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SRI-2030

SRI rice methods practiced on 50m hectares by 2030

A summary of notable SRI projects, the evidence surrounding SRI, and areas of opportunity for SRI development.

SRI-2030 SUMMARY REPORT

A summary of notable SRI projects, the evidence surrounding SRI, and areas of opportunity for SRI development.

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1.0 Key Country and Regional Insights regarding SRI

The SRI methodology has been evaluated and validated in over 60 countries (SRI-Rice, 2022a). It has been selected and recommended by Project Drawdown (Hawken, 2017) as a currently-available, proven technology for reaching net-zero greenhouse gas emissions by 2050. Supported by extensive worldwide research and reporting (SRI-Rice, 2022b), SRI is well-placed to be implemented on a broad scale as a low-cost, high-return course of action towards halting global warming and climate change. There is no reason why its utilisation should not be accelerated to hasten the reduction of methane emissions and to increase carbon sequestration in agricultural soils.

1.1 Past Projects with Large-Scale Applications of SRI

The following are a selection of large-scale regional projects that have demonstrated beneficial results from scaling up SRI. There are many more smaller programs and projects in Asia, Africa, and Latin America.

1.1.1 Chhattisgarh Irrigation Development Project (CIDP), supported by Asian Development Bank (ADB), India, 2006-2013.

- Wijayaratna, C.M. (2014) *Un-Noticed Green Revolution in Chhattisgarh: Doubling Farmers' Crop Output and Returns through Collective Action.* Available at: http://sri.cals.cornell.edu/countries/india/chhattisgarh/InChhtatt_ADBproject_Wijay2014.pdf

- Asian Development Bank (2015) *India: Chhattisgarh Irrigation Development Project Completion Report*, Asian Development Bank, Manila. Available at: https://www.adb.org/sites/default/files/project-document/173318/37056-013-pcr.pdf [Accessed 07/04/2022]

Between 2006 and 2013, the Asian Development Bank (ADB) supported the Chhattisgarh Irrigation Development Project (CIDP) implemented by the state government of Chhattisgarh. CIDP was designed to improve irrigation delivery, enhance agricultural practices, and strengthen water-resource management to increase agricultural productivity while improving rural livelihoods and reducing poverty. This project organised 100 Water Users Associations (WUAs) through its Intervention Programme (IIP) to follow a strategy entitled 'Managing Kharif for Rabi' which entailed shortening the duration of Kharif (wet season) crops and maximising the use of rainfall through storage for year-round water management to improve productivity in the following Rabi (dry season) for a second crop. With the Kharif crops in the region being predominantly rice, SRI was chosen as a key component of the project that saved water, time, and cost.

In 2010, the IIP introduced SRI across an initial 29 hectares, with 52 farmers in 11 WUAs. By the 2012 Kharif season, SRI uptake had rapidly scaled, reaching over 4000 hectares, with more than 5000 farmers in 82 WUAs. The overall results from the project, for which SRI accounted for around 4% of the overall paddy cultivation area, saw yields more than double from the initial 2.4 tons per hectare baseline at the beginning of the project to 5.9 tons per hectare recorded from the 2012-13 Kharif season. SRI positively contributed to the project's yield improvements with pronounced yield outputs. One SRI farmer even recorded a notable 11.3 tons per hectare.

1.1.2 Jeevika, Bihar Rural Livelihood Project, supported by the World Bank, Bihar, India: 2007-2012

- Behera, D., Kumar, A., Vinay, C., Vutukuru, K., Gupta, A., Machiraju, S., Shah, P. (2013) *Enhancing Agricultural Livelihoods through Community Institutions in Bihar, India*. New Delhi: World Bank. Available at: https://documents1.worldbank.org/curated/en/467261468258525242/pdf/763380NWP0P0900030Note10Box0374379B.pdf

Between 2007 to 2012, The World Bank and the Government of Bihar partnered to implement Jeevika, a state-wide program to customise and scale-up agricultural and institutional innovations to improve the well-being of households in Bihar state. Agriculture was the focus for the project as this sector is pivotal to the livelihoods of millions of people living in Bihar, employing more than 80% of the labour force; 80% of the population are smallholder farmers. SRI was selected as a key intervention as many of the constraints faced by farmers in Bihar, such as access to improved inputs and external resources, as well as the poor agricultural productivity in the region, could be simultaneously addressed through SRI's low-cost and proven methodology.

In 2007, SRI was piloted by an NGO with 127 farmers using SRI methods on over 30 hectares. After the first-year success, the project scaled up the methods for further crops beyond rice such as wheat, green gram, and rapeseed through the System of Crop Intensification (SCI), which follows SRI principles. By the end of the project in 2012, over 103,000 farmers were practising

SRI for rice, generating US $5.2 million of additional income. The project was a success for enhancing food security and strengthening the community's economic outcomes.

Table. 1: Results from Jeevika Program in Bihar State, India

No. of households	Yield increase per ha	Increase in farmer profits from rice	Overall net income increase ($US)	Source
103,028	86	250%	5.2 million*	Behera *et al.*, 2013
* = Approximately US $31 per household				

1.1.3 Irrigated Agriculture Modernisation and Water-Bodies Restoration and Management (IAMWARM), supported by the World Bank, Tamil Nadu, India, 2007-2015.

- Nayar, V., Ravichandran, V. K., Barah, B. C., Uphoff, N. (2020) Sustainable SRI and Rice Production: Learnings from an Irrigation Management Project in Tamil Nadu, *Economic and Political Weekly*, 2, 46-51. Available at: https://www.im4change.org/siteadmin/tinymce/uploaded/EPW%20System%20of%20Rice%20Intensification.pdf

- World Bank Group (2019) *India -Tamil Nadu Irrigated Agriculture Modernization and Water-Bodies Restoration and Management Project. Project Performance Assessment Report. Independent Evaluation Group.* Washington, DC, World Bank.

The Irrigated Agriculture Modernisation and Water-Bodies Restoration and Management (IAMWARM) project, funded by the World Bank and state government of Tamil Nadu, was implemented by the latter starting in 2007. The project aimed to maximise the efficiency and productivity of land and water-resource management while achieving greater economic growth and was implemented through four phases, in 61 of the 127 sub-basins in Tamil Nadu. SRI was selected as one of the key technologies for this development. In 2007 SRI was introduced over an area of 1,300 hectares, and by project completion, SRI adoption had undergone a rapid increase reaching over 272,700 hectares, succeeding the project's appraisal target four times over.

Average yield increases from the project were reported up to 22%. The water-saving aspect of the alternate wetting and drying (AWD) technique was particularly important for a water-stressed state such as Tamil Nadu, and SRI achieved water savings of 42% per hectare compared to traditional cultivation methods. Of further note, SRI reduced farmers' production costs by almost 16% overall, due to significant savings in seed requirements (87%), in labour (17%), as well as in pesticides and fertilisers, contributing to a 45% net increase in farmer income through adopting SRI methods.

Due to SRI's success, the state government has continued to include SRI in its implementation policies and programs since the project's completion. SRI is a key technology for farmers in Tamil Nadu with around 1.62 million hectares under SRI paddy cultivation across the state recorded in 2019. Tamil Nadu has also received wide recognition both within India and internationally with 250 officials from 26 countries visiting SRI sites to learn from the states' experience.

1.1.4 NABARD Farmers Technology Transfer Fund (FTTF), India, 2010-2013.

- NABARD (2016) *The System of Crop Intensification-Agroecological Innovations for Improving Agricultural Production, Food Security, and Resilience to Climate Change.* Department of Economic and Analysis and Research, National Bank for Agriculture and Rural Development, Mumbai, India. Available at: http://sri.cals.cornell.edu/aboutsri/othercrops/SCImonograph_SRIRice2016.pdf

In 2010, the National Bank for Agriculture and Rural Development (NABARD) embarked on a multi-state program to promote SRI across 13 major rice-growing states in India. This was supported through NABARD's Farmers Technology Transfer Fund (FTTF) and followed a phased implementation approach over three years. In each participating district, a cluster of 16 villages was selected for SRI demonstration and adoption in the first year, with 25 farmers selected per village, totalling 400 farmers per district. Each participating farmer was to apply SRI methods on one acre of land (Year 1 = 0.3 acre; Year 2 = 0.5 acre; Year 3 onwards = 1.0 acre). Field level advisory support from SRI facilitators and coordinators were provided to farmers, as well as monetary incentive to cover costs of organic manure and equipment such as markers and weeders in order to secure the best outcomes.

A slight adjustment in the model approach was taken in Jharkhand state, which saw improved results, and for which detailed data are available. In Jharkhand, NABARD partnered with a total of 49 NGOs. A very experienced NGO, *Professional Assistance for Development* (PRADAN), led the project with four NGOs working under its supervision as Resource Agencies, in turn guiding 44 smaller, local NGOs working directly with farmers. In the model approach taken in Jharkhand, farmers were encouraged to take up SRI practices on 0.25 acres adjacent to a 0.25-acre conventional plot for comparison. The four Resource Agencies each undertook: awareness creation; training local NGOs; data collection and monitoring and evaluation; and media aids. This well-designed approach meant that out of the 13 states participating, Jharkhand State contributed 52 out of the 175 project units with around 35,000 farmers adopting SRI for the first time.

Cumulatively, across the three-year phased program, 175 projects were implemented in 13 States with a financial outlay of Rs. 25.6 crore. A total of 142,000 farmers benefited covering an area of 36,935 hectares. Further benefits included demonstrated climate resilience in SRI rice plants, a drought-tolerant variety performed comparatively better than conventional rice crop yields, as well as increased resistance to pests and diseases. Furthermore, SRI provided large savings for farmers by reducing seed requirements, 2-2.5Kg per hectare for SRI planting compared to the 20-25Kg per hectare required for conventional methods. This directly benefited farmers, particularly those in poorer households. The success and impacts of SRI have sparked interest within NABARD to mobilise the potentials of SCI for broadening its assistance to reach a wider range of crops that can benefit Indian farmers.

Table 2: Results from NABARD FTTF Program in India, 2013

No. of farmers	Area covered (ha)	Increase in grain yield		Increase in straw yield	Lower seed requirem ent	Source
142,000	36, 935	194%		189%	90%	NABARD, 2016

1.1.5 SRI-Lower Mekong Basin Project (SRI-LMB), supported by the European Union, Lower Mekong River Basin Region, Southeast Asia, 2013-2018.

- Mishra, A., Ketelaar, J.W., Uphoff, N., Whitten, M. (2021) Food security and climate-smart agriculture in the lower Mekong basin of Southeast Asia: evaluating impacts of the system of rice intensification with special reference to rainfed agriculture, *International Journal of Agricultural Sustainability*, 19:2, 152–174. Available at: DOI:10.1080/14735903.2020.1866852

SRI-LMB was a regional project that involved four Lower Mekong Basin (LMB) countries in Southeast Asia during 2013-2018: Cambodia, Laos, Vietnam, and Thailand. The project was implemented over 72 months, with main funding coming from the European Union to support the €3.4 million project. The aim of this initiative was to increase crop yields, productivity, and profitability in a sustainable manner for smallholder rice farmers in rainfed areas of the LMB. The project was led by the Asian Institute of Technology (AIT), and implemented through partnership of the FAO, OXFAM, SRI-Rice Cornell University, and the University of Queensland.

Irrigated rice production methods are usually the focus for GHG emission reduction due to the significant impact that AWD provides in reducing methane emissions. This project, however, worked mostly in rainfed areas, where farmers rely on rainfall rather than on irrigation. Even so, the field-level measurements showed a 17% reduction in GHG emissions, resulting from the reduced plant density and the use of organic fertiliser in preference to inorganic fertiliser, according to the recommendation with SRI. For the four countries in this project, rainfed rice represents the leading method of rice cultivation with 64% of the rice production grown under rainfed conditions, producing a calculated 6.31 million t CO_2eq. In comparison, the remaining 36% of the production area is cultivated through irrigated methods, producing 5.18 million t CO_2 eq. By adopting SRI methods, GHG emissions could be reduced to 5.13 million t CO_2 eq and 4.11 million t CO_2 eq from rainfed and irrigated rice areas, respectively, in the region. This highlights the opportunity that SRI offers for rainfed regions, as most of the Lower Mekong Basin is, to deliver food-security benefits for resource-limited smallholder farmers while also achieving significant results for global-warming mitigation.

Table 3: Results from SRI-LMB Project in Cambodia, Laos, Thailand, and Vietnam

No. of farmers	Yield increase	Reduction of GHG	Increase in water productivity	Reduction of energy use ha^{-1}	Increase in economic returns	Source
15,000	52%	14%* , 17%**	59%	34%	70%	Mishra *et al.* 2021
* = irrigated rice ** = rainfed lowland rice						

1.1.6 West Africa Agricultural Productivity Program, supported by the World Bank, West Africa, 2014-2016.

- Styger, E., Traoré G. (2018) *50,000 Farmers in 13 Countries: Results from Scaling up the System of Rice Intensification in West Africa: Achievements and Regional Perspectives for SRI.* SRI-WAAPP Project Summary Report 2014-2016 for West Africa Agriculture Productivity Program (WAAPP). West and Central Africa Council for Agricultural Research and Development (CORAF/WECARD), Dakar, Senegal. Available at: https://sriwestafrica.files.wordpress.com/2018/04/sri-waapp-book-single-p-8mb.pdf

The West Africa Agricultural Productivity Program funded a sub-project for 'Improving and Scaling Up the System of Rice Intensification (SRI) in West Africa' (SRI-WAAPP) between January 2014 to December 2016. The project was conducted in 13 countries in West Africa: Benin, Burkina Faso, Côte d'Ivoire, The Gambia, Ghana, Guinea, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. More than 50,000 farmers at 1,088 sites benefitted from a total 13,944 ha of SRI coverage that was reached. The estimated additional quantity of paddy produced 20,113 tons of milled rice, valued at over 10 million US dollars.

Table 4: Results from SRI-WAAPP from 13 West African countries

No. of farmers	Yield increase	Increase in farmer economic returns	Additional amount of rice produced (tons of paddy)	Value of additional rice produced ($US)	Source
50,084	54% * ,86% **	41%	31,458	10,066,452***	Styger and Traoré, 2018
* = irrigated rice ** = rainfed lowland rice *** = calculated from estimated milled rice production (500 USD/ton)					

1.1.7 AgResults Vietnam Greenhouse Gas Emissions Reduction Pilot (AVERP), supported by USAID, UK Aid, the Australian Government, Canadian Government, Bill and Melinda Gates Foundation and the World Bank, Vietnam: 2017-2021

- AgResults (2021) *Vietnam Greenhouse Gas Emissions Reduction Challenge Project: Final Report.* Available at: https://agresults.org/learning/73-final-report-vietnam-ghg-emissions-reduction-challenge-project/file

The AgResults Vietnam GHG Emissions Reduction Challenge Project (AVERP) was a four-year, US$8 million prize competition in the Thai Binh province of Vietnam. This project incentivised the private sector to develop, implement, and scale-up rice cultivation technologies that will increase yield, reduce greenhouse gas emissions, and improve livelihoods of smallholder farmers. Key characteristics of the winning technologies used were: rice variety; rice straw treatment; transplanting density; fertiliser application; and water management. Although not specifically promoting SRI, sustainable rice cultivation methods based on the same principles were promoted such as '3 decrease, 3 increase (3G3T)[1] and '1 must 5 decrease' (1P5G)[2], and constituted key innovations within the project. SRI was endorsed by the Ministry of Agriculture

1 The '3 decreases' are in expenditure per unit of area, fertiliser use, and the number of pesticide applications; the '3 increases' are in yield, quality, and profit.

2 The '1 must' refers to the compulsory use of certified seed; the '5 decreases' are decreases in water, energy, post-harvest losses, pesticides, and fertiliser use.

and Rural Development as long ago as 2007, and its practices have been integrated into rice production in Vietnam.

Table 5: Results from AVERP Project in Thai Binh, Vietnam

No. of farmers	Yield increase	Reduction of GHG	Water reduction	Economic return	Source
47, 762	14%	3 – 10%	40%	10 – 15%	AgResults, 2021

1.2 Current and Upcoming Projects

1.2.1 LINKS SRI, Northern Nigeria, 2019-ongoing.

- Bello, M.M., Shuaibu, A. S., Shehu, B, M., Lawan, B. A. (2022) *Report of Soil and GHG Monitoring for the System of Rice Intensification (SRI) Under Rainy Season for the LINKS-SRI Project in Kano and Jigawa States.* Centre for Dryland Agriculture, Bayero University.
- LINKS Website. Available at: https://www.links-nigeria.com/systems-of-rice-intensification-sri/

LINKS is a pilot project introducing SRI into states in Northern Nigeria to address the adverse effects of climate change on smallholder farmers. The program began in 2019 and is currently in its primary phase with 27 demonstration plots in Jigawa and Kano states, educating 1,350 smallholder farmers about SRI practices over a period of two seasons. Field coordinators and lead farmers who oversee the demonstration plots are trained in SRI practices and are in the area to disseminate SRI knowledge over the following seasons to other farmers in the area.

Monitoring and analysis of the soil and GHG emissions are being conducted. In the first wet season, evaluations showed that SRI methods affect carbon sequestration, the highest reported at a rate of 350,455 kg/ha/yr with lower CH_4 emissions by up to 41%, and further reductions in CO_2 and N_2O compared with conventionally-managed paddy fields.

The preliminary results also demonstrate above average yields for SRI farmers, in both Kano and Jigawa states. In Kano, farmers averaged 3.41Mt per hectare, while comparator sites reported an average of 2.36Mt per hectare. The state average reported at 3.0Mt per hectare. In Jigawa, comparator sites recorded 3.47Mt per hectare (below the state average of 4.5Mt per hectare), however, Jigawa farmers following SRI practices more than doubled the comparator average, achieving 7.35Mt per hectare.

1.2.2 RICOWAS Project, with support from the Adaptation Fund established by the UN to implement the 'clean development mechanism', West Africa, 2021-2025

- Adaptation Fund (2020) Regional Project Proposal, RICOWAS Project, Scaling-Up Climate-Resilient Rice Production in West Africa. Available at: https://www.adaptation-fund.org/wp-content/uploads/2020/05/ Highlighted-OSSRIE-Regional-Project-RICOWAS-ConceptNote-19May2020.pdf

Based on knowledge and capacity from the preceding SRI-WAAPP project, the RICOWAS project aims to improve climate resilience and increase rice system productivity of smallholder rice farmers across West Africa, using a climate-resilient rice production approach. The project aims to adopt a comprehensive strategy known as Climate-Resilient Rice Production (CRRP), developed specifically for the project. CRRP is based on SRI methodology as the fundamental element, but integrates additional practices relating to soil, water, and pest management. This project will target 250,000 farmers directly, with 1-1.5 million farmers as indirect beneficiaries, and will contribute to Regional Agricultural Policy for West Africa's "Rice Offensive" initiative aiming for rice self-sufficiency for West-Africa by 2025.

2.0 Evidence base for SRI

2.1 Increased Yields

SRI enhances rice plant phenotypes to achieve significantly higher crop yields, with improved resilience to stresses from extreme weather, pests, and diseases (Styger and Uphoff, 2016). As with any biological process, each variable (water, soil biota, climate, seasonal variance, etc.) plays a considerable role in the outcomes. The extent of impact on the plant phenotype also depends on how fully the recommended SRI principles are applied. Data on increased yield can therefore show wide variance. It is widely agreed that SRI increases grain yield by at least 20-50% (ibid.; Thakur *et al.* 2022; Africare/Oxfam/WWF, 2010), with some studies reporting increases from 50% up to 100% or more (Hawken, 2017; Styger and Traoré, 2016; Africare/Oxfam/WWF, 2010, p. 32).

In addition to giving greater paddy yield, SRI methods increase grain quality. The final outturn of milled polished rice after harvested and threshed paddy grains are milled is usually around 10% higher than from conventionally-grown paddy rice, due to there being fewer unfilled grains (thus reduced chaff), with also less breakage of grains during the milling process (SRI-Rice, 2022a). The grains also have less chalkiness.

2.2 Increased Income for Farmers

With SRI increasing yield per unit area by at least 20-50% and with costs of production lowered by 10% or more, farmers' net income from rice production increases by more than solely the increase in yield. The higher production also gives greater food security. As seen in section 1.1, all the projects provided demonstrated improved economic returns from the use of SRI methods, with economic increases ranging from 40% - 70% (Nayar *et al.*, 2020; Styger and Traoré, 2018; Mishra *et al.*, 2021) and even up to 250% (Behera *et al.*, 2013).

SRI enables farmers to improve their crop production by using their locally-available resources more productively, which reduces their need to purchase external inputs. SRI is relevant for achieving the UN's Sustainable Development Goal #1 (No Poverty) because it is a matter of knowledge and skill rather than capital inputs. Therefore, SRI allows poor and marginalised households to improve their economic situation by using their available resources more productively, and capitalising upon natural biological processes and potentials that are mobilised by changes in how plants, soil, water, and nutrients are managed.

2.3 Climate Resilience and Food Security

Pests, diseases, and climatic hazards such as droughts and storms play a significant role in crop loss. These impediments to production will increase as the impacts from climate change continue to worsen. The communities most vulnerable to severe climate impacts are those that are already marginalised (IPCC, 2022). It is imperative to enable farmers to adapt their practices to make their crops more climate-resilient and to safeguard their environmental resources. SRI provides climate-resilience through reduced water requirements for cropping (Jagannath *et al.*, 2013); increased resistance to biotic and abiotic stresses (Thakur and Uphoff, 2017); as well as increased resilience to cold temperatures, storm-damage, and pests and diseases (Adhikari *et al.*, 2018; Thakur *et al.*, 2021).

Further, with less reliance on use of synthetic chemical inputs, the beneficial soil biota is more abundant and diverse and this adds to SRI plants' resilience. A study in India showed that per unit of water transpired, SRI-grown plants photosynthesised more than twice as much carbon dioxide from the air, converting it into carbohydrates and, quite literally, producing 'more crop per drop' (Thakur *et al.*, 2010). This will become increasingly important in the decades ahead.

Also, SRI practices improve resistance and resilience to many of the pests and diseases that afflict rice plants (Chapagain *et al.*, 2011). The increased resistance and resilience against both extreme weather events and pests and diseases results primarily from changes in the plant's characteristics induced by SRI practices (Thakur *et al.*, 2016). These practices improve rice plants' phenotypes, among other ways, by inducing larger, deeper and denser root systems, which anchor plants better and support more microbial activities in the rhizosphere. By accessing more water and nutrients, this plays a role in reducing the incidence of pests and diseases (Rajkishore *et al.* 2015; Randramiharisoa *et al.* 2006). SRI practices are also reported to increase silica in the rice stalks and leaves, making it harder for chewing insects to penetrate them (Randriamiharisoa *et al.* 2006). The increased space between plants creates microenvironments that are less favourable for many pests and diseases, and SRI's shortening of the crop cycle by 5-15 days reduces crops' exposure to biotic and abiotic stresses (Thakur and Uphoff, 2017).

SRI also enhances the micronutrient content of rice grains with increased levels of iron, calcium, manganese, and zinc due to enhanced uptake into the plant (Thakur *et al.*, 2020). There are also lower levels of arsenic and mercury in the grain, by up to 90%, due to alternate wetting and drying (Ishfaq *et al.* 2020). With increased grain quality, yields, and enhanced nutritional value, SRI methods significantly improve both the quality and quantity of rice production, also giving the crop more resilience against damaging pests and diseases and extreme climate conditions.

This makes SRI a practical, low-cost innovation for improving food security (FAO, 2016, pp. 44-47).

2.4 Water Reduction

Water usage in irrigated rice production varies greatly depending on the cropping season, the climate, soil characteristics, and the rice variety planted. Higher yields are achieved with reductions in water consumption through SRI practices (Jagannath *et al.,* 2013; Wu *et al.*, 2015).

A meta-analysis of 29 published studies from 8 countries that reported on 251 comparison trials found that SRI methods consistently saved water and improved its productivity when compared with standard crop and water management for irrigated rice production (Jagannath *et al.*, 2013). On average, SRI management saved 3.3 million litres of water per hectare, giving an overall water saving of 22%, including rainfall, compared to conventional crop management.

In terms of irrigation water, 17 of the 29 studies specifically analysed irrigation water use; analysis of these data showed that SRI reduced irrigation water applications by 3.9 million litres per hectare (7.2 million litres compared to 11.1 million). This amounts to 35% less consumption of irrigation water with higher yield. SRI methods, by increasing grain yield and reducing water input, improved total water use efficiency by 52%, and irrigation water use efficiency by 78% compared to conventional crop management.

All of the studies showed a reduction in water inputs resulting in higher yields under SRI rice production practices, with an average increase of 0.3 tons per hectare. Water productivity is a critical consideration these days, with water availability becoming increasingly constrained. Enhancing water security is a priority for many countries by improving their resilience and adaptation to climate change.

Table 6: Summary of yield, water, and income impacts of SRI from evaluations by researchers in 8 countries.

Country	Year of study	N	Evaluation for/by	Yield increase (%)	Water saving (%)	Increase in income per ha (%)	Comments
Bangladesh	2002-03 2003-04	1,073**	IRRI-BD/BRAC, SAFE, and Syngenta-BD	24	NM	59	
Cambodia	2004	500*	GTZ	41	RF	74	Farmers in this trial had 3 years of experience with SRI methods as of 2004
Cambodia	2004	120	CEDAC	105	50	89	
China (Sichuan)	2004	82*	CAU	29	44	64	
India (Tamil Nadu)	2004	100**	TNAU	28	45	112	
India (Andhra Pradesh)	2003-04	1,535**	ANGRAU	38	40	NM	
India (West Bengal)	2004	108**	IWMI—India	32	RF	67	One out of the two villages had severe drought in 2004.
Indonesia	2002-06	12,112**	Nippon Koei	78	40	100+	
Nepal	2006	412**	Morang District Agricultural Development Office, Govt. of Nepal	82	43	163	
Sri Lanka	2004	120*	IWMI—SL	44	24	104	
Vietnam	2007-08	96,544	National IPM Program	17 (13-29)	33	23 (8 – 32)	

* based on random samples
** results from all of the cases using SRI methods covered in evaluation, so there was no sampling.
N = number of farmers
NM = not measured
RF = rainfed

Source: Africare/Oxfam/WWF, p. 32, 2010

2.5 Greenhouse Gas Reductions

SRI practices have been shown to lower greenhouse gas (GHG) emissions from rice cultivation in a variety of countries, e.g., Nigeria, Vietnam, Laos, Cambodia, Thailand, India, and Korea (Bello *et al*., 2022; Mishra *et al*., 2021; Nirmala *et al*., 2021; Gathorne-Hardy *et al*., 2016; Choi *et al*., 2014). SRI methods influence GHG emission reduction through several processes. SRI water management practices (alternate wetting and drying) have significant potential to mitigate methane (CH_4) by making soil conditions more aerobic. Alternate wetting and drying by itself provides reductions in methane emissions ranging from 48% (Richards and Sander, 2014) to 70% (Hawken, 2017), and even to 85% or more (Islam *et al*. 2020; Lahue *et al*. 2016). Variation reflects different soil, climatic and other conditions.

There can be some offset against methane reduction by an increase in nitrous oxide (N_2O), but this also varies and is reduced by cutting the use of synthetic nitrogen fertiliser. Thakur *et al*. (2021) report that overall, SRI methods reduce net GHG emissions by 20-30% per hectare in irrigated rice cultivation, and by more per kilogram of rice produced, because of the higher yield. For rainfed rice cultivation in Southeast Asia, Mishra *et al*. (2021) measured an average GHG emission reduction of 17% per hectare.

2.6 Benefits for Women

Women play a major role in rice cultivation globally, providing up to 80% of the labour invested in growing rice (Vent *et al*., 2016). SRI provides benefits especially for women. Weeding rice crops by hand, traditionally done by women in most countries, requires many long hours spent in uncomfortable bent postures in flooded, muddy paddy fields with conventional rice cultivation. Using a simple mechanical weeder, which is recommended with SRI, reduces labour time and allows upright posture, thereby avoiding long exposure to unsanitary conditions in the field and reducing drudgery. A study in India found that the use of the mechanical weeder alone reduced women’s labour requirements by up to 76% per hectare (Mrunalini and Ganesh, 2008).

Working in SRI fields that are not kept continuously flooded and with less or no use of agrochemicals, women avoid prolonged water exposure and water-borne disease vectors. SRI further lessens women's labour requirements by greatly reducing plant density (by 80-90%), lessening the size of the nurseries needed for SRI seedlings and reducing the time required to manage them. Transplanting can be completed more rapidly and easily as SRI seedlings are smaller, lighter and fewer; they can be carried more conveniently in baskets and trays, further reducing the physical impact on women's bodies (Vent *et al.*, 2016; SRI-Rice, 2014). Reducing women's labour time gives them more time for activities of their choice, which can result in diversified incomes and better outcomes for the family (Africare/Oxfam/WWF, 2010; Resurreccion *et al.*, 2008).

Enhanced equity and status for women is a further benefit of SRI. An Oxfam study in Vietnam found that 70% of the participants in Farmer Field Schools (FFS) learning about SRI were women. Once they finished the course, women promoted SRI to 5-8 other farmers, while men encouraged only 3. This is because women are more likely to collaborate and support each other (Africare/Oxfam/WWF, 2010). With women acting as farmer-leaders, women's status and voice within their families and communities were enhanced. A leading example is a woman SRI farmer in Bihar, India, from a *dalit* community with lowest status in her society, who was popularly elected to the state's Legislative Assembly. Women raising their social status and gaining more voice to influence affairs around them is a corollary benefit of SRI. More detail on these considerations is found in Vent *et al*. (2016).

3.0 Key evidence gaps and priorities to address

SRI principles and practices, appropriately adapted to the ecological context, have been validated empirically in more than 60 countries (Uphoff and Thakur, 2019) and in various and diverse regions of the world: from Mali, on the edge of the Sahara Desert (Styger *et al.*, 2011) to the tropical climate of Panama (Turmel *et al.*, 2011) to Afghanistan's mountainous regions (Thomas and Ramzi, 2011). As SRI practices were pragmatically assembled and have been mainly promoted at the grassroots level through a bottom-up approach with the active participation of farmers, SRI theory has followed practice, but the methods have substantial scientific basis (Uphoff, 2017).

After some 20 years of research and application, the validity of SRI principles has been confirmed repeatedly, with solid scientific explanations for the observed results. Over 1,000 studies are reported in the published literature (http://sri.cals.cornell.edu/research/JournalArticles.html), confirming SRI impacts on yield, reduction in water consumption, and generation of higher incomes for farmers. However, further studies are warranted to establish a better understanding of some of the dynamics involved in SRI use, such as its effect on the plant-soil microbiome and optimising water applications to achieve further increases in SRI benefits and more efficient resource use.

3.1 Context-related CH_4 emissions reduction

A major feature of SRI is its potential for climate mitigation and adaptation. Stopping the continuous flooding of rice fields in itself decreases the production of CH_4 by reducing the anaerobic conditions of soil which support the proliferation of methanogens (Singh *et al.*, 2021; Thakur *et al.*, 2014; Yan *et al.*, 2009). One of the main principles of SRI is to keep rice fields unflooded, in mostly aerobic conditions through AWD. The magnitude of any reduction of methane emissions is highly context-dependent due to variances in soil type, soil pH, soil moisture, temperature, soil organic carbon content, growth stage and the complex interactions of all these variables (Setiawan *et al*. 2014; Yan *et al.*, 2009; Thakur and Uphoff, 2017; Malyan *et al.,* 2016).

The adoption of AWD is not the only SRI practice that reduces methane emissions. Applying less or no inorganic nitrogen (N) fertilisers to rice paddies also reduces CH_4 emissions under SRI management (Wu and Uphoff, 2015). Rajkishore *et al*. (2013) report that 19-63% of the reductions in CH_4 emissions recorded under SRI management derive from the practice of active soil aeration through the use of simple mechanical cono-weeders that break up the soil's surface as they eliminate weeds. Ly *et al.* (2013) demonstrated that SRI practices combined with the impacts of different treatments (composted farmyard manure, mineral fertiliser, and both combined) reduced methane emissions by 22%, 17%, and 24%, respectively. The impact of SRI management on GHG emissions is thus attributable not just to changes in irrigation practices, but to the set of modifications of standard practice. As local conditions and practices can vary, however, there is not a single or summary number that can be reported on methane reduction, only ranges that reflect conditions and practices.

3.2 Dynamics of CH_4, CO_2 and N_2O emissions

The relationships among greenhouse gases are not simple and linear, so the impact of SRI practice on global warming potential (GWP) needs to be considered in terms of net effects. Emissions are affected by factors like temperature, soil structure, and particularly soil moisture. Therefore, effects are more appropriately considered in terms of *ranges* rather than single numbers because of this complexity.

Furthermore, due to methane (CH_4) being emitted by aerobic bacteria that thrive under soil conditions with no or little oxygen, switching from continuous flooding (which makes the soil hypoxic) to AWD with alternating irrigation, has a big impact in reducing methane emissions. Among other things, microbes that consume methane (methanotrophs) thrive in aerobic, unflooded soil (Rajkishore *et al.*, 2013). So, the largest impact of SRI cultivation is on methane reduction.

Nitrous oxide (N_2O), a greenhouse gas that is 25 times more potent than methane, is produced by microbial activity in unflooded soil, so conversion to SRI is likely to increase this. But N_2O is emitted in much smaller quantities than methane (Yan *et al.,* 2009), and most evaluations have shown that with SRI increases in N_2O are minor (Gathorne-Hardy *et al.*, 2016), or there may even be decreases (Dill *et al.*, 2013).

What predominantly drives the generation of N_2O is an abundance of nitrogen in the soil, and SRI's reduction in the use of synthetic N fertiliser decreases the substrate for N_2O emissions, possibly enough to reduce these with aerobic soil conditions. A global meta-analysis found that N_2O emissions from organically-managed soils are lower (by 492 ± 160 kg CO_2 eq. per hectare per year) than from soils managed with non-organic amendments (Skinner *et al.*, 2014).

Carbon dioxide (CO_2) emissions constitute the bulk of GHG being put into the atmosphere, but its effect on global warming is less immediate than that of methane. With SRI there is a reduction in CO_2 that is hard to measure; the indirect GHG emissions resulting from the production, transportation and distribution of inorganic N fertiliser and agrochemicals (Lal, 2004). This can only be estimated, but it should be considered when assessing the global warming potential of alternative production systems.

Gathorne-Hardy *et al*. (2016) undertook a comprehensive analysis of SRI impact on all three GHGs in India. They calculated a 40% net reduction in GWP per hectare, and per kg of rice produced there was a reduction of 60% in net GHG emissions as more rice was produced per unit of land and other inputs. On top of this, with irrigation use reduced by 60% per hectare, SRI lowered the consumption for fossil fuel (mostly for pumping water) by 74% per hectare.

Sequestration of carbon in the soil is another factor that affects and can abate global warming, to the extent that plants photosynthesise CO_2 and put the carbon products below-round as root growth or as exudates. Rice soils are very important sites for global carbon cycling because of their capacity to retain high amounts of resilient carbon (Rajkishore *et al.*, 2015). The approximately 160 million hectares cultivated with rice on a global scale have great potential for absorbing and storing CO_2 from the atmosphere (IPCC, 2022; Lal, 2004).

Under SRI management, the most evident difference in the rice plants is their greater root length and density, for example, in an early study in Madagascar, it was found that there 2.3 times more root biomass at 30-40 cm depth with SRI rice plants compared the same variety grown conventionally in the same soil and under the same conditions, and 3.8 times more at 40-50 cm (Barison, 2003).

Cuba (2004): Two rice plants of the same variety (VN2084) and same age (52 days after seeding).
The plant on the left was grown with conventional methods; on the right an SRI plant.

The proliferation of root growth resulting from the uptake of SRI practices promotes an expansion of the rhizosphere and enhances microbial abundance and activity. With more root biomass, more carbon is put into the soil as roots and exudates. So, in addition to reducing GHG emissions, SRI cropping also sequesters more carbon in the soil. Studies evidenced the beneficial effect of SRI practices on the prosperity of soil microbes; ICRISAT and other scientists in India found that the microbial biomass carbon in SRI soils is 2-41% higher than under conventional rice-growing practice (Gopalakrishnan *et al.*, 2014; Rupela *et al.*, 2006).

3.3 Integration of agroecological practices with SRI

A further opportunity to better understand the potential of SRI is the quantification of the impact on yield and carbon footprint that can be achieved when SRI is combined with other agroecological practices. According to Singh *et al*. (2021), agronomic practices are mostly analysed in an isolated way, and it is only in the past few years that researchers have started focusing on the combination of multiple agronomic approaches. It is through the consideration of a whole package of interlinked practices that a consistent and holistic understanding of farming systems in specific agro-climatic zones can be achieved. However, some reviews have been conducted on the combination of SRI and CA (Kassam and Brammer, 2016).

Due to the focus of agroecological practices on improving ecosystem services, and particularly promoting healthy soils, the combination of SRI and CA is considered to further support root development and consequently enhance the cropping systems' performances (Kassam and Brammer, 2016). Research was conducted on CA applied to rice and wheat crops where SRI and the System of Wheat Intensification (SWI) were adopted, suggesting that SRI followed by SWI is the best option for improving the grain yield of the wheat crop, while zero or minimum tillage and residue retention also demonstrated beneficial effects on wheat grain yield. The ill effects of puddling on the succeeding of wheat crop could be avoided by using SRI and CA methods along with keeping crop residues on the field and organic manure management (Kumar *et al.*, 2015).

A study focused on the opportunity to practise intercropping in rice farming under SRI management showed further water savings, increased yield and net income for farmers (Shah *et al.* 2021). Intercropping beans with rice under SRI management led to a 65% decrease in weed infestation, a 33% increase in rice yield, and a 57% enhancement of net farmer income when compared to conventional methods (Shah *et al.*, 2021). The combination of SRI and other agroecological practices deserves further promotion and evaluations across various agro-climatic conditions to better understand the environmental, economics, and social implications (Kassam and Brammer, 2016).

3.4 Variety Selection

SRI has been found to enhance the grain yield of both 'new' and 'old' varieties, i.e., both 'improved' and 'unimproved' (Uzzaman *et al.*, 2015). The highest yields with SRI methods have been with hybrid or high-yielding new varieties, but 'heirloom' varieties, which do not respond well to 'green revolution' management, also give higher yields, often 5-10 tons ha^{-1}. Given consumer preferences and higher market prices for the latter (Blakeney *et al.*, 2020), traditional varieties can be as profitable as, and competitive with, more modern varieties under SRI management. This means that traditional varieties can help maintain the biodiversity of rice species, which has been greatly diminished in most countries by the promotion of high yield varieties and hybrids.

Some varieties do respond better than others to SRI practices; but an SRI growing environment often brings out potentials in varieties that have not been seen before, for example, in the modern variety Swarna which is very popular in South Asia which was previously considered, even by its breeders, as 'shy-tillering.' But with SRI management, it tillers profusely and develops similarly enlarged roots. The plant shown below was grown from a single seed with SRI practices (picture from Dr. A. Satyanarayana, former Director of Research, ANGRAU, Hyderabad, Andhra Pradesh state, India).

With SRI management, all varieties can make better use of space and get more exposure to sunlight, resulting in a higher rate of photosynthesis which is one reason for the heavier grains usually produced under SRI management (Thakur et al., 2010). Identifying optimum varieties, old or new, is best done at the local level to take account of local conditions.

4.0 What is holding back concerted action and investment?

All rice-growing regions have some context-specific barriers that are limiting the adoption of SRI resulting from ecological, social, political, or economic situations. Here, the main barriers that commonly impede SRI uptake are reviewed with potential solutions proposed.

4.1 Lack of Institutional Support

SRI did not originate through the usual institutional channels or with support from predominant institutional interests; rather it was developed in Madagascar far from the centres for rice research through decades of work by a French priest (Prasad, 2020). The dissemination of SRI has been promoted through an open-source strategy with non-proprietary knowledge shared freely to give farmers, governments, researchers, and NGOs easy access to new opportunities. Over the last 20 years, without any major institutional backing such as the Green Revolution had, SRI use has spread to over 60 countries and some 10 million farmers. But it has taken time to persuade governments and donor agencies of SRI merits and to gain approval from the scientific establishment.

There has been little incentive for commercial enterprises to promote SRI methods as they did the practices of the Green Revolution, because SRI reduces farmer requirements for seed, water, fertilisers and agrochemicals. However, SRI could increase farmers' use of hybrid rice seeds because by cutting seed requirements per hectare by 80-90%, the new seeds' high cost would not be a deterrent. As governments are typically responsible for providing irrigation water to farmers, SRI's water-saving should give governments (and donors) incentive to support its dissemination. As water becomes scarcer and its economic value increases, investments in the hardware and software that can give agencies and farmers more ability to deliver smaller amounts of irrigation water more reliably will become economically attractive.

Where governments and/or donor agencies have accepted and supported SRI methods, as in Vietnam, the Sichuan province of China, and the Indian states of Tamil Nadu and Bihar, SRI use and its benefits have spread rapidly to hundreds of thousands of farmers within half a dozen years (Verma, 2013; Nayar *et al.*, 2020; Zheng *et al.,* 2004) [See section 1.0 above]. The World Bank, FAO and other international organisations, as well as a number of bilateral donor agencies, found that SRI methods can deliver extensive benefits quickly and at low cost in countries like Mali, Tanzania, Cambodia, and Indonesia. While there were some efforts to dismiss SRI by articles published in the scientific literature in the mid-2000s, these have abated. Unfortunately, there are some residual effects and inhibitions from those initial critiques and objections published 15 years ago.[3]

4.2 Lack of Government Investment and Promotion

A lack of support from national or subnational governments has often been a limiting factor for SRI adoption in some countries. This is often a result of two factors. Governments may be too politically unstable to support developmental activities (Uprety, 2005), or there is a lack of support from agricultural research or extension institutions, which dampens policymakers' interest in SRI.

At present, many governments are realising the necessity of ensuring food security in the context of rising populations and volatile weather patterns resulting from global warming (IPCC, 2022). As a result, countries are looking to increase their domestic agricultural production which, as seen above, can be achieved through SRI and its adaptation to wheat, maize, sugarcane and other crops. State governments in India are notable examples of the benefits that can be gained when SRI is accepted and promoted by a government. The states of Bihar and Tamil Nadu have taken effective advantage of SRI opportunities. The number of farmers in Bihar using SRI for rice and SWI for wheat rose from a little more than 100 in 2006 to over 300,000 six years later with support from the state government and the World Bank, working together with NGOs and community organisations (Behera *et al.*, 2013; Verma, 2013).

SRI has also been implemented in some very unstable and difficult environments. In Afghanistan, SRI was introduced by the Aga Khan Foundation and then expanded under an FAO project, saving water upstream and improving water access for farmers downstream (Thomas and Ramzi, 2011; Ramzi and Kabir, 2013). The NGO Africare started and demonstrated SRI in Mali around Timbuktu in 2008 (Styger *et al.*, 2011). Subsequently, USAID helped to expand its use, and then GIZ. Now with EU support, SRI expansion has become national policy in Mali.

To have a significant impact at scale, the involvement of governments is usually essential, which may not be possible in areas with political instability. However, the benefits brought by adopting the technology may go some way towards reducing political instability, especially if conflicts are amplified by water or food insecurity. Also, SRI's non-dependence on external inputs makes it something that farmers can continue during times of disruption (Uphoff, 2020).

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[3] For a more conclusive meta-analysis of SRI results, with a larger and more rigorous database and with more defensible methods, see a review of all published evaluations by Chinese researchers (Wu *et al.*, 2015).

Second, increased support and advocacy for SRI from institutions that guide governments' agricultural decisions would be of benefit. Integrating cross-cutting research of SRI with newer technologies, such as rice varieties, genetics, mechanisation, or e-agriculture systems, as conducted by research institutions such as IRRI, could help move SRI into mainstream awareness, while improving the performance of those organisations (Choi *et al.*, 2013). If applied with an economic and political understanding of farmers' social context, and resulting access to assets like labour, water, and extension networks, this research will increase the likelihood of SRI adoption.

4.3 Access to Appropriate Equipment

Equipment is an important investment opportunity as the use of appropriate machinery rapidly decreases time and labour required for weeding and transplanting operations, thereby increasing labour productivity and also decreasing drudgery. Whilst weeding can be done by hand, mechanical manual weeders, manual or motorised, increase the income per hectare as labour and herbicide requirements are reduced, thereby decreasing input costs (Kathia *et al.,* 2019).

The inaccessibility of mechanical weeders for smallholder farmers is a significant barrier to SRI adoption in many countries, mainly due to the unavailability of machinery. Weeders can be too expensive for a smallholder farmer to buy independently, so it has been recommended that farmers invest together (Sims and Kienzle, 2016). Where this is not possible, government and non-government organisations are alleviating this barrier by providing farmers with partial or whole subsidies, or credit schemes, to increase accessibility of mechanical weeders and other inputs. Moreover, many countries have to import machinery as there isn't the infrastructure or resources to meet demand. For example, Nepal imports machinery from India, where equipment costs an average 5 times less (Uprety, cited in Khanal, 2021), which further increases inaccessibility.

Most equipment for conventional rice cultivation needs to be adapted so that it can meet the requirements of SRI practices, such as having mechanical transplanters that are able to plant 1-2 seedlings per hill, rather than larger clumps, placing them a certain distance apart. Some such machines have been developed and more are in development. Opportunities for equipment development can be increased with CAD visualisations, open-source file-sharing of ideas, and crowdsourcing of designs. For example, the Californian organisation Earth Links works with farmers to develop equipment CAD blueprints that can be shared across the world and used to create cheaper SRI equipment for farmers (Earth Links, Inc., 2022).

Examples of appropriate weeding equipment for small-scale farmers includes the Mandava weeder, which can be commercially or locally produced, costing a farmer between 25 and 50 USD. The cono-weeder developed by IRRI is also widely used with SRI. A Cambodian NGO (Rachana) found that farmers could increase their yield from an average of 2.2 tonnes to 5.6 tonnes per hectare by combining push-weeders with SRI, compared with farmers' traditional practices (Oxfam International, 2022). Another form of machinery that can be used with other SRI practices is the drum seeder, which is used for direct seeding. This has been shown to decrease manual labour by 97% compared to transplanting, whilst mechanical weeders reduce manual input by 29% compared to manual weeding (Kathia *et al.*, 2019). Motorised weeders that weed several rows at a time reduce time and labour even more.

4.4 Adapted Irrigation Systems

The fact that SRI methods for irrigated rice production require less water per hectare than conventional practice actually raise some difficulties for SRI adoption, as the smaller amounts need to be delivered in a regular and timely manner. Many irrigation systems were not designed or are not managed to deliver less but more reliable water. SRI cultivation is more water-efficient than standard irrigation designed and managed for continuous flooding. A meta-analysis carried out by Jagannath *et al.* 2013 demonstrated that SRI methods under controlled conditions increased yield with 22% less total water per hectare (including rainfall) and 35% less irrigation water. This should make it very welcome in a world where water is becoming an increasingly scarce resource.

Both appropriate physical structures and proper water management by farmers are required for effective application of the AWD technique. Depending on their current design and condition, some investment may need to be made to restructure and adapt irrigation systems. Due to climate change, the water supply for agriculture is becoming diminished and less reliable, so the economic value of water, whether price or not, is inexorably rising, which makes such investment more and more bankable.

Development agencies such as the World Bank tend to be the main mobilisers of investment for large 'hardware' changes these days, such as the irrigation upgrading project that assisted the Tamil Nadu government to implement modernisation of irrigation facilities and operations between 2007 and 2015 (World Bank Group, 2019)[4]. The gains in rice production and savings of

[4] The project aimed to assist sub-basin stakeholders in increasing the productivity of irrigated agriculture in Tamil Nadu state within a framework of integrated water resources management. 5,260 irrigation tank systems were

water were noted in 1.0 in the review of large-scale projects that promoted SRI. There needs to be effective collaboration between line departments and agencies, research institutions, and the project entity for most effective implementation. Generally, less developed countries are not financially able to carry out such projects without some assistance.

4.5 Differentiated Marketing Channels

While SRI adoption reduces farmers' costs of production, its initial use requires more time and labour than familiar practices, as gaining skill and confidence in the methods involves a learning curve. So many farmers will need some incentive to make a change in practices. Since the SRI rice produced is of higher quality, especially if grown without chemical use, it is fair but also an incentive if this rice is rewarded with a higher purchase price. Consumers in many countries, if they know about SRI or inspect the rice, will pay a higher price, but market channels presently do not make any differentiation between SRI and conventionally-grown rice (Arsil *et al.*, 2019).

Where there are no appropriate channels for procurement and remuneration of SRI-grown rice, there is less incentive to make the changes in production practices that will increase output, save water, and reduce GHG emissions. If farmers take up SRI methods, it has been seen that there is about a 10% increase in final rice production because SRI paddy rice when milled gives at least that percentage in milled rice.[5] Differentiated marketing channels for the purchase and sale of SRI rice would give impetus to the spread of these methods, benefiting both farmers and the environment.

Getting 'organic' certification for their SRI rice is an expenditure that can be a barrier for smallholder farmers or farmer cooperatives. Governments can defray or eliminate this cost by paying some or all of the cost of SRI and/or organic certification. Or this cost could be borne by trading corporations that buy up much of the rice produced and often export rice profitably. Farmers' costs of SRI production would also be reduced if governments were to subsidise organic fertilisers in the way that they now subsidise inorganic fertiliser. Less use of inorganic N fertiliser will reduce GHG emissions and help governments meet their Nationally-Determined Commitments (NDCs) for GHG reduction (Skinner *et al.*, 2014). Increased use of SRI methods

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rehabilitated or modernised, benefiting an area of over 404,000 hectares. By 2019, the area under SRI paddy cultivation covered 1.62 million hectares.

[5] In 2005, the Andhra Pradesh Millers Association began printing and distributing brochures and calendars to promote SRI adoption, and also paying a higher price for SRI paddy because their members could make higher profits due to less chaff and less breakage of kernels during milling for SRI. In Sri Lanka, once SRI was introduced in parts of the Mahaweli Project private millers started offering 10% higher purchase price for SRI paddy, and some even made offers to SRI farmers before harvesting to purchase their paddy. Similar reports of this effect have come from other states of India, Kenya, Indonesia, China and Cuba, but there have not been systematic studies of this 'bonus'.

would also increase carbon sequestration thereby both abating global warming and improving soil health (Ghosh *et al.*, 2012).

The international rice market currently has no provision for the sale of SRI rice to US and EU markets. These countries are also under pressure to reduce GHG emissions for achieving NDCs. Government and international initiatives could support international rice marketing channels that focus on conserving rice biodiversity, enhancing soil quality, and reducing water consumption. The costs of certification could be covered within the price if there were some government action.

4.6 Carbon Credit Programmes

There are two ways in which SRI use can reduce the dynamics that are driving climate change and global warming – GHG emissions, and C sequestration. The development of carbon credit programmes is highly relevant for upscaling SRI adoption through the remuneration of SRI farmers for their contribution against climate change. SRI potential in mitigating GHG emissions is its major contribution to the reduction of the dynamics that are driving climate change. SRI reduces GHG emissions by 20-30% per hectare in irrigated rice cultivation (Thakur *et al*. 2021), but it can result into 70% (Hawken, 2017) and even up to 85% reduction of GHG emissions from paddy fields (Islam *et al.* 2020; Lahue *et al.* 2016).

Also, according to Rajkishore *et al*. (2015), SRI is among the most effective strategies to enhance carbon sequestration in rice ecosystems. The promotion of mycorrhizal symbiosis in aerobic rice systems is in fact an effective way to improve the ability of soil to sequester carbon as the rhizosphere microorganisms are very efficient in converting the CO_2 present in the atmosphere into biomass carbon (Xu *et al*. 2017). The adoption of SRI principles enhances the enzyme activities in the rhizosphere, as reported by Rajkishore (2013), and therefore improves carbon sequestration in rice fields (Rajkishore *et al*. 2015).

Watkins *et al.* (2009) have pointed out how the provision of carbon-credit payments can boost the adoption of no-till systems for rice farming, which also promotes carbon sequestration; the same concept could be valid for SRI. However, there are no current programs that reward SRI farmers with carbon- credit payments for their contribution to GHG reduction and carbon sequestration to abate global warming.

The carbon-credit market is a novel entity, and many countries have not yet created a mechanism to develop policies supporting the system required to establish this channel. On the other hand, various private and public actors have been working to fill the existing gap and to develop a carbon-credit marketplace for rice farmers who sequester carbon. Two examples are the Vietnam Low-Carbon Rice Project (VLCRP, 2016) and CarbonFarm (CarbonFarm, 2022). This could therefore be an opportune moment for the creation of mechanisms that can establish carbon credits which would qualify SRI farmers for carbon-credit schemes based on GHG reduction and C sequestration. There would need to be rigorous field studies to determine how to assess, compensate and monitor the contribution that SRI farming makes to lowering GWP.

4.7 Training and Awareness

A lack of training and awareness is often the main obstacle to widespread SRI adoption (Laksana and Damayanti, 2013; Mwidege and Katambara, 2020). There is a need for governments at a national and subnational level to spread awareness within farming communities (Barrett *et al.*, 2021) through effectively designed and implemented agricultural extension programmes (Laksana and Damayanti, 2013).

There are studies which confirm that access to extension services has a positive impact on the adoption of SRI (Kaloi, 2020; Bello *et al.* 2022). If these pathways already exist, SRI can be added to these established pathways. Extension programmes should be followed-up by implementing agencies, as this is often missing and can lead to disadoption. SRI dissemination should also be integrated into large-scale government development initiatives such as upgrades to irrigation infrastructure, as evidenced above. Moreover, awareness of SRI needs to be generated within governments, development agencies and the general public, not just farmers. The benefits of SRI should be broadcasted in order to shift the movement into the mainstream media, which could be done through a media communication strategy

Furthermore, Farmer Field Schools (FFS) such as those pioneered by the FAO are effective bottom-up mechanisms for farmer training of the knowledge and skills required to practice SRI and water conservation (Kabir and Uphoff, 2007) and to increase farmer-to-farmer knowledge transfer, resulting in increased levels of adoption (Kaloi, 2020). Identifying lead farmers who have experience in practising the technology and can mentor farmers from their community throughout the SRI methodology is an option to support farmers whilst they adopt SRI. For example, an NGO introduced SRI to the Dharwad district of Karnataka, India, in 2008. Initially 82 farmers adopted SRI practices through FFS; by 2014, this number grew to almost 29,000 in Dharwad and neighbouring districts (Balamatti and Uphoff, 2017). Pairing the top-down approach of well-designed agricultural extension services with the bottom-up dissemination of knowledge by FFS would achieve an effective multidirectional strategy to upscaling SRI practices.

5.0 CONCLUSION

Already implemented large-scale projects for the dissemination of SRI (section 1.0) have shown that rapid, low-cost, and effective spread is possible. There is extensive evidence of SRI's positive outcomes (section 2.0), in terms of yield increase, climate resilience, food security, reduction in water consumption, GHG reduction, and gender equity as well as increase in farmers' income.

The evidence accumulated through two decades of SRI principles implemented in diverse agroecological contexts around the world and resulting in multiple context-adapted practices have been backed by extensive research. Collaborations between farmers and research institutions is key for a deeper context-related understanding of SRI outcomes (section 3.0) and it should be facilitated. The main barriers to the development of concerted action plans for SRI promotion at national and international levels were presented (section 4.0).

SRI can play an effective and low-cost role in tackling the global perils of GHG emissions, water insufficiency, food shortfalls, etc. This innovation is best implemented with a landscape perspective with local governments and community organisations involved in the implementation. Donor agencies and multinational organisations can accelerate the spread of this eco-friendly system that makes land, labour, water, seed, and capital more productive, with a beneficial impact on the drivers of climate change. Time is ripe for governments and donor agencies to foster the diffusion of SRI, assisting and coordinating the actions already launched and successful at the grass root level, enlisting government, civil society, and private sector actors to each contribute in whatever ways utilise their respective comparative advantages.

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