incentive to use the new water-saving methods.
- **Mechanization:** Labour shortage for agricultural work is a common problem now, and it will become more severe in the future due to labour migration from rural to urban areas. This is a situation where encouraging mechanization of rice production (not only SRI) is warranted. Appropriate State or private institutions can test and disseminate equipment designs, regulating the patenting of certain innovations that deserve patent protection. Rather than

invest in big research projects, the Government could encourage the best designs or best methods of construction, valuing ease of operation, durability and other traits in addition to the cost and effectiveness of implements. Evaluation should be done with the involvement of farmers to incorporate user perspectives. In making evaluations, special attention should be paid to women's needs and capabilities because they perform the most rice-producing operations. Hire-purchase schemes could be subsidized or guaranteed so that farmers can purchase, individually or in groups, what they consider the best implements making a modest down payment, with the balance due at harvest time, when the use of the implements would have generated more than the additional income for farmers. As with the other suggestions, relatively small amounts of Government funding or startup grants should stimulate market solutions.

- **Subsidies:** The use of excessive chemical fertilizers, pesticides and herbicides has resulted in the deterioration of soil health and water quality which is affecting human health. SRI recommends the use of organic soil amendments as much as possible to improve soil health. There is a need for support and promotion besides the development of compost/organic fertilization units to increase use at the household level in villages. The continued subsidization of chemical fertilizers is fiscally unsustainable and has unaccounted-for ecological costs. Government expenditure on these inputs should be reduced in favour of more economically and environmentally favourable methods of soil fertility enhancement. Raising India's abysmally low levels of soil organic carbon, usually less than 1% when they should be 3% or higher, is an essential investment in the Country's future. Also, the subsidization of electricity and petrol for tubewell operation could be reduced with SRI, having positive externalities by slowing and eventually stopping the draw-down of water tables in places like Punjab, where the declining water table is a major concern.

In conclusion, decision-makers in India should recognise that SRI is a high-production, climate-smart, environment-friendly, and resource-conserving methodology which can provide more food and income, reduce government fiscal burdens, provide protection against the hazards of climate change, enhance soil health and human health, and reduce methane emission, the prime driver of global warming. SRI can enable policy-makers to move the Country toward achieving food, nutritional, and economic security for future generations. Constraints to adoption should be addressed by Government policy interventions and support SRI as one of the most cost-effective innovations currently available to Indian farmers, communities, and consumers.

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References

Behera, D. et al. (2013) *Enhancing Agricultural Livelihoods through Community Institutions in Bihar, India*, World Bank South Asia Office, New Delhi (https://documents1.worldbank.org/curated/en/467261468258525242/pdf/763380NWP0P09 00030 Note10Box0374379B.pdf)

Bender, S.F. et al. (2014) Symbiotic relationships between soil fungi and plants reduce N_2O emissions from soil. *ISME Journal* 8:1336-1345.

Chang, Y.C. et al. (2016) A conceptual framework for eco-friendly paddy farming in Taiwan, based on experimentation with System of Rice Intensification (SRI) methodology. *Paddy & Water Environment* 14:169-183.

Chapagain, T. and E. Yamaji. (2010) The effects of irrigation method, age of seedling and spacing on crop performance productivity and water-wise rice production in Japan. *Paddy & Water Environment* 8:81-90.

Chintalapati, P. et al. (2023) Insect Pest Incidence with the System of Rice Intensification: Results of a Multi-Location Study and a Meta-Analysis. *Agronomy* 13: 1100.

Chapagain, T. et al. (2011) Assessment of System of Rice Intensification (SRI) and conventional practices under organic and inorganic management in Japan. *Rice Science* 18:311-320.

Choi, J.D. et al. (2015) Effect of SRI methods on water use, NPS pollution discharge, and greenhouse gas emissions in Korean trials. *Paddy & Water Environment* 13:205-213.

Dass, A. et al. (2017) Agronomic fortification of rice grains with secondary and micronutrients under differing crop management and soil moisture regimes in the north Indian Plains. *Paddy & Water Environment* 15:745-760

Dill, J. et al. (2013) *Promoting the System of Rice Intensification: Lessons Learned from Trà Vinh Province, Vietnam*. German Agency for International Cooperation (GIZ) and International Fund for Agricultural Development, Hanoi. https://wocatpedia.net/images/f/f2/Giz2013-0503en-rice-lessons-learned-vietnam.pdf

Dung, N.T. (2007) SRI Application in Rice Production in Northern Ecological Areas of Vietnam: Report of National IPM Program to Ministry of Agriculture and Rural Development, Hanoi. http://ciifad.cornell.edu/sri/countries/vietnam/vndung ipmrpt06.pdf

FAO (2016) *Save and Grow: Maize, Rice and Wheat – A Guide to Sustainable Crop Production*, pp 44-47. UN Food and Agriculture Organization, Rome. https://www.fao.org/3/i4009e/i4009e.pdf

Gathorne-Hardy, A. et al. (2016) System of Rice Intensification provides environmental and economic gains but at the expense of social sustainability: A multidisciplinary analysis in India. *Agricultural Systems* 143:159-168.

Hameed, K.A. et al. (2011) Irrigation water reductions using System of Rice Intensification compared with conventional cultivation methods in Iraq. *Paddy & Water Environment* 9:121-127.

Jagannath, P. et al. (2013) Meta-analysis evaluating water use, water saving, and water productivity in irrigated production of rice with SRI vs. standard management methods. *Taiwan Water Conservancy* 61:34-49.

Jain, N. et al. (2014) Mitigation of greenhouse gas emission with system of rice intensification in the Indo-Gangetic Plains. *Paddy & Water Environment* 12:355-363.

Lin, X.Q. et al. (2011) Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics. *Paddy & Water Environment* 9:33-39.

Lin, X.Q. et al. (2009) Effect of plant density and nitrogen fertilizer rates on grain yield and nitrogen uptake of hybrid rice (*Oryza sativa* L.). *Journal of Agrobiotechnology & Sustainable Development* 1:44-53.

Ly, P et al. (2012) The System of Rice Intensification: Adapted practices, reported outcomes, and their relevance in Cambodia. *Agricultural Systems* 113:16-27.

Mati, B.M. et al. (2011) Introduction of the system of rice intensification in Kenya: experiences from Mwea irrigation scheme. *Paddy & Water Environment* 9:145-154.

Mohapatra, K.K., et al. (2023) Multi-criteria assessment to screen climate-smart rice establishment techniques in coastal rice production system of India. *Frontiers in Plant Science* 14:1130545.

Mrunalini. A. and M. Ganesh (2008) Work load of women using cono-weeder in SRI method of paddy cultivation. *Oryza* 5:56-61.

Namara, R. et al. (2008) The practice and effects of System of Rice Intensification (SRI) in Sri Lanka. *Quarterly Journal of International Agriculture* 47:5-23.

Ndiiri, J.A. et al. (2013) Water productivity under the System of Rice Intensification from experimental plots and farm surveys in Mwea, Kenya. *Taiwan Water Conservancy* 61:63-75.

Pathak, M. et al. (2012) Prevalence of insect pests, natural enemies, and diseases in SRI (System of Rice Intensification) of rice cultivation in North East Region. *Annals of Plant Protection Science* 20:375-379.

Rajkishore, S.K. et al. (2013) Methane emission patterns and their associated soil microflora with SRI and conventional systems of rice cultivation in Tamil Nadu, India. *Taiwan Water Conservancy* 61:126-134.

Sato, S. and N. Uphoff (2007) A review of on-farm evaluations of system of rice intensification in Eastern Indonesia. *CAB Reviews,* Commonwealth Agricultural Bureau International, Wallingford, UK.

Satyanarayana, A. et al. Opportunities for water saving with higher yield from the system of rice intensification. *Irrigation Science* 25:99-115.

Sharif, A. (2011) Technical adaptations for mechanized SRI production to achieve water-saving and increased profitability in Punjab, Pakistan. *Paddy & Water Environment* 9:111-119.

SRI-Rice (2023) Website of the SRI International Network and Resources Center, Cornell University, Ithaca, NY: http://sri.cals.cornell.edu

Stoop, W.A. et al. (2002) Research issues raised for the agricultural sciences by the System of Rice Intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-limited farmers. *Agricultural Systems* 71:249-274.

Styger, E., and N. Uphoff. (2016) *The System of Rice Intensification: Revisiting Agronomy for a Changing Climate.* GACSA Practice Brief. Global Alliance for Climate-Smart Agriculture, FAO, Rome.

Sudhakar, T.R., and P.N. Reddy. (2007) Influence of system of rice intensification (SRI) on the incidence of insect pests. Presentation at 2nd National SRI Symposium, Agartala, India, Oct. 3-5, slides 16 and 17. http://www.slideshare.net/SRI.CORNELL/0729-influence-of-sri-on-the-incidence-of-insect-pests

Tata Trusts (n.d.), *The System of Rice Intensification Initiative*, Mumbai. (https://www.tatatrusts.org/our-work/livelihood/ agriculture-practices/system-rice-intensification-initiative#:~:text=The%20System%20of%20Rice%20Intensification, multiple%20 mature%20seedlings%20close%20together)

Thakur, A.K. et al. (2010) An assessment of physiological effects of system of rice intensification (SRI) practices compared with recommended rice cultivation practices in India. *Experimental Agriculture* 46:77-98.

Thakur, A.K. et al. (2011) Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. *Paddy & Water Environment* 9:13-24.

Thakur, A.K. et al. (2015) Enhancing water and cropping productivity through Integrated System of Rice Intensification (ISRI) with aquaculture and horticulture under rainfed conditions. *Agricultural Water Management* 161:65-76.

Thakur, A.K et al. (2016) Scientific underpinnings of the System of Rice Intensification (SRI): What is known so far? *Advances in Agronomy 135:* 147-179.

Thakur, A.K. and N. Uphoff (2017) How the system of rice intensification can contribute to climate-smart agriculture. *Agronomy Journal* 109:1163-1182.

Thakur, A.K. et al. (2020) Impact of crop and nutrient management on crop growth and yield, nutrient uptake and content in rice. *Paddy & Water Environment* 18:139-151.

Thakur, A.K.et al. (2022) How agroecological rice intensification can assist in reaching the Sustainable Development Goals. *International Journal of Agricultural Sustainability* 20:216-230.

Thakur, A.K et al. (2023) Do System of Rice Intensification practices produce rice plants phenotypically and physiologically superior to conventional Practice? *Agronomy*, 13, 1098.

Thomas, V., and A.M. Ramzi. (2011) SRI contributions to rice production dealing with water management constraints in northeastern Afghanistan. *Paddy & Water Environment* 9:101-109

Uphoff, N. et al. (2015) Improving the phenotypic expression of rice genotypes: Rethinking "intensification" for production systems and selection practices for rice breeding. *Crop Journal* 3, 174-189.

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, 38-50.

Uzzaman et al. (2015) Growth and yield trial of sixteen rice varieties under System of Rice Intensification. *Scientific Agriculture* 11(2): 81-89.

Visalakshmi, V. et al. (2014) Impact of paddy cultivation systems on insect pest incidence. *Journal of Crop & Weed* 10:139-142.

Watanarojanaporn, N.et al. (2013) Effect of rice cultivation systems on indigenous arbuscular mycorrhizal fungal community structure. *Microbes & Environment* 28: 316-324.

World Bank Institute (2016), *The System of Rice Intensification: A Multi-Media Toolkit*, Washington, DC. https://brooktown.com/SRI/wp-content/uploads/2017/06/SRI-DB-World-Bank-Toolkit-brochure.pdf

Zheng, J.G. et al. (2013) Agricultural water savings possible through SRI for water management in Sichuan China. *Taiwan Water Conservancy* 61:50-62.