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Keynote and Lead Lectures

ICSCI-2022

Society for Advancement of Rice Research

Society For Advancement of Rice Research

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- To advance the cause of rice research and development in the country.
- To disseminate knowledge on latest developments in rice research through publications, seminars, lectures and training programmes.
- To provide consultancy in rice production and development.
- To facilitate research and industry collaboration and public private partnership at national level.
- To honour outstanding achievers in rice research and development.
- To cooperate with other organizations having similar aims and objectives.
- To promote any other scientific/professional activities conducive for the advancement of science of rice and rice improvement.

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International Conference on System of Crop Intensification (ICSCI 2022) for Climate Smart Livelihood and Nutritional Security

12-14 December 2022

ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India

Guest Editors

Debashish Sen, Lucy Fisher, Francesco C Zampaolo, Subba Rao LV, Sai Prasad SV, Gangaiah B, Sreedevi B, Vidhan Singh T, Ravindra Naik, Meera SN, Abha Mishra, Jagadeeswar R, Amtul Waris, Chandra Mohan Y, Biksham Gujja, Nirmala B, Mahender Kumar R, Sundaram RM

Society for Advancement of Rice Research

INTERNATIONAL CONFERENCE

System of Crop Intensification (ICSCI 2022) for Climate-Smart Livelihood and Nutritional Security

12-14 December, 2022

Indian Institute of Rice Research, Hyderabad, India

Keynote and Lead Lectures

Organized by

Society for Advancement of Rice Research

Hyderabad, Telangana, India

FOREWORD

Society for Advancement of Rice Research (SARR) is organizing the **"International Conference on System of Crop Intensification (ICSCI 2022) for Climate-Smart Livelihood and Nutritional Security"** from 12 – 14 December, 2022 at Indian Institute of Rice Research, Hyderabad, Telangana, India.

One of the sustainable development goals (SDGs) set by the United Nations is SDG 2.0, which entails as 'End hunger, achieve food security and improved food nutrition and promote sustainable agriculture' by the year 2030. To address issues like malnutrition, hunger and diet related non communicable diseases, innovations in food system are required for food and nutritional security and sustainability. But, over dependence and reliance on intensive use of agrochemicals, fossil-fuels and other external inputs seems to be a nonviable option for sustainable production. The use of agro-ecological approaches potentially reduces the dependence on external inputs, and support our crops in a sustainable manner. There is a substantial evidence demonstrating the usefulness of these agro-ecological approaches in impacting livelihood and welfare. The innovations in different crop systems have enhanced productivity and helped in saving of water, energy, and improved soil health.

The impact of "System of Rice Intensification (SRI)" in other crops has led to the wider implementation of these principles in other crops. System of Crop Intensification (SCI), a new model has emerged that improves the productivity and resilience of crops like wheat, etc. SRI, SCI coupled with other practices (conservation agriculture etc.) are now called as agro-ecological practices. These practices are relevant especially for the resource-limited farmers. These practices can be scaled up by use of appropriate machinery. Further, these practices positively impact the effects of climate change (drought, storm damage, extreme temperatures, emergence of pests and diseases etc.).

For ensuring food security and farm profitability, farmers will have to produce more food and also ensure a lighter 'footprint' on the environment. The SCI principles have received wide appreciation across the world including Asia. Many of these initiatives were given impetus through conferences/ workshops (e.g. Hyderabad-2006, Agartala, Tripura-2007 and Coimbatore-2008). ICAR-IIRR has participated and played a major role in improving, promoting and innovating agro ecological practices, and their spread. The proposed International Conference ICSCI 2022 will provide a platform to share the advances in the knowledge gain and know-how of the SCI practices in the changing climate scenario.

In this context, the topics presented in this special issue of Journal of Rice Research will be helpful to bring focus on major agro-ecological practices. I complement the 'Society for Advancement of Rice Research (SARR)' for bringing out this special issue.

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(Dr. RM Sundaram)
Director, ICAR-IIRR &
President, SARR

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SRI 1.0 and Beyond: Understanding the System of Crop Intensification as SRI 3.0

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Abstract

The System of Rice Intensification (SRI) and the System of Crop Intensification (SCI), which has developed from SRI experience, should not be understood as technologies like those of the Green Revolution. Thinking of them as methodologies is more appropriate, in part, because they keep evolving rather than being something fixed and given. This paper reviews and organizes the many versions of rice and other crop management that have emerged from SRI, using the computer software convention of numbering successive versions with a series of ascending numbers, 1.0, 2.0, 3.0, etc. SRI 1.0 is the original set of practices developed and recommended by Fr. Henri de Laulanié in Madagascar some 40 years ago. As SRI has spread to over 60 countries, they have proved to be generally quite effective. Happily, as the experience was gained with these practices, their underlying principles were discerned and systematized, as discussed in the paper. SRI 2.0 is a set of adaptations of the original practices to be effective under different constraints or opportunities. The principles remain the same – rainfed SRI, direct-seeded SRI, mechanized SRI, etc. SRI 3.0 is the extension and adaptation of SRI ideas and principles to other crops – wheat, ragi, sugarcane, mustard, etc. – in other words, the System of Crop Intensification. SRI 4.0 is the integration of SRI ideas and practices into farming systems, going beyond mono-cropped rice production. SRI 5.0 is the use of SRI for purposes beyond agricultural production like reducing emissions of greenhouse gases, climate-proofing crops against the hazards of climate change, improving women's conditions of work, increasing the nutritional quality of grains and other foods, and other 'externalities'. SRI 6.0 is the research that scrutinizes SRI practices and results to advance scientific understanding that will benefit crop science, soil science, microbiology and other disciplines. These versions are not sequential as all are currently operative, and none displaces the others.

SRI has shown the prime importance of two factors: plant roots' growth and functioning; and the soil's life – the myriad organisms from microbes to earthworms that improve soil and crop performance. SRI seeks to elicit the genetic potentials that already exist in crop plants and in soil systems. By getting the fuller expression of this potential, SRI and SCI evoke better, more robust phenotypes from a given variety (genotype). Particularly as Indian and other farmers must cope with the adverse stresses of climate change, it will become important to grow crops with better, bigger root systems in soil systems that have greater abundance, activity, and diversity of beneficial soil organisms. This suggests that SRI and SCI alternatives will better suit the farmers' and the country's needs over time than past and present agricultural technologies.

Keywords: SRI 1.0, SRI 2.0, SRI 3.0, SRI 4.0, SRI 5.0, SRI 6.0, System of Crop Intensification, root systems, soil microbes

From its beginning, the System of Rice Intensification (SRI) has been understood as something different from the kind of agricultural technology exemplified by the Green Revolution. Such technology was *input-dependent* rather than being *idea-dependent* like SRI. It sought to raise production by *changing the plant* while SRI focused on *changing the plant's growing environment*, above- and especially below-ground.

SRI seeks to capitalize on genetic potentials that already exist rather than changing these. It aims to produce from any plant variety (genotype) actual plants (phenotypes) that are more productive and robust. SRI is not variety-dependent, although some varieties respond better to SRI management practices than do others. The highest SRI yields have been achieved with hybrids or improved varieties, but the yields from traditional varieties can be doubled or more, so since their market value is often higher, when SRI methods are used and production costs are lowered, they can be more profitable than HYVs or hybrids.

There are two basic consequences of following SRI principles and practices that are not easy to see: (a) greater growth of *root systems*, and (b) increased *life in the soil*, from microbes to earthworms. We refer to SRI as a methodology rather than as a technology because it is more mental than material. It relies more on ideas, insights and skills, than on physical inputs like new seeds, more fertilizer, more water. It has been a mistake to try to pour 'the new wine' of SRI into 'the old bottles' of Green Revolution technology.

To elaborate on this topic, I would like to use *the terminology of computer software*, where successive versions are given ascending numbers, 1.0, 2.0, 3.0, 4.0, etc.

SRI 1.0

This is *the original set of practices* that were assembled and validated by Fr. Henri de Laulanié in Madagascar over his half a lifetime of living and working with small, poor farmers there. SRI was put together inductively, created from observations and measurements, not guided by theory or preconceptions. It was thoroughly inductive and empirical. As Fr. Laulanie stated humbly but aptly, the rice plant was his teacher. He wrote in French that the rice plant was '*mon maître*,' meaning that it was his "master."

SRI became known and was initially propagated in terms of certain practices, most of them counterintuitive -- like planting fewer plants, planting very young seedlings, and not keeping rice paddies flooded. Those of us who have learned from Fr. Laulanié's work and have worked with his ideas and insights have synthesized from the success of these practices a set of principles that constitute 'SRI,' although number and wording can vary. From having read Laulanié's papers after he died in 1995, I am sure that he would have approved this progression from practices and methods to principles and concepts.

As I currently understand SRI, I would summarize the core of this methodology in the four principles stated below Also, as a preface, I would like to suggest that wen SRI is introduced to farmers, they should be informed not only about what is being recommended (various practices), but also why these are being recommended, and the interactions among them. This will assist farmers in taking ownership of the methodology and in making appropriate adaptations that suit their local conditions and constraints.

1. **Reduce plant density, so that each plant can express its maximum potential. How to do this?**

- **Plant single seedlings per hill**, not clumps of seedlings, so that plant roots and canopy can spread and grow, with little competition for sunshine, nutrients and water, and with no shading. If the soil is not very fertile, two plants per hill may give more yield at first, but this number can usually be cut back to one per hill as the soil's fertility improves as a result of following SRI principles.
- **Space the hills wide apart**, in a square pattern for mechanical weeding; 25x25 cm is usually optimal, but closer or wider spacing of hills is better initially with poorer or better soil. SRI practices reduce by 80-90% the plant population (and seed requirement) per m^2, while giving greater yield.

2. **Establish the crop carefully and well, paying attention to minimize any trauma to the plant roots.**

- For irrigated rice production, transplant young seedlings at the 2-3 leaf stage (8-15 days old) and plant them soon after removal from nursery as well as very carefully and gently. Minimizing 'transplant shock' will enable the transplants to resume their growth quickly.

Note: Direct-seeding of the crop is an alternative way to establish the rice crop, with the other SRI principles being applied.

3. **Manage water and soil to optimize and balance the provision of water and oxygen to the soil.** Plant roots and most beneficial soil organisms need both. There should be no continuous flooding because too much water in the soil reduces or eliminates the oxygen required by roots and the soil biota. Continuous flooding suffocates both plant roots and soil organisms.

- Where there are irrigation facilities, practice alternate wetting and drying. If the rice crop is rainfed, on the other hand, do not hoard rainfall in the field during the early part of the season. This will cause the roots to deteriorate, and then when the water recedes, the plants will have less root growth and will become more water-stressed.
- Apply just enough water to meet the needs of the plants and soil biota. Laulanié advised giving "*le minimum de l'eau*." Some amount of water stress promotes more and deeper root growth.
- By not flooding rice paddies, their soil is aerated passively. By using a mechanical weeder to control

weeds, the soil is actively aerated, stimulating the growth of roots and the life in the soil.

- **Active soil aeration** from doing multiple mechanical weedings, as many as 4, can usually raise the crop yield by 1-2 tons per hectare, compared with doing just a single weeding.

4. **Use organic fertilization in preference to inorganic fertilizers**. Compost does more than just provide nutrients for plants. It 'feeds the soil,' meaning the life in the soil, this in turn makes the soil better able to feed the plants. Increasing soil organic matter will improve the structure and functioning of the soil system, thereby supporting the growth of both plant roots and soil inhabitants.

- Organic and inorganic sources of nutrients can be combined to optimize soil nutrient supply or to remedy particular soil nutrient deficiencies where these are present (*aka* Integrated Nutrient Management). Inorganic fertilizer and chemical pest control should not be used where, and to the extent that, they adversely affect the soil's biodiversity and degrade soil and human health.

Note: all of these principles for good crop performance can be extended or adapted to *other crops beyond rice*. This is the foundation for the System of Crop Intensification (SCI), as discussed below**.** Note also that good SRI practice involves several other things like soil leveling, seed selection, having an unflooded, sparsely-sown nursery, and maybe also seed priming or inoculation with beneficial microorganisms like *Trichoderma* or Indigenous Microorganisms (IMOs). But these are practices not unique to SRI, so they are not considered to be part of SRI as such. On the central importance of roots and the soil biota for SRI effectiveness, see Chapters 4 and 5 of Uphoff (2022).

SRI 2.0 – Modifications of SRI 1.0 that Deal with Local Conditions and Constraints

After the use of SRI practices moved outside of Madagascar, to farmers cultivating under different circumstances than those with whom Laulanié had worked, various adaptations have been made over time:

SRI 2.1. Rainfed SRI: SRI practices have been adapted by farmers for unirrigated rice cultivation, first in upland areas in Madagascar, but then in the Philippines, Cambodia, Myanmar, India (Purulia district in West Bengal) where farmers were managing rainfall rather than irrigation water. Rainfed SRI was extended within four Southeast Asian countries under an EU-funded project (Mishra *et al.,* 2021). While rainfed SRI has modified some practices of SRI 1.0, it remains clearly part of the SRI 'family.'

SRI 2.2. Mechanized SRI: Where agricultural labor supply was limited or too expensive or to be able to use SRI on a larger scale, various equipment and implements have been devised and introduced to reduce labor requirements and also reduce the drudgery and other undesirable features of labor in rice production. SRI does not have to be labor-intensive and small-scale as the principles are scale-neutral.

SRI 2.2.1. Direct-seeded SRI: Transplanting seedlings is not required for SRI if it is understood in terms of core principles rather than just SRI 1.0 practices. If a high germination rate can be achieved, plant density can be reduced with spacing that permits soil-aerating weeding, e.g., drum-seeding developed in Chitoor, Andhra Pradesh, India; and in Vietnam (SNV, 2015); also, broadcasting rice seed and then thinning it with a mechanical weeder at 10 days to have plants in a geometrical pattern, developed in Sri Lanka.

SRI 2.2.2. Mechanical transplanting with SRI spacing and density: First developed by Oscar Montero in Costa Rica (Montero, 2009); since then, other mechanical transplanters have also been developed.

SRI 2.2.3. Motorized weeding: Multi-row, engine-powered weeders have been developed in many countries to save time and labor, first in the Philippines and Sri Lanka. There are even some solar-powered weeders now. This speeds up and makes easier the most laborious part of SRI operations.

SRI 2.2.4. Full mechanization: Crop establishment, weeding, and harvesting can all be mechanized. Smaller-scale mechanization has been developed in Nepal by Rajendra Uprety. In Pakistan, Asif Sharif in the Punjab province has developed large-scale mechanization, with laser-leveling and raised beds. This can reduce both labor and water requirements by 70%, with 12 t/ha yields (Sharif 2011).

SRI 2.3 SRI for cold climate: In the Heilungjiang province of northern ***China***, a system known as 3S was developed in the 1990s by Prof. Jin Xueyong, following most of the

SRI principles. Because temperatures there are so low, with rice seedlings started in heated-greenhouse nurseries while snow is still on the ground, seedlings are transplanted when 45 days old, widely-spaced, not flooded, and with more organic matter (Uphoff, 2004, pp. 1-4).

SRI 2.4 Other variations: Research by Amod Thakur and colleagues at ICAR-IIWM in Bhubaneswar has shown that land and water productivity can both be raised under SRI by continuing alternate wetting-and-drying throughout the whole rice crop cycle rather than just until panicle initiation, thereafter maintaining a thin layer of water (1-2 cm) on the field during the reproductive phase, as has been recommended with SRI 1.0. This finding (see Thakur, 2018) may depend upon soil type and climate, so further evaluations should be done before making this a generalized practice. Other variations could be noted, but these examples suffice to give an overview of SRI 2.0, showing that (and why) SRI 1.0 was not something 'set in stone' as some skeptics have expected or would have preferred it to be.

SRI 3.0 – Modifications of SRI Extended to Other Crops to Improve Their Performance

These constitute **SCI, the System of Crop Intensification**, which in Bihar is called the System of Root Intensification, another 'SRI.' My PPT presentation of this paper focuses on these extensions of SRI 1.0. The listing below of crops, countries, and initial contributors to each crop unfortunately cannot be complete. It indicates that India has been the main source of SCI innovation thus far (Abraham *et al.,* 2016; Adhikari *et al.,* 2018).

- **Finger millet/ragi** – ***India*** (Jharkhand /PRADAN, Bihar /PRAN, Odisha/PRAGATI); ***Ethiopia*** (Tigray/ ISD).
- **Wheat** – ***India*** (Madhya Pradesh/MPRLP; UKD-HP/PSI, Bihar/PRADAN-PRAN), Mali (Africare) (PRADAN, 2012a; Dhar *et al.,* 2015); ***Ethiopia*** (ISD); ***Afghanistan*** (AKF-FAO); ***Nepal*** (FAYA)
- **Sugarcane** – ***India*** (Andhra Pradesh –farmers, ANGRAU, and AgSRI); ***Cuba, Kenya, Tanzania, Uganda,*** and ***Philippines*** (AgSri)
- **Maize** – ***India*** (UKD-HP/PSI); ***Pakistan*** (PEDAVAR)
- **Mustard** – ***India*** (Bihar/PRADAN-PRAN) (Sathpathy, 2009; PRADAN, 2012b)
- **Teff** – ***Ethiopia*** (Oxfam) (Berhe *et al.,* 2017)
- **Pulses** – ***India*** (red gram, groundnuts, black gram, etc. – PSI and many others)
- **Vegetables** – brinjal, tomatoes, etc. -- PRAN/Jeevika, Bihar, ***India***; green leafy vegetable/mallow – ENGIM, ***Sierra Leone***; carrots, onions, etc. – Lookfar Farms, ***USA***
- **Spices** – turmeric – Thumbal SRI Farmers Association, Tamil Nadu, and cumin and coriander – AKRSP-I, Gujarat, ***India*** (Baskaran, 2012)
- **Other crops** – orchards/horticultural SRI, Lookfar Farms, ***USA***; chickens/avian SRI, CEDAC, ***Cambodia***; lac production/entomological SRI, farmers and PRADAN, Jharkhand, ***India***. Note that all of these different versions of SCI are elaborated in Chapter 14 of e-book (Uphoff, 2022).

SRI 4.0 – Integration of SRI into Cropping and Farming Systems

As SRI principles have become better understood and more widely used, they have been used to intensify and diversify a number of kinds of farming systems, going beyond growing monoculture cropping.

- **Convergence of SRI with Conservation Agriculture** – This synthesis was begun in Pakistan in Punjab province – Sharif, 2011; and PQNK website); and in China in Sichuan province (Lu *et al.,* 2019). Much more remains to be done to further this convergence.
- **Integrating SRI with horticulture and fish culture** – in both Cambodia (CEDAC) and Indonesia (Khumairoh *et al.,* 2012). I have myself observed a SRI rice-duck combination by farmers in Zhejiang province of China. An important scientific evaluation of SRI rice combined with fish culture and horticulture had been done at ICAR-IIWM in India, showing a phenomenal increase in the productivity of rainfall cycled through this integrated farming system (Thakur *et al.,* 2015).
- **Rotation with horticulture** – e.g., SRI rice alternating with no-till potatoes in Vietnam (Phu and Ha, 2022). I have observed a very profitable farming system developed by farmers in Sichuan province of China, alternating SRI rice with mushroom production (Uphoff, 2004, pp. 8-9).

- **Intercropping with legumes** – SSI sugarcane in Andhra Pradesh (Gujja *et al.,* 2009) and SRI rice with beans in Kashmir (Shah *et al.,* 2021). The latter has given 33% higher yield with 40% water saving, 65% fewer weeds, and 57% higher income per ha -- both India.

Because SRI 4.0 is still in its early stages, we expect that there will be many more versions and variations of such integration, e.g., SRI with agroforestry, in the future.

SRI 5.0 – Scientific Explanations

Work in this area began after SRI 1.0 became known, but it has accompanied all of the succeeding versions that followed, not being a sequential aspect of SRI. Here are some examples.

- **The effects of SRI practices on microbial populations** -- in the soil rhizosphere around plant roots, in the phyllosphere around plants, and in the endosphere within plants. The first study on this was done at TNAU, and it was then taken further at ICRISAT and IARI (see Doni *et al.,* 2022).
- **Plant-microbial interactions** – this is a large subject with ongoing research, e.g.:
    - Inoculation of SRI plants with beneficial microbes, e.g., with *Trichoderma*, to enrich crops' plant-soil microbiomes. Studies have been done in Malaysia, Nepal, and India (Doni *et al.,* 2018; Khadka and Uphoff, 2019).
    - The effects of endophytic microbes on plants' expression of their genetic potential. This could be a partial explanation for SRI improvement of plant phenotypes. Some transcriptomic studies of SRI have been started in Malaysia, but this subject is only beginning to be examined.
- **Effects of mechanical weeding on root performance.** Does root pruning by weeders induce deeper plant root growth? This simple subject should be studied rigorously. What can account for the profuse root growth with SRI management? This will become increasingly important to understand to prepare cropping for future water stress.
- **Nutrient enrichment of grains.** Why do SRI-produced grains have higher micronutrient content? Three studies in India have shown this to be greater with SRI management (Adak *et al.,* 2016; Dass *et al.,* 2017; Thakur *et al.,* 2019). This is probably associated with microbial activity, but mechanisms should be further studied.

Another whole paper could be presented on the scientific aspects of SRI, what has been learned so far and what remains to be assessed. The SRI-Rice website maintains a large collection of research papers on SRI, journal articles, and theses: http://sri.ciifad.cornell.edu/research/JournalArticles.html, and all can be accessed on line by joining the SRI Research network (free).

SRI 6.0?

From the start, we have recognized that SRI is 'a work in progress,' something not yet finished. We have no idea whether or when it will be finished, if it ever is. Clearly, SRI is not a technology like the Green Revolution. It is an assembly of ideas and insights that has shown potential to change the paradigm for contemporary agriculture, not just for the monocropping of irrigated rice. SRI capitalizes upon productive processes and potentials that already exist within crop plants and within the soil systems that support them.

We hope that farmers, scientists, extensionists, civil society actors, administrators, and businessmen will all work together with mutual respect and with productive curiosity to further advance the knowledge and practice set in motion by the development of SRI 1.0 some 40 years ago in Madagascar.

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Current Status of the System of Rice Intensification in India and Constraints to Overcome for Large-scale Adoption

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Abstract

System of rice Intensification (SRI) has the great potential to be promoted in large scale. However, with the policies and suitable recommendation, it did not spread to large scale in India. Suitable measures are required further upscaling the SRI in all the states of the country. The paper gives brief account of the initiation of SRI work (demonstrations and research), basic principles of SRI, advantages and initial experiences of the SRI adoption especially in Andhra Pradesh. The lack of skill development specially to adopt SRI principles hindered the large scale adoption even though NGO's and other organisations involved in promotion of SRI. There is need to relook the SRI promotion across the country with proper skill development and suitable programme and integrating with ongoing programmes and mainstreaming the SRI in National Agriculture

Keywords: SRI, Constraints, large scale adoption, GHG, Region

SRI's potential has opened up greater debates and discussions to understand it better and to adopt this method of cultivation in larger areas. SRI is too good to believe. SRI is a more versatile innovation than many have thought. Unfortunately, despite making several policies and recommendations, the area under SRI in the country is very less. Where did we go wrong, or the measures suggested are not in tune with the production constraints and need greater attention for promotion and scaling up of SRI?

Factors responsible for higher yields in SRI include transplanting young seedlings singly at a wider spacing in well-aerated soil rich in organic matter with a thin film of water, preferably alternate wetting and drying. SRI principles require skill teaching in the following areas:

1. Transplant young seedlings carefully with the seed still intact along with mud. Young refers to seedlings when they are in their 2nd-3rd Phyllochron to achieve dramatic productivity. The skill point involved is how young seedlings are grown and handled.
2. Tilling the Paddy paddies 2-3 times at 10-day intervals with the help of a rotary weeder not only helps to keep the field free from weeds but also creates active soil aeration, a critical operation for enhanced productivity with SRI. The rice paddies get compact under alternate wetting and drying conditions, and farmers experience difficulty in operating the weeder. This priority area needs intensive research work to develop alternatives. I consider this is the operation that makes the farmers do away from SRI.
3. Careful water management keeping the field wet and not flooded, supports healthy root growth while minimizing water requirement. Irrigation water management under canal irrigated conditions needs regulations.

Advantages of SRI

- More productive tillers
- Better root development
- Water saving potential- More crop per drop
- Improves soil health
- Resistance to Biotic and Abiotic stresses and hence, cope with Climate change
- Rice quality improved through biofortification
- Reduced costs and increased profitability
- Requirements for external inputs are much lesser

- SRI principles and practices improved rice productivity and income
- Black gram crop grown succeeding the SRI paddy is giving higher yields.
- Under SRI, rice crop matures ten days earlier.
- SRI utilizes biological power

In January 2003, I was able to learn about SRI on a study Tout to Srilanka, and I was amazed to see the changed phenotype with heavy tillering, healthy and rough leaf blades, which cut my finger, to realize the genotype x environment interaction, where the same variety performs differently under different environments. On return to Andhra Pradesh, I started educating the farmers on skills involved in SRI by developing literature, CVDs and organizing 150 demonstrations (0.4 ha.) in all the districts under SAU and state Department of Agriculture collaboration, exposure visits, utilized print and electronic media simultaneously to start with. The SRI was a great success giving an average yield advantage of over 2.0 t/ha. The highest yield recorded was 17.4 t/ha. During 2004-05 Mr. Nagaratnam Naidu, Rangareddy district, realized a 17.6 t/ha paddy yield. The crop cutting was personally witnessed by the then Chief Minister of A. P., Sri Y. S. Rajasekhara Reddy. It is unfortunate to say that such an excellent practice was not given the support it deserves for scaling up SRI in the state. SRI is more a knowledge-intensive technology compared to input-intensive modern agriculture; hence, imparting knowledge and skills is essential.

Greater attention needs to be paid to why the total SRI conceptual practices are not adopted and actions taken by the researchers, developmental agencies, and policymakers to overcome the constraints in adoption. Though some State Governments and NGOs like WASSAN and PRADAN are actively promoting SRI, the policy framework has not been put in place to take it forward.

The reasons for non-adoption may be attributed due to lack of skills. Little attention has been paid to transferring critical skills to the farmers. Hence, skill development at all levels in the following areas might help in sealing up SRI.

- Nursery management
- Main field preparation and marking
- Careful transplanting of young seedlings with seed, mud still intact
- Use of cono weeder for tillage and weeding
- Water management

This paper discusses the performance of SRI, which raises more questions than we currently have answers to.

- SRI is knowledge Intensive
- SRI principles require skill teaching
- Little attention has been paid for transferring critical skills to farmers
- This can be achieved if only the skills are mastered from top to bottom
- Some state Governments and NGO's are actively promoting SRI, but policy frame work has not been put in place to take it forward

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Overview of System of Rice Intensification (SRI) Around the World

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Abstract

During the past several decades, the System of Rice Intensification (SRI) has been validated in 65+ countries in Asia, Africa, and the Americas, with support from NGOs, government agencies, and the private sector. This presentation includes SRI updates from various regions and countries, insights into SRI networks, and a discussion of future trends and directions. While national networks have been established in ten Asian countries, regional networks are emerging in Africa and Latin America. Globally, a research network, equipment forum, resource center (SRI-Rice), and policy group (SRI-2030) are also active. Strengthening linkages within the global SRI community and between SRI networks can help with creating solidarity, collaborative problem-solving, sharing/providing information, and creating a more enabling policy environment. Climate change threats related to water shortages and GHGs, together with mounting food insecurity, have led some countries to consider SRI as a low-cost way of tackling these issues simultaneously. In 2021, nine countries included SRI in their Nationally Determined Contributions (NDC) to reduce methane emissions, showing increased government attention to SRI. Of 1,500+ journal articles about SRI from 60 countries, 43% are from India, 15% from Indonesia, and 9% from Africa. A third includes comparisons between SRI and other production methods, with the majority favorable to SRI regarding yield, water use, economics, and GHGs. Scaling up SRI globally can be assisted by increasing/improving extension, water management infrastructure/policies, SRI-adapted equipment access, marketing support, prioritized research, information access, and investigating/applying digital technologies and new financial incentives such as carbon credits, rice bonds, and other decarbonization strategies.

Keywords: System of Rice Intensification, SRI, rice

Introduction

During the past few decades, System of Rice Intensification (SRI) methods have been validated in 65+ countries. These countries, located in Asia, Africa, and the Americas, have experienced various levels of adoption. Some, like Vietnam, have experienced widespread adoption and strong government support. SRI was named the 2020 climate policy "breakthrough" for government initiatives in Vietnam to increase agricultural production there while reducing methane emissions from rice paddies (2020, Apolitical). Other countries, such as Uruguay and Argentina, are just beginning to investigate SRI.

SRI is an agroecological method of rice production that increases resource efficiency, reduces the carbon footprint, and is accessible to resource-limited farmers. It is based on the cropping principles of significantly reducing plant population, improving soil conditions and irrigation methods for root and plant development, and improving plant establishment methods. As SRI is a form of "open source agronomy," farmers are encouraged to adapt these methods to their own needs. In some countries, SRI is entirely organic, as in the Philippines, and in others, such as India, it may not always be. In addition, SRI, which was originally designed with irrigated systems, is now commonly adapted to rainfed systems in Asia and Africa. While SRI has long been successfully practiced by smaller farmers in the Global South, especially those who are resource-limited, a few larger farms in Pakistan, the USA, and elsewhere have shown that, with SRI-adapted equipment, SRI can be successful for larger-scale farmers as well. And, if SRI is to be scaled up to address the coming climate crisis, these larger farms will need to play a role.

While SRI was not a high priority for many governments or international research organizations over the past few decades, climate change threats, especially related to water shortages and GHGs, together with the increasing food insecurity exacerbated by the pandemic's effects on the global economy, have led a number of countries to take a closer look at SRI as a low-cost way of tackling some of these issues simultaneously, while many other agricultural innovations cannot. During COP26 in 2021, nine countries specifically included SRI in their government's Nationally Determined Commitments (NDCs) that embody countries' efforts to reduce national emissions and adapt to the impacts of climate change (Hong *et al.,* 2021). Thus, a new era of government interest in SRI may be within reach that could push forward needed policies for irrigation, extension, equipment access, and market opportunities. A new international NGO, SRI-2030, has emerged that encourages policies to reduce methane emissions through SRI.

Rice consumes up to 43% of the world's irrigation water and 24–30% of the total global freshwater (Surendran *et al.,* 2021). While SRI can demonstrably reduce water use for irrigated rice, current water shortages, together with labour issues, have led farmers in many countries to consider SRI adaptations that further reduce water use, including direct-seeded rice (DSR), conservation agriculture, and in some cases, ratooning. Gender-appropriate -adapted equipment for weeding and transplanting, if affordable, can further reduce required labour. As regenerative agriculture is gaining acceptance, more emphasis is being placed on soil health through better understanding and inclusion of organic inputs such as biochar, Trichoderma, vermicompost, manure, cover crops, and purchased or homemade organic formulations. Other future benefits for SRI farmers could accrue from carbon credits, regenerative agriculture certification, rice bonds, water credits, and other incentives related to decarbonization.

Regional Progress

Africa

Of the 27 African countries with SRI experience, the most active countries in terms of both SRI research and field programs are Kenya, Nigeria, and Tanzania, with the latter producing the most research. As few countries in Africa are self-sufficient in rice production, and food security is a growing issue in the region, SRI is being given more consideration. In addition, Benin, Burkina Faso, Togo, Mali, and Senegal have noted SRI in their 2021 NDC pledges to reduce global methane emissions (Hong *et al.,* 2021). The World Bank-funded SRI project associated with the West Africa Agricultural Productivity Program (SRI-WAAPP), which ran from 2014-2016, resulted in scaling up of SRI to 50,000 (primarily) smallholder farmers in 13 West African countries (Styger and Traoré, 2018). During 2023, the Scaling-up Climate-Resilient Rice Production in West Africa (RICOWAS) project, funded by the Adaptation Fund (Ramanujan, 2021), will follow on to SRI-WAAAP's efforts. The most recent country found to be successfully implementing SRI in Africa is Guinea Bissau, with up to four-fold increases in yield reported (World Food Program, 2022). Regarding knowledge-sharing, SRI-Africa.net in Kenya has a website serving the continent, and a West Africa facebook group posts regional updates. In October 2022, a new vertically integrated SRI network in Nigeria began to coalesce.

East Asia

Japan has an active national SRI network, meeting quarterly at the University of Tokyo since 2007. News reports from North Korea allude to the success of government SRI trials there, though details are scarce and unconfirmed. Although adoption in South Korea has been limited, SRI research continues, with most studies concerned with water reductions, water pollution, on GHGs. While SRI made steady progress in China, the numerous adaptations in spacial orientation, mulching, etc., and the variety of alternate names for SRI have made it more difficult to track. As theoretical questions on SRI's validity were satisfied, research in universities and national institutes have declined in the past few years in China, moving to local agriculture stations where SRI practices are fine-tuned for local adoption (SRI-Rice website, 2022).

Latin America

SRI has been slower to spread in Latin America than in Africa and Asia. Currently, 14 countries in the region have validated SRI methods over the past two decades. New ventures have begun with Inter-American Institute for Cooperation on Agriculture (IICA) in collaboration with the governments of Uruguay, Argentina, and Brazil. SRI interest began in Cuba, which led to adaptations for sugarcane. More recent regional leadership has been provided by IICA, a Costa Rica-based group that hosted a panel discussion on SRI for Food Security and Climate Resilience at the Sustainable Agriculture of the Americas Pavilion at COP27 in 2022. In South America, farms in general, tend to be larger, and farmers are more likely to request mechanized equipment to convert to SRI methods. Hence SRI-adapted transplanters, seeders, and weeders are an important consideration in these areas. Governments in Latin America are showing increasing interest in SRI. For some countries, water conservation is the primary driver, though increasing interest in methane reduction and food security may result in additional studies and scaling up. Recent programs in Chile and Ecuador have shown success in adopting SRI to tackle water issues, with Chile moving toward direct seeding (DSR). Peru has also shown an interest in SRI related to malaria reduction.

North America

Although most USA rice farms are engaged in industrial agriculture and have not shown much interest in SRI, smaller organic farms in several eastern and southern states have successfully grown and marketed SRI-grown rice on a small scale. Most recently, the Jubilee Justice NGO in the southern USA has been working with traditionally marginalized black farmers to grow and market SRI-grown rice in Louisiana and Mississippi. While large-scale producers that either seed from airplanes or drill hybrid seeds in lines have yet to move to SRI, a farmer in Arkansas has shown that SRI can be quite profitably be grown on larger farms using an adapted row crop seed plate planter to direct seed single rice seeds at a wider spacing following a cover crop, with additional reduction in both water and agrochemical inputs.

South/Southeast Asia

SRI is being practiced to some degree in nearly all South and Southeast Asian countries. Indonesia and India continue to scale up SRI through many NGOs, Corporate Social Responsibility (CSR) projects and scattered government projects; a significant number of SRI research articles are being published in both countries. The most active national SRI networks/groups in South and Southeast Asia are located in India, Indonesia, and the Philippines. Vietnam has seen strong government support and widespread adoption, including over several million rural households as of 2016 (Mishra *et al.,* 2021). Myanmar and Laos included SRI in their governments' Nationally Determined Contribution (NDC) pledge at the COP26 (2021, Hong). The Philippine SRI Network, SRI-Pilipinas, has trainers available in nearly all provinces and is currently increasing efforts to engage the government. A network of partners across mainland Southeast Asia became active during the 6-year EU-financed SRI Lower Mekong River Basin (SRI-LMB) regional project that concluded in 2018. This project trained over 15,000 farmers in Cambodia, Laos, Thailand, and Vietnam, and was proven to raise yields, incomes, and labor efficiency on primarily rainfed farms (Mishra *et al.,* 2021).

Research

Over the last two decades, SRI-Rice, in association with the SRI Global Research Network, has collected over 2,000 research items that discuss SRI. Of these, over 1,500 are journal articles, which were written by over 1,000 first authors from 60 countries. 43% of journal articles are about India, 15% relate to Indonesia, and 9% are about Africa (as a whole). A third includes comparisons between SRI and other production methods, with the majority favorable to SRI regarding yield, water use, economics, and GHGs. Nutrient management, economics, and water management are top items for research (SRI Research Database, 2022). While there are nearly 100 journal articles on GHGs/climate change, interest in this area may increase research undertaken both on GHG mitigation and climate change adaptation in the future, along with conservation agriculture adaptations that reduce water use and soil disturbance. While the quality of some research articles from smaller institutions can be poor, the results may contain valuable, often local, insights that are not captured by researchers publishing more theoretical research in high-impact journals. Rather than exclude this research, it may ultimately be more productive to help authors in smaller universities and institutions to produce better quality work. Perhaps the SRI Global Research Network could be useful here.

Networks and Scaling Up

Ten national SRI networks have operated at various times in Asia over the past decade, some of which are very active while a few have become dormant. While many of the national networks are underfunded and could be strengthened, a dilemma remains, not only to figure out how to support them but how to fund them in a sustainable way that outlasts short-term support by donors. Regional networks are emerging in Africa (SRI-Africa.net) and Latin America (Red SRI). International groups include 1) SRI-Rice, a Cornell University center supporting SRI/SCI knowledge creation and sharing; 2) SRI-2030, an NGO focused on methane reduction through promoting policies supportive of SRI; 3) The SRI Equipment Innovators Forum (currently a Facebook group); 4) The SRI Global Research Network, which provides access to 2,000+ SRI research items and other resources; and 5) other social media groups (SRI-Rice website).

Strengthening linkages within the global SRI community as a whole and between existing SRI networks not only creates solidarity but can help with scaling up, collaborative problem-solving, and getting information about SRI to those who need it. International, regional, and national SRI knowledge-sharing networks/groups, if adequately supported, have the potential to assist greatly with specific tasks, helping stakeholders locate information, reaching a wider audience, and creating a more enabling policy environment.

In addition to supporting national and regional networks, scaling up SRI globally can be assisted by increasing/improving 1) access to SRI-adapted gender-friendly small- and large-scale production equipment; 2) extension and follow up; 3) quality research on important priorities such as GHG measurements, nutrient management (especially organic inputs), adaptations towards conservation agriculture, water management, and gender issues; 4) access to domestic and international markets (and storage and milling facilities); 5) water management, policies, and infrastructure; 6) investigation and use of farmer incentives, including newer ideas such as carbon credits, rice bonds, crop insurance, certification (regenerative, etc.) assistance; 7) investigation and use of new communications and production technologies that are compatible with SRI and economically feasible; 8) data collection on the SRI spread, adoption and adaptation; and 9) awareness-raising through media, making use of increasing interest in reducing GHGs, water use, and food insecurity (all of which SRI does very well).

Conclusion

With support from NGOs, government agencies, and the private sector, the System of Rice Intensification (SRI) is increasing resource-use efficiency, improving food security, and reducing the carbon footprint associated with rice production in 65+ countries in Asia, Africa, and Americas. A number of national, regional, and international networks serve the global SRI community, though more support and strengthening of linkages within the global SRI community and between SRI networks would help with scaling up, accessing information, and reaching policymakers. As SRI is one of the few agricultural innovations that can help farmers both mitigate and adapt to climate change as well as reduce food insecurity, SRI is attracting more attention from governments as they try to reduce GHGs and help farmers deal with water shortages, extreme weather events, and other climate-related challenges. During 2021, nine countries included SRI in their Nationally Determined Contributions (NDC) to reduce methane emissions, showing increased government attention to SRI. Perhaps this spotlight on SRI will help direct policymakers to improve extension services, water management infrastructure and systems, and market access. Scaling up can also be assisted by investigating/applying digital technologies and new financial incentives for farmers, such as carbon credits, rice bonds, and other decarbonization strategies.

In order to further reduce water use and, in some cases, labour shortages, SRI is increasingly being adapted to use direct seeding (DSR), conservation agriculture, ratooning, and drip and sprinkler irrigation systems. In terms of scaling up and addressing labour issues, more emphasis needs to be given to providing access to (and in some cases gender-appropriate SRI-adapted equipment available for both small- and large-scale farmers in all regions.

While there is already a significant body of SRI research, quality remains an issue. More work on GHG measurements needs to be undertaken in order to better understand SRI's potential contribution to the mitigation of emissions. Priority research that will yield more benefits for farmers includes water management, economics, and nutrient management (especially fine-tuning organic inputs.) While SRI researchers come from a variety of educational and research institutions in over 60 countries, more effort is needed to help researchers in smaller universities and research stations produce better quality publications as their work contains valuable work on local adaptations that are often not covered by larger entities interested in investigating more complex theoretical issues.

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From 'Miracle' Rice Plants to Technology Hybridization: My SRI Journey

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Abstract

This paper is prepared based on the author's experiences in working with SRI ideas and methods in diverse agroecological and socioeconomic contexts in Nepal and abroad. I have found that rice farmers used diverse field management strategies to incorporate SRI into their farming systems. Some farmers used all of the SRI practices introduced during their training, i.e., young seedlings, single seedlings, wider spacing, alternate wetting and drying irrigation, mechanical weeding, and the use of compost. However, the majority modified their methods to be appropriate for their farming situation. Farmers used younger seedlings in areas where irrigation was reliable and drainage facility was better. The use of mechanical weeding was very effective for higher yield; however, its effectiveness and productivity were not the same everywhere. Similarly, many farmers did not follow the advice to use compost (alone, or with fertilizer). It was interesting to note that the poorly-producing farmers were using more fertilizer than required. By contrast, the farmers who attended the SRI training have reduced their fertilizer use. In short, the introduction of SRI methods influenced the traditional rice farming system, but not in a uniform way. After years of experience, the majority of farmers adjusted these practices to fit their personal farming situation. Most farmers who changed their rice farming system were following neither SRI nor traditional practice, but rather a hybrid of methods, and they developed a hybrid system that is more feasible and productive in Nepal.

Keywords: Rice, SRI, hybridization, technology, diversity

Introduction

Agricultural intensification, which makes more productive use of available resources, is thus vital for food security and for better livelihoods of farmers. This is particularly true for rice intensification, in order to produce more of this major staple grain for domestic use. Rice demand has been increasing year after year everywhere because of population growth, improved access to rice in the different geographical areas due to better road-network and transportation facilities, and greater purchasing power of the people through non-agricultural sources of income. Increasing domestic rice demand explains why the government puts the priority on rice production and the production of other food crops by increasing productivity. But the priorities of farmers are changing in an opposite direction because of the low-profit margin in rice farming.

Due to the wide diversity in agroecological and socio-economic conditions, and hence in rice-farming systems, it is evident that there is not one single solution that suits all farmers and all fields. Rice intensification is not achievable as a general strategy. Rice intensification, and SRI in particular, is, therefore, more of a choice, an option, than an imperative. Solutions for individual farmers should be appropriate for local situations, and this location-specificity includes both the agroecological and socio-economic contexts. Farmers try to modify or re-shape any new technologies and incorporate appropriate parts of them into their farming systems to suit their respective situations (Uprety, 2016).

Nutrient management is a very important aspect of rice farming. Government policies (fertilizer subsidies) encourage increased fertilizer use but its efficient utilization is always questionable. Results indicated that the use of higher amounts of inorganic fertilizer did not increase yields (Uprety, 2018). Irrigation management is another important factor for better rice yield. But the reliability of the water supply is more important than its amount. A reliable water supply makes land preparation easier and on time. Water availability makes land preparation, early transplanting, and mechanical weed control become easier.

Agricultural training can play a vital role in technology dissemination and agricultural intensification. The introduction of SRI brings several changes in rice farming, but only part of the farmers has adopted such technologies, and adoption has been only in part of their fields. Other farmers have incorporated some of the SRI practices into their conventional practices. Later rice-growing practices became hybrid practices, conforming neither to the norms of conventional practice nor to the perfect type of SRI.

In order to reform rice farming, we need to recognize that different farmers, with different livelihood strategies, and with access to different kinds of fields, need different forms for agricultural intensification. Even though some agencies and organizations might try to promote SRI in a formulaic manner, the original ideas of SRI have always been to be adaptive and to encourage farmer experimentation and adaptation. There is an ideal type, but the methodology of SRI (not a technology) is to utilize available resources more productively, recognizing that getting more output is not a direct function of using more inputs, but of managing inputs differently and more appropriately.

SRI journey

Miracle rice plant and the start of my SRI journey

One February afternoon in 2002 a photo of a rice plant published in LEISA, which seemed unusually big, attracted me to read that article written by Norman Uphoff (LEISA magazine, Vol. 16.4, December 2000) which was surprising and interesting to me. I was especially attracted to the possibility of obtaining higher rice yields by using available rice varieties, without increasing the dose of chemical fertilizers and other additional investments (Uprety 2009). That article linked me with Norman and some more information from him I prepared myself to start the SRI journey from eastern Nepal.

In the beginning, I had little confidence in such an unbelievable story. No one farmer is interested to test SRI with me. At last one farmer was ready to try it in a small plot (100 m2), and we grew seedlings out of a handful of Radha-12 (155 days' variety) rice seeds. When we transplanted the 10- day seedlings, at a 30 x 30 cm distance, the field looked empty and sad when we finished transplanting. After two weeks of regular farm management practices (such as weeding), the whole field started to look better: all plants were looking healthy and attractive. The plants' development seemed amazing, and by the end, we had a very attractive rice field. We harvested the equivalent of more than 7 t/ha, more than double that of the surrounding rice fields. The first trials gave me more excitement, energy, and confidence to intensify my efforts.

SRI fields and rice plants advertised our work

Next season, we replicated SRI trials in more numbers of fields in larger areas. All fields performed well and attracted the attention of farmers and the media, and we got encouragement to spread more (Uprety, 2006). Later I got Nepal Development Marketplace Award 2005 for SRI

Photos: NDM award ceremony and BBC report

promotion organized by the World Bank. It provides 20000 US$ for our project work. Our area increased, the number of farmers increased, and increase our excitement (Uprety, 2009). Our SRI work got coverage in several prestigious national and international media, including BBC World Service.

After those work and media support, the SRI movement has been going on, and all users and promotors promote it as a "silver bullet" and used a "copy and paste" type strategy. Everyone from every corner was reporting about higher yield, bigger plants with more and more tillers, bigger root systems, handsome panicles, and hundreds of grain numbers per panicle.

We also found similar results. But with the majority of better results, there were some results were not as expected. These were bigger plants with higher tillers numbers, larger root systems, and larger panicles with higher numbers of grain, but the final yield per unit are was not as expected or lower than expected. Somewhere, weed management became a problem; in other areas, AWD was not effective; in some places, wider spacing reduced yields. No SRI promotor had reported this type of result or discussed how to manage those negative consequences. But in working with farmers and connecting to their day-to-day work, we need to find and share solutions to address those problems. So, we started to search out context-specific solutions, and our SRI journey innovated several versions (hybrids) of SRI which will better fit specific situations and give SRI benefits to the farmers (Uprety, 2013b).

Learning from farmers: a participatory approach for SRI hybridization

By maintaining regular interactions with the farmers, researchers and extension agents learned what works and what does not. We found that the farmers with the most productive fields used younger and fewer seedlings of photo-insensitive varieties spaced wider apart. The type of land and the availability of water greatly influenced the approaches the farmers chose. A majority of farmers only used SRI methods in the higher parts of their fields. Farmers used younger seedlings in areas where irrigation and drainage can be controlled better, responding to the evidence that transplanting young seedlings in water-scarce areas is riskier. Water availability also determines the timing of land preparation and transplanting. When the rains are late or when water is not available, the preparation of the field is delayed while the seedlings continue to grow in the seedbeds.

Similarly, mechanical weeding appeared problematic. Although farmers used fewer seedlings and wider spacing, they were not laid out in the straight lines or square patterns necessary for mechanical weeding. Weed management, manual or mechanical, requires sufficient and skilled labour. Mechanical weeding was found to produce higher yields and increase the nutrient use efficiency of rice, but most of the farmers complained about the inefficiency of locally-made weeders. The heavy equipment was not suitable for predominantly female workers.

Extension workers saw that their own recommendations were not followed and started a process of reviewing the techniques with the farmers. This broke the traditional one-way deliverer-recipient system of learning. After joint trials and learning, mutual interactions became more common (Uprety, 2011). Such interactions helped reshape the general recommendations of the extension staff. When extension workers began making recommendations based on farmers' suggestions, other farmers became more interested in testing and disseminating the new approaches (Uprety, 2013a).

Local innovation and technology hybridization

Farmers and extension workers'/SRI workers work together and repackage different context-specific hybrid – SRI methods aiming to increase their rice production. Some examples are given here:

a. Older seedlings SRI

Sometimes seedlings become older because of the unavailability of irrigation water and delay in land preparation. Our farmers used older seedlings (even up to 45 days), planted 2-3 seedlings/hill at 25 cm spacing, and used mechanical weeding, AWD irrigation and got more than 600 kg/ha yield compared to the conventional method with less labour for weeding and other management.

a. Direct-seeded SRI by use of drum-seeder

To reduce production costs, some farmers used direct-seeded SRI by using plastic drum seeders. In better soil conditions and levelled fields, this method performs well, but in weed-problematic areas with unreliable irrigation facilities, it was not performed well.

b. Mechanical SRI by using rice transplanter

Because of labour scarcity and high labour wage rates, many farmers are attracted to mechanized rice farming. The rice transplanter used younger seedlings (10-12 days) and planted 2-3 seedlings at 24-30 cm line spacing (it is adjustable) and 15 cm plant-to-plant spacing. It reduces transplanting costs by up to 40%, facilitates mechanical weedings, and gives higher yields and profits (Uprety, 2010

c. Solarization of healthy seedlings with the SRI method

Healthy seedlings are very important for rice farming as well as the SRI method. So in root-knot nematode-affected rice areas, we encourage farmers to use the solarization method for nursery bed treatment. Its effect was very positive on rice seedlings, growth, and production.

Photos: Solarized rice nursery and seedlings from treated and untreated nursery beds

Conclusion: The journey of learning is never-ending

SRI's journey is evolving and evolving rice farm management around the world. Its environment is becoming favorable day by day. I already completed two decades of working and struggling for this movement. We face several challenges and modified/improve our SRI movement many more. There are hundreds of research articles published from around the world and making our knowledge treasury very rich. But still, we are behind to use it.

We are excited to publish more and more but we are behind in utilizing that knowledge to innovate more and more context-specific possibilities or hybrid SRI which will be more doable, more scalable, and more productive to uplift rice farmers' situations and to save our environment and make rice farming sustainable.

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Can System of Rice Intensification Boost Smallholders' Rice Production in Rainfed, Lowland Areas of Tanzania?

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Abstract

Based on challenges identified and approaches proposed, the paper builds a case for boosting rice production in rainfed lowland areas of Tanzania. The proposed initiative is designed as an action in the field of development cooperation. Despite its complex nature, the initiative aims at an intensification of the prevailing rice production system in rainfed areas, whereby improving the availability of suitable rice seeds and adopting elements from systems of rice intensification (SRI) are proposed as the main agronomic components, which shall be supported by respective research. Further elements to be considered are the management of land and water in these rainfed areas, which are seasonally used for rice production, while the rest of the year they remain fallow, as well as the economics of the production system, which at present is critical and may remain a stumbling block for intensification, also due to the threat from more competitive local production in irrigated areas and cheap imports.

Keywords: Tanzania, rice production, system of rice intensification, development cooperation

Introduction

In Tanzania, rice is the second most important food crop after maize (Bucheyeki *et al.,* 2011), and is a major source of employment, of income and for food security. Rice is grown by over 1 million farmers on the (*Tanzania*) Mainland, mostly in the regions of Morogoro, Shinyanga, Mbeya, Mwanza, Tabora, Kilimanjaro and Rukwa, and by 72,000 farmers on (*the Islands of*) Zanzibar (The World Bank, 2021; TARI, 2021). Despite the increasing importance of rice in Tanzania, the mean yield of the crop is 1.5 tons/ha, which is far below the yield averages reported in Sub-Saharan Africa (4.4 tons/ha), Asia (4.6 tons/ha) and South America (5.2 tons ha) (Atera *et al.,* 2018). In fact, average rice yields stagnated at about 1.2 to 2 tons/ha against a demonstrated on-farm potential of 6 to 8 tons/ha. This was due to limited improved seed availability, with only 15 percent of paddy farmers growing improved varieties, less than 1 percent exposed to improved technologies including System of Rice Intensification (SRI) and farmers only growing one cropping season due to poor irrigation infrastructure and water management (The World Bank, 2021). Yet, The World Bank (2021) concluded that, the rice subsector was and remains a strategic priority for agricultural development in Tanzania.

The fastest growing demand for rice in the world has been noted in Africa, owing to the rapid population growth of about 4 % per annum (URT, 2019). In Tanzania (…) rice consumption increased from 818,699 tons in 2011/12 to 976,925 tons in 2015/16 (Msafiri, 2021). Rice consumers in Tanzania have strong preference for rice varieties grown locally in comparison to imported rice due to their aromatic attribute.

To ensure sustainable rice production and productivity, research institutions have been working in collaboration with various research projects such as; (i) Piloting quality management systems in rice production (Rikolto East Africa), (ii) Expanding rice productivity project (ERPP), Fast tracking Delivery and scaling of agricultural technologies in Tanzania (AfricaRISING), (iii) Capacity Development and experience sharing for rice value chains through South-South and Triangle Cooperation (FAO).

In support of the rice sector and the rice farmers, various development initiatives have been implemented such as the WB/GASFSP project in Morogoro and Zanzibar (2015 – 2021) or the EU funded rice initiative in Morogoro and Iringa regions (2017 – 2021) which was implemented by FAO, the Aga Khan Foundation and Helvetas. In 2019, the Government of the United Republic of Tanzania (URT) revised and updated its National Rice Development Strategy - NRDS II (URT, 2019).

However, in Tanzania, most initiatives have been favouring boosting rice production in irrigated areas, with little emphasis on the much larger rainfed areas in the lowlands and partly uplands. Despite the fact that farmers producing rice under rainfed conditions outnumber by far the farmers with developed irrigation systems, there was in the past (too) little attention on this producer group and their production context. There needs to be even urgency in turning towards rice production under rainfed conditions in lowland areas of Tanzania, as these farmers are increasingly impacted by other and partly new key issues such as climate resilience in rice production, quality management, postharvest losses, commodity value addition, labour saving technologies and innovations in processing, and utilization of rice by-products.

This paper looks at the challenges rice producers in rainfed lowland areas of Tanzania face and suggests entry points for tackling these challenges.

Advocating for the stakeholders in Tanzania, Helvetas together with rice producers and relevant public and private actors along the rice value chain would like to embark on a sizeable comprehensive pilot in selected regions of Tanzania with focus on quality inputs and good agronomic practices, including system of rice intensification (SRI), to boost smallholders' rice production in rainfed, lowland areas of Tanzania. Hence, with this paper Helvetas and its partners seek exchange and feedback from the research community on the proposed action as well as invite potential donors to support this initiative.

Method

This paper is not based on any empirical research. It rather summarizes insights on rice production in rainfed lowland areas of Tanzania and on the rice value chain in general, which have been obtained from secondary literature, from discussions with rice farming communities as well as public and private institutions involved in the rice sector, and from experiences of Helvetas while implementing rice projects in Tanzania and Asia (India, Myanmar).

The identified challenges and potential approaches as outlined are the results from the study of secondary literature, as well as from focus group discussions with rice farmers and exchanges with relevant value chain actors, namely:

- The Ministry of Agriculture (MoA), United Republic of Tanzania, Dodoma
- Various agricultural offices in the regions of Rukwa, Katavi, Tabora and Shinyanga
- The Tanzania Agricultural Research Institute (TARI), Dodoma Head Office
- TARI Dakawa, the rice research centre of TARI
- The Sokoine University of Agriculture (SUA), Morogoro
- The Tanzania Official Seed Certification Institute (TOSCI)
- The Agricultural Seed Agency (ASA), Morogoro
- The Rice Council of Tanzania (RCT), Dar es Salaam
- MW Rice Millers, Morogoro

However, please note, the information provided in the following chapters 3 to 5, i.e., potential approaches, the proposed logframe and the conclusions drawn are of some preliminary nature. The farmers and the various further stakeholders consulted may differ on how some of the issues are to be approached, on where emphasis for solutions should be put, and on the conclusions drawn.

Therefore, even though the paper reflects and summarizes to a large extent the view and ideas of the various rice sector stakeholders, the responsibility for the paper's content lies entirely and solely with Helvetas Tanzania.

Results

Identified challenges and potential approaches

i) Land

Challenges: The typical rainfed rice fields are flooded and often submerged during the rainy season. However, during the dry season they look quite abandoned, though they are often grazed by livestock. Ownership, access to land, leasing of land, etc. mostly follow customary law, which may not always be entirely clear, and sometimes discriminatory towards women. In the end, such land issues become a hindrance for farmers to invest into their rainfed rice fields.

Approaches: Create clarity and transparency on ownership, access to land, and user rights. With such security created, farmers are better prepared to invest into the land, investing in improved land preparation (levelling), including mechanization.

ii) Irrigation and water management

Challenges: Characteristics of a rainfed area under rice cultivation may differ considerably, in terms of inflow of water from neighbouring areas and outflow/

runoff. But in general, there is hardly any proper water regulation/management, even if in some areas some small, crude, seasonal water channels might be there, which are poorly maintained, often damaged during dry season.

Approaches: Objective should be to minimise the risk of crop failure in rainfed lowland areas, which could be achieved where feasible through small complementary water structures such as check dams or percolation dams together with irrigation channels to regulate water in- and outflow in a better way. The structures should be set up in an unbureaucratic way by the local administration and be managed by the respective water users themselves through water stewardship committees or water user associations.

iii) Seeds

Challenges: The seed challenge is demonstrated with an example: Saro 5 is the name of a high yielding variety released in Tanzania more than 20 years ago. Yet, today, less than 10% of farmers are using it, despite the researchers say Saro 5 produces five times more than local varieties. Do we have the right variety but unfortunately the wrong farmers? Unfortunately, Saro 5 is not suitable under rainfed conditions, as it has been developed for high potential areas with good, permanent water availability. Furthermore, Saro 5 is also not the most desired variety, since farmers as well as consumers in Tanzania prefer aromatic rice, while the aroma often disappears in new high yielding varieties.

Approaches: Concerning seeds a participatory approach between researchers'/plant breeders and farmers shall be followed to identify more suitable, drought-resistant rice varieties. Though it is to be mentioned, that the Tanzania Agricultural Research Institute (TARI) is on the job, while seed multiplication is done by the Agricultural Seed Agency (ASA) with the Tanzania Official Seed Certification Institute (TOSCI) being the respective certification agency. TOSCI has also developed a seed multiplication programme directly involving farmers who produce quality declared seeds (QDS).

iv) Good agronomic practices, including SRI

Challenges: Apart from challenges related to land and irrigation, poor agronomic practices hinder production and productivity. However, one should not attribute the poor practices alone to a lack of farmer's knowledge about rice cultivation. The way many farmers still grow rice in rainfed areas is also an expression as well as indicator of the risks involved. The low input – low output approach is a risk minimising strategy, in which farmers keep their investments low.

Approaches: One is often quite quick in asking for more capacity building and training of farmers on good agricultural practices (GAP), though training on GAP alone may not do the trick. Can the promotion of system of rice intensification (SRI) make a difference in such a context? Helvetas and its partners in Tanzania would like to answer this question with "*yes*" and take it up as a hypothesis for a proposed pilot on rice production in rainfed lowland areas of Tanzania, by developing location specific production protocols for SRI.

v) Postharvest management and storage

Challenges: Post-harvest losses (PHL) are generally high in Tanzania with estimations in cereals of up to 40% (URT, 2017). PHL challenges in rice occur during threshing, and later due to insufficient drying and poor storage of the crop.

Approaches: The increased use of threshing machines and even (mini) combine harvesters contributes to reduced losses while threshing. The construction of proper warehouses can be a way out of storing the crop under unsuitable conditions at the farm level. In addition, central storage of crops by a farmer group or cooperative may also allow the introduction of a warehouse receipt system, which can support farmers in accessing credits for farm inputs.

vi) Processing and marketing

Challenges: Rice millers in Tanzania also complain about the low milling quality of high yielding varieties and therefore prefer local varieties, which in addition, as mentioned earlier, face a higher demand in the local market. In fact, the market, i.e., own/home consumption, local markets versus export markets, is a key factor which determines farmers' choices and decisions when it comes to rice production. From the consumers' side there is a big demand for rice, but with increasing prices and inflation all around, consumers' preferences increasingly go towards cheaper rice, which is less/not aromatic and often imported.

Approaches: Development of new varieties, apart from farmers' preferences and considering specific cultivation aspects, should also consider the preferences of rice millers and particularly of the consumers. To which extent the local production which faces high production costs should be protected against cheaper imports, is a policy issue which needs careful assessment of the producers' and the consumers' interest. However, with more than half of its population still living in rural areas and directly linked to farming, Tanzania must keep in mind that by serving the producers it also serves at the same time more than 50% of its consumers.

Transversal issues

vii) Gender and social equity

Challenges: Women are well involved in the rice production, though mostly with specific tasks which are seen as women's work. Participating in farming decisions however is less.

Approaches: Promoting an inclusive approach concerning gender and social equity, when it comes to rice farming in rainfed areas, would in particular mean, involving women in aspects related to land (ownership, access, user rights) as well as in the planning and decision making concerning land improvement and irrigation structures. Furthermore, it is paramount to have women attending trainings on good rice production practices and SRI.

viii) Climate change

Challenges: Changed rainfall patterns and increased temperatures are threats for cropping which is done under rainfed conditions.

Approaches: There are several approaches and actions one can take to respond to climate change, which can be summarised as building climate resilience among farm households and consists of climate smart agricultural practices. At the same time, on the research side, climate resilient rice varieties may be bred or improved, climate adapted practices may be researched, including aspects related to water management.

ix) Environmental and social sustainability

Challenges: Rainfed lowland rice production is seen as a risky business. It is for that reason, that farmers with low-risk handling capacity turn to low input – low output farming and often also to unsustainable production practices.

Approaches: Integrate rainfed lowland rice production into the prevailing farming system, which could mean using the areas for other crops like production of vegetable with the residual moisture after harvest or growing a crop as green manure or for fodder. Even using crop residues (rice straw) as fodder or planting trees on bounds could be part of a local farming system. In the end, such areas become part of a regenerative production landscape.

x) Economics

Challenges: Tanzania's local wholesale prices for rice are relatively higher than the world market prices. (…) domestic wholesale prices increased from 701 USD per ton in 2018 to 762 USD per ton in 2019, while world market prices declined slightly from 421 USD per ton in 2018 to 418 USD per ton in 2019. Tanzania's domestic rice prices are higher than imported rice. This is more likely attributed to higher transaction costs, transport costs and the quality (Msafiri, 2021).

Approaches: More favourable economic returns are more likely to be achieved through an intensification of the system with improved seeds and improved agronomic practices based on more favourable frame conditions regarding land and water, rather than continuing with a low-risk low input - low output approach. Intensification of the rice production in rainfed lowland areas of Tanzania not necessarily means going big, but opting for a feasible, viable and sustainable way.

Discussion

A potential result framework for a pilot

Table 1 shows the result framework for a potential development initiative with rice farmers in rainfed lowland areas of Tanzania. It somehow summarises the challenges and considers the approaches outlined. Nevertheless, this result framework is work in progress; as such it is more of an entry point which needs to be further scrutinised by the concerned actors and stakeholders.

Table 1: Result framework for a rice initiative in rainfed lowland areas of Tanzania

Goal: Improved and strengthened rice production in rainfed lowland areas of Tanzania provides a feasible, sustainable and viable livelihoods, food security and income opportunity for smallholder farmers					
Outcome 1: Improved land and water management increase the value of rainfed lowland areas		**Outcome 2**: Appropriate seed systems and the adoption of SRI boost rainfed rice production (in combination with improved water management)		**Outcome 3**: Rice produced in the rainfed lowland areas of Tanzania has become an attractive, viable crop with its own niche in the national and international markets	
Output 1.1 Improved access to and secured use of land increase farmers' willingness to invest in rainfed seasonal arable land	**Output 1.2** Increased water availability and improved irrigation reduce the risk of crop failure and increase crop production	**Output 2.1** Suitable seed varieties are produced, which then are locally multiplied by the farmers as QDS	**Output 2.2** SRI is adapted to location specific rainfed conditions and introduced to rice farmers through training and production protocols	**Output 3.1** Due to its aroma, preferred by consumers, rice mills and traders promote local rainfed rice as specialty rice	**Output 3.2** Concerned stakeholders monitor the viability of rainfed rice on a regular base

Conclusion

After a brief introduction to the rice sector in Tanzania, this paper lists challenges faced by the sector as well as approaches to address and overcome these challenges, which result in a framework for a potential comprehensive initiative to boost rice production in rainfed lowland areas of Tanzania.

Talking about system of crop/rice intensification, the scope for research is with the proposed *Outcome 2: Appropriate seed systems and the adoption of SRI boost rainfed rice production (in combination with improved water management)*, where it would be interesting to see to which extent and how fast suitable varieties can be identified and multiplied, and to which extent SRI provides interesting and feasible options to tackle the challenges faced by smallholder farmers in the rainfed lowland areas of Tanzania.

Acknowledgment

This note has been prepared based on exchanges HELVETAS Swiss Intercooperation had in Tanzania with smallholder rice producers and relevant sector stakeholders. Helvetas would like to thank the interviewed rice farmers for their interest and willingness to provide insight into their rice farming. Thanks also go to relevant public and private institutions involved in the rice sector, which expressed in their exchange with Helvetas their interest to join the proposed initiative and to take up responsibility and ownership.

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System of Rice Intensification in Indonesia: Research, Adoption and Opportunities

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Abstract

The conventional rice cultivation method is observed to be ineffective in increasing rice production in Indonesia, compounded further by the frequent occurrence of various diseases, pest infestations, and weather uncertainties. The long-term practice of using high agrochemical inputs has adversely affected natural resources such as water, soil, and air. Thus, farming transformation is much needed in order to address the nation's food security. This transformation can be done via the adoption of agroecological practices which rely on biological processes rather than on agrochemicals to maintain soil fertility and protect plant health. The System of Rice Intensification (SRI) is an agroecological method of rice cultivation that relies primarily on creating conditions for healthy plant growth by minimizing inter-plant competition through individual planting and wide spacing, at the same time improving soil structure and functioning by applying organic amendments, facilitating soil-surface aeration during weeding, and managing water to avoid both continuous flooding and water-stressed conditions. This combination of management practices results in better rice growth and yield compared with standard cultivation methods. For this purpose, the impacts of the SRI method on the economic, environmental, and social perspectives were studied. We conclude that the high productivity obtained by the SRI farmers and field trials has proven the suitability of the SRI method for sustainable rice farming in Indonesia. SRI improves the productivity of land, water and increases rice yield by three times higher than the conventional method. SRI is now regarded as a good option to be practiced by farmers in order to bring about a new kind of green revolution that relies upon ecosystem services to increase yield.

Keywords: System of Rice Intensification, Indonesia, microbiome, agroecology

Introduction

Conventional rice farming methods, which rely on the intensive use of chemical inputs introduced by the Green (chemical-inclined) Revolution, deplete agriculture's natural resource base, jeopardizing the future productivity of the land (Pronti and Coccia, 2020). FAO (2011) recommended that cropping systems should be based on low input (fertilizers and water) methods and optimizing ecosystem services to increase yield.

The concept of food sovereignty and agriculture based on agroecology has found attention among researchers and policymakers because this approach has been successful in bringing positive changes in economic, environmental, small farmers, rural communities, and urban populations.

Agroecology as a new paradigm in agriculture is focused on the return of the condition of self-reliant local communities, conservation of nature and biodiversity, production of healthy food produced using a low amount of input, and empowerment of rural communities (Altieri and Nicholls, 2020). One of the agroecological practices is the System of Rice Intensification (SRI), which relies on a set of principles of cultivation that has a major impact on the efforts to create sustainable farming towards the realization of a green economy (Doni *et al.,* 2019).

SRI methodology was synthesized in the early 1980s by Henri de Laulanié, S.J. To date, many farmers around the world are using the SRI method to increase rice production. SRI has managed to reduce the use of chemical fertilizers and chemical pesticides, thereby reducing production costs. Scientists have shown interest in agriculture to understand how SRI can increase rice production up to 3 times more than a non-SRI cultivation technique (Thakur *et al.,* 2016). SRI is touted to be a good option to be practiced by farmers in order to bring about a new kind of green revolution, one that relies upon ecosystem services to increase yield (Thakur *et al.,* 2022).

SRI is a remarkable innovation in the organic farming method that improves the productivity of land, labour, water, and capital investment in paddy cultivation. SRI can be a cost-effective system of labour as well as saving water (25-50 %) and seeds (80-90%), reducing costs (10-20%) and increasing crop yield by at least 25-50%, sometimes 50-100% and there are sometimes even more than 100%. SRI productivity has been proven in 28 countries, from China to Cuba, Peru to the Philippines, Gambia to Zambia, and even Iraq, Iran, and Afghanistan (Uphoff, 2008).

SRI cultivation techniques start with the preparation of the soil to allow the planting of rice seedlings (5-7 days old) planted, one seedling per square measuring (35 x 35) cm. It is recommended that seeds belong to the farmers themselves. The rice field does not have to be flooded with water, restricted to water levels of only two centimeters or less.

SRI was first practiced in Indonesia in 1999. Since then, the interest in using SRI has grown rapidly on the back of government agencies, universities, NGOs, and the private sector. SRI's advantage is in the case of supporting sustainability and sustainable agriculture fields in Indonesia (Uphoff, 2008).

Our previous studies have reported the experimental trials of SRI in Indonesia, such as Java, Sumatra, Bali, Sulawesi, and Kalimantan. For this purpose, the impact of the SRI method on the economic, environmental, and social perspectives was studied.

System of Rice Intensification (SRI) in Indonesia

The basic principles of the SRI methods

The System of Rice Intensification (SRI) is a yield-increasing methodology practiced by probably more than 20 million farmers, with benefits having been demonstrated in over 60 countries (Thakur *et al.,* 2022). SRI methods modify the most common rice-growing practices in a number of ways. The changes include: (1) growing seedlings in nurseries with a minimum of water, a maximum of organic matter, and low plant density; (2) transplanting seedlings into rice fields at a young age, as little as 10-12 days old and no more than 15 days; (3) planting single (rather than multiple) seedlings in hills in a square pattern at a distance of 25-30 cm; this encourages healthy root growth with reduced competition for nutrients and induces profuse tillering and canopy growth; (4) mechanical weeding that eliminates weeds at the same time it aerates the top layer of soil; (5) using organic matter, as much as available, to enhance soil fertility in preference to chemical fertilizers; and (6) intermittent irrigation, alternating wetting, and drying of rice paddies instead of continuous flooding as this favours aerobic over anaerobic microorganisms (Thakur *et al.,* 2016). Fertilizers can be used where there is not sufficient organic matter to meet soil and plant needs, but results are better to the extent that the soil's reserves of organic matter are enhanced. Also, organic and inorganic nutrient sources can be combined (optimized) when the first is limited or the soil has particular deficiencies, but the purpose is to be supporting soil microbial communities, not just the plants.

SRI methods not only increase the production of rice but also the biodiversity in the soil, giving plants greater resistance against pest infestation and, to some extent reducing the uptake of arsenic. SRI also helps to conserve rice biodiversity by giving farmers financial incentives to plant local/indigenous/heirloom varieties. Thousands of these varieties have already become extinct, and most of the surviving varieties face extinction. SRI methods can make producing traditional varieties more profitable by raising their yields while reducing costs of production; these varieties usually command a higher market price because of consumers' tastes and preferences. So even if their yields are not as high as from 'improved' varieties, they can be more remunerative. Furthermore, when SRI methods are used, soil and water quality are improved (Doni *et al.,* 2019).

Growing rice plants with SRI methods enhances their root growth while the roots support the plants' canopy, leaf and tiller growth, and grain filling. These plants have better physiological performance, such as higher rates of photosynthesis that increase the supply of carbohydrates to the roots, which prolongs the roots' longevity and thereby contributes to the grain-filling process (Thakur *et al.,* 2010). Under SRI management, yields are increased by 20–60% or even more (Thakur *et al.,* 2016), while water requirements are reduced by about 25% (Jagannath *et al.,* 2013). According to some research in India, net greenhouse gas emissions, consumptions of groundwater, and fossil energy use are, respectively, lower by 40%, 60%, and 74%

kg^{-1} paddy rice produced compared to standard practices. Farmers' net returns ha^{-1} was increased by as much as 300% (Gathorne-Hardy *et al.,* 2016).

SRI adoption in Indonesia

There are many lessons that Indonesia can learn from the experience of other countries that have been practicing SRI. Expanding SRI is effective in handling three different interested parties, namely (i) the farmers, (ii) the officers, and (iii) the government. Farmers benefit from low seed input, low water usage, more productive panicle, reduction of pest and disease infestation, ability to generate their own seed, high-weight grain, and high-quality seed. On the other hand, the factors that often hinder the farmers from practicing SRI are the long duration needed to cover the land, difficulty in moving the young seedlings, difficulty in controlling the wet and dry needs, absence of organic materials, the requirement of experienced workers and the lack of proper tools.

Thiyagarajan and Gujja (2013) also mentioned that a low understanding of SRI principles and the requirement for detailed attention and monitoring are also among the main causes that contribute to farmers' low interest in SRI. Like the other new farming methods, the farmers may try on this method for a while and then possibly discontinue it for some reason. Therefore, technical support and continuous encouragement for several seasons are needed to change the farmers' ways of managing rice planting.

Conclusion

The high productivity obtained by the SRI farmers and field trials has proven the suitability of the SRI method for sustainable farming in Indonesia. The enhanced soil microbial diversity and activities contribute to the growth of the rice plants and productivity, as attested by the high-yield components under the SRI cultivation method. The agroecosystem also supports the existence of a balance between the pest and non-pest insect populations. The volunteers of farmers to try different cropping methods are the key success of this cultivation method. This augurs well with the good agricultural practice methods in sustainable rice farming.

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A Systemic Review of System of Rice Intensification Journey and System of Crop Intensification Development in the Rice Sector of Viet Nam

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Abstract

Started in Viet Nam in 2003 and was piloted in small areas via the demonstration fields in four provinces in northern Viet Nam, Systematic Rice Intensification (SRI) has proven its agronomic, economic, and environmental benefits and thus has been promoted widely in Viet Nam for almost two decades to almost 50 rice production landscapes that helped to improve livelihood for more than one million of smallholder farmers; reduced water irrigation by 40%; production cost of 32% and increased yield by 13-29% as compared to the conventional practices during the period of 2010- 2015. Viet Nam has been recognized as the world's third largest rice exporter (Department Crop Production of Vietnam, 2021), given almost 80% of agricultural land for rice cultivation (IRRI Online) and mobilization of advanced farming practices among other efforts. Overtime, key principles of SRI have been further developed and refined to be ecological-based suitable and enhance multi-dimensions efficacy. Mobilizing the combination of both literature review and primary data, this paper reviews the key milestones and results of SRI over the past two decades in VN; and makes a systematic review of the transition from SRI to System Crop Intensification (SCI) that are more relevant and pragmatic to the rice farming practices in different eco-systems and market needs in Viet Nam. A case study of the AgResults Vietnam Emissions Reduction Challenges Project (AVERP) showcases the sophisticated and innovative development of key principles of SRI to ecological and market-based SCI for sustainable and low carbon rice cultivation as well as the readiness of the roles of private sector in technology transferring and scaling those SCI to almost 48,000 smallholder rice farmers of 89 Co-ops over four (04) cropping season in Thai Binh province of Viet Nam.

Keywords: Systematic Rice Intensification (SRI); Systematic Crop Intensification (SCI); SRI in Viet Nam; AgResults low-carbon rice cultivation in Viet Nam.

Rice Production Context in Viet Nam

Rice production is central to Vietnamese culture, food security, poverty reduction and socio-economic development. Over the last 30 years, Viet Nam has made tremendous gains in increasing productivity to address food insecurity - average rice yields now trail only China, and it is now among the most food-available Middle-Income Countries (MIC) globally.[1] As the country has opened up to investment, trade and export markets, the country has become the third-largest global producer and exporter of rice.

Viet Nam is recognised as one of the country's most vulnerable to the impacts of climate change due to the large number of people living in low-lying coastal and delta regions, many of whom are directly dependent on land and agriculture as a primary livelihood strategy and source of income. Viet Nam's Mekong River Delta (MRD) is one of the world's most climate-vulnerable landscapes, already and expected to be increasingly impacted by water shortages, droughts, rising sea levels, and saline intrusion. Yet it is also Viet Nam's, and one of the world's most important rice baskets – where 90% of Viet Nam's rice for export is grown. There is an urgent need for a wide-scale transition to climate-resilient production in the MRD.

At the same time, Viet Nam is rapidly developing and, on the way, to becoming a Middle Income Country. As such, the country is expected to, and has made, ambitious climate mitigation commitments. Agriculture is now the third largest sector contributing to climate change, with around half of GHG emissions resulting from rice production. Therefore, reducing GHG emissions from rice production is a key priority for the agriculture sector.

Viet Nam's rice production is characterised by intensive production by millions of SHFs with high yields for low-value export markets. Very thin margins have meant that many rice farmers remain perilously positioned at just above the poverty line and vulnerable to commodity price shocks in global markets. The Covid-19 pandemic has severely impacted agricultural supply chains and demonstrated the vulnerability of SHFs to such global shocks. As Viet Nam rapidly develops to become a MIC, the costs of land and living rise, as do inequalities. Farmers need to increase their profit margins to remain above the poverty line. There is a need for the rice sector to shift to higher-value markets.

For all the above reasons, the Vietnamese rice sector urgently needs to transition towards low-carbon sustainable, and climate-resilient production practices. It started in Viet Nam in 2003 and was piloted in small areas via the demonstration fields in four provinces in northern Viet Nam; Systematic Rice Intensification (SRI) has proven its agronomic, economic, and environmental benefits and thus has been promoted widely in Viet Nam for almost two decades to almost 50 rice production landscapes that helped to improve livelihood for smallholder farmers; reduced water irrigation by 40%; production cost of 32% and increased yield by 13-29% as compared to the conventional practices during the period of 2010- 2015. Overtime, key principles of SRI have been further developed and refined to be ecological-based suitable and enhance multi-dimensions efficacy. Mobilizing the combination of both literature review and primary data, this paper reviews the key milestones and results of SRI over the past two decades in VN; and makes a systematic technical review of the transition from SRI to System Crop Intensification (SCI) that are more relevant and pragmatic to the rice farming practices in different eco-systems in Viet Nam. A case study of the AgResults Vietnam Emissions Reduction Challenges Project (AVERP) showcases the sophisticated and innovative development of the key principles of SRI to ecological and market-based SCI for low-carbon and sustainable rice cultivation as well as the readiness of the roles of the private sector in technology transferring and scaling those SCI to almost 48,000 smallholder rice farmers of 89 Co-ops over four (04) cropping season in Thai Binh province of Viet Nam.

Review of SRI application and results in Viet Nam and Transitions to System Crop Intensification: A Case Study of AgResults Viet Nam Emissions Challenges Project Body of paper

Introduction

Started in Viet Nam in 2003; SRI was piloted in small areas via the demonstration fields in four provinces in northern Viet Nam. With proven records of enhancing yield, reducing seed/fertilizer, water irrigation, and pesticide while increasing yield, since 2007, SRI has been promoted for wide-uptake in almost 50 rice production landscapes in Viet Nam; and received notable recognition for its efficacy and contributions to the realization of key development policy for sustainable agriculture development of Viet Nam. **Figure 1** below shows key milestones and a hallmark of the Government of Viet Nam's formal acknowledgement of SRI as an advanced rice farming tool for nationwide take in Viet Nam.

Methods

Mobilizing the combination of both literature review and primary data, this paper reviews the key milestones and results of SRI over the past two decades in VN; and makes a systematic review of the transition from SRI to System Crop Intensification (SCI) that are more relevant and pragmatic to the rice farming practices in different eco-systems and market needs in Viet Nam.

Results

Consolidated Results of Application of SRI in Viet Nam 2003-2015

Over decades, the application of SRI to rice production consistently delivers significant benefits in terms of agronomic, economic, social, and environment. These are critically important in the context of the proven thin margin for rice farmers, degradation of soil health, and adverse phenomena of climate change. **Table 1** below shows concrete records and a wide range of benefits that the application of SRI provided to millions of rice growers in Viet Nam.

Figure 1: SRI Journey in Viet Nam 2003 – 2015

Table 1. Efficacy of SRI application to rice production in Viet Nam

Efficacies of SRI	Increase	Efficacies of SRI	Decrease
Yield	8-25%	Seed	90%
Production efficiency	19-31	Labour	50%
		Water	25-67%
		Pesticide	75%

Source: System of Rice Intensification in Viet Nam: A Decade of Journey

Ecological and market-based Transitions from System of Rice Intensification to System of Crop Intensification for Rice Production in Viet Nam

The origination of contemporary System of Crop Intensification (SCI) for Rice cultivation in Viet Nam such as 3 Reductions – 3 Gains (3Rs-3Gs) and 1 Must Do – 5 Reductions (1M5Rs), had been deeply rooted in the key principles of System of Rice Intensification (SRI). In 2006, the Crop Production of Viet Nam approved and promoted rice farmers to apply the three reductions of i. Seed; ii. Fertilizer, and iii. Pesticide. The results of these three reductions are three Gains: i. Yield; ii. Rice quality, and iii. Production Efficiency. In 2009, to be more sufficiently addressing the large-scale rice production for export, the 3Rs3Gs was improved to be 1M5Rs which one must do, and that is, rice growers must use the certified quality seed; five reductions mean that rice growers are encouraged to reduce i. Seed density; ii. Fertilizer application; iii. Pesticide; iv. Water irrigation and v. post-harvest loss (**Table 2**). The application of 3Rs3Gs and 1M5Rs delivers similar results in reducing input cost and water consumption, thus reducing lodging and fertilizer in SRI; but more suitable to the ecosystem and large-scale rice production for export in the Mekong Delta of Viet Nam. From 2010, thanks to experiments from the internationally funded project from the Environmental Defense Fund via the Vietnam Low Carbon Rice Project (2011-2015) and Sowing the Seed of Changes (2012-2014); both SRI and SCI such as 1M5Rs in which the alternate wet dry irrigation was identified and concluded as the technology for reducing the methane emissions from rice cultivation.

Table 2. Technical review of the transition from SRI to SCI for Rice Cultivation in Viet Nam for period 2003-present

SRI	3 Reductions - 3 Gains	1 Must Do - 5 Reductions	Ecological and Market-based SCIs (via AVERP)
Started in 2003	Started in 2006	Started in 2009	Started in 2017
Key Principles	**3 Reductions:**	**5 Reductions**	**Improvised 5 key components**
Low seed density young seedlings	- Seed	- Seed	- Smart & crop-based Variety, low Seed density
Promotion of organic and microbial fertilizer	- Fertilizer	- Fertilizer	- Smart fertilizer application
Manual grass removal	- Pesticide	- Pesticide	-Bio-fungi treatment of stubble and rice straw
Irrigation: Alternate wet dry		- Water via AWD	- Eco-based AWD water irrigation
		- Post-harvest loss	- Mechanized transplanting and harvesting
	Resulted in 3 Gains: Yield; Quality, Efficiency	Resulted in reduction of input cost and GHG emissions	Resulted in reduction of input cost and GHG emissions

Source: Literature review and consolidation by the Author

Discussion

A case study from AgResults Viet Nam Emissions Reduction Challenge Project

The AgResults Vietnam Emissions Reduction Challenges Project – abbreviated as AVERP – is an initiative of the AgResults program that aims to promote the development, testing, and scaling up of innovative technologies, tools, and approaches to reduce greenhouse gas (GHG) emissions in the land cultivation and production stages for Rice, while also supporting provincial and national poverty reduction, environmental protection and climate change goals. The AVERP utilizes a "pull" mechanism to spur a diverse pool of actors to achieve significant GHG emissions reductions from large-scale rice production while also strengthening market linkages. AVERP has been implemented in the Thai Binh province in the Red River Delta for the period of 2016 – 2021.

Upon reviewing the results and impact of SRI on rice production in Viet Nam; and the ecological and market-based transitions to the System of Crop Intensification for Rice production in the main rice bowl of Viet Nam; this paper continues to review and analyse the advanced refinements of key principles of SRI and innovations made to formulate the diverse and optimized sustainable rice farming technology package that target five main components of rice productions:

1. Rice Variety
2. Planting/Sowing density and spacing
3. Fertilizer application
4. Water irrigation
5. Crop residues management

Competitors who participated in AVERP were allowed to experiment with their SCI for rice cultivation in Phase I of AVERP. With proven efficacy for increasing yield and economic gain and reduction of CO2 equivalent, four (04) out of eleven (11) Competitors with top results were allowed to participate in Phase II for scaling their tested SCI technologies in intensive rice production communities in Thai Binh province. Key features of the four winning SCI are shown in **Table 3**.

Table 3: Key characteristics of the modifications and advancement

Variety Characteristics	Stubble and Rice Straw Treatment	Transplanting/ Sowing Density (kg seed/ha)	Fertilizer Application (N-P2O5-K2O) kg/ha	Organic Fertilizer (kg/ha)	Irrigation Management
Advanced Aromatic + yield improvement + pest resistant	Bio-fungi treatment	35	83-83-62	830 kg microbial/ha	2 intermittent irrigation/crop
Advanced Aromatic + yield improvement + pest resistant	Bio-fungi treatment	35	85-73-43		4 intermittent irrigation/crop
Advanced Japonica + high yielding +pest resistant	Bio-fungi treatment	35	91-112-97		6 intermittent irrigation/crop
Advanced high yielding + pest resistant	Bio-fungi treatment	33	66-20-41	200 kg microbial/ha	3 intermittent irrigation/crop
Advanced Aromatic + yield improvement + pest resistant	Bio-fungi treatment	42	80-83-68	15% organic fertilizer	2 intermittent irrigation/crop

Source: Evaluation of Technological Methodology, AVERP, Tran Thu Ha et al 2021

Yield increase, return on investment, and reduction of CO2 as a result of applying the four improvised SCI for rice cultivation by almost 48,000 smallholder rice farmers over almost 5,000 hectares of land area are shown in **Table 4**.

Table 4: Key outcomes and efficacy on yield, economic and CO2 equivalent reduction

Com-petitor	Vari-ety	Dry yield (kg/ha)		Total investment cost (000 VND/ha)		Net profit (000 VND/ha)		Average yield increase (tons/ha)		Average GHG reduction (tons/ha)		Return on Invest-ment (ROI)
		Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer	
I4	DS1	5,016	4,790	27,209	28,472	15,640	17,122	0.2	0.1	1.0	1.9	30%
I5	BC15	6,330	5,696	30,542	28,506	30,084	32,190	0.5	1.8	0.3	1.3	79%
I18	LTH31	5,750	5,545	28,908	31,096	20,178	16,138	0.1	0.6	0.3	0.8	36%
I23	BT7	4,571	4,757	27,809	33,325	13,841	21,956	0.0	0.1	0.1	1.1	26%

Source: Evaluation of Economic Efficacy of four SCI Technological Packages, AVERP, Tran Thu Ha *et al.,* 2021

Conclusion

Rice production has long been central to the society and culture of Vietnam. It has also been one critical pillar in Vietnam's remarkable socio-economic success story over the three decades since the 'Doi Moi' (Policy Reforms) was launched in 1989. Continuous improvements and progress in rice production through policy enhancement and the application of advanced farming technologies include SRI and contemporary SCI have helped lift millions of smallholder farmers out of poverty and lifted Vietnam from food insecurity in the 1980s to the world's 3rd largest rice exporter today. The adoption of SRI/SCI approaches and technologies in rice production presents a range of other climate, environmental and socio-economic co-benefits, including: i) Increased climate resilience: The development of stronger plants which are more resilient to the floods and storms which negatively affect rice production areas with increasing frequency and severity as a result of climate change; ii) Socio-economic stability and poverty reduction in rural areas: SRI/SCI rice production methods lead to lower input cost while maintaining equal or higher yields and hence increased incomes for vulnerable smallholders; iii) Environmental co-benefits: SRI/SCI rice production methods have a range of other positive environmental impacts, including reduced water consumption and thus reduced methane emissions, reduced application of agro-chemicals and reduced air pollution as stubble is not burned.

Acknowledgments

This paper is developed from the literature review of official records documented by the Department of Plant Protection, Ministry of Agriculture and Rural Development of Viet Nam for the period of 2003-2015; and the outputs of the AgResults Viet Nam Emissions Reduction Challenge Project implemented in Thai Binh, Viet Nam during the period of 2016-2021.

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System of Rice Intensification National Network Bangladesh (SRINNB) Enhancement of Food Security and Climate Resilient Livelihood Opportunities for the Farming Community in Bangladesh - An Exploratory Study Report

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Abstract

The System of Rice Intensification (SRI) was initiated in Bangladesh in 1999-2000 when the government's Department of Agricultural Extension (DAE) and CARE-Bangladesh introduced SRI to a few groups of farmers in Kishoregonj. The average SRI yields in that first Boro season were 6.5-7.5 t/ha, which was around 20% higher than farmer practice. The SRI movement started in 2000 after Prof. Norman Uphoff visited Dhaka and spoke on the benefits of SRI to representatives of agricultural-related organisations and NGOs in the BRAC Head Office. The objectives of SRI NNB are to enhance crop intensification, production, and income for the farmers. The crop intensification initiative of SRI NNB followed the farmer participatory action (PAR) research approach for involving the farmers in undertaking field experiments, observation, analysis, and adoption processes to increase farm productivity and income. Though SRI practice was initiated about two decades ago in Bangladesh, it didn't expand much throughout the country. The farmer-to-farmer extension took place in localized proximity. Institutional management support and resource allocation are considered to be inevitable to expand the benefit of SRI among the farmers. It is expected that farmers might exercise the SRI principles in other crops as well. The recent emerging impact of climate change is to be addressed together with SRI practice and appropriate climate smart technologies in Bangladesh to improve food security of the poor and marginal farmers.

Keywords: Farmer participatory action, Climate smart, Food security, Marginal farmers, Learnings

Introduction

The Agriculture sector plays an important role in overall economic development of Bangladesh. This sector, provides employment about 41 percent of the labour force and provides 14.74 percent to the country's GDP Achieving the target of self-sufficiency in food is one of the avowed goals of the present Government. To attain this, the Government has placed highest importance on the overall development of the agriculture sector. To achieve this the Government has taken a number of steps. These include expansion of small irrigation facilities, reduction of water logging, production of improved quality and high-yielding varieties of seeds and their preservation and distribution. Food availability, access and utilization remain challenged considering Bangladesh's unique context and the emergence of issues such as climate change, food prices crises, food safety and nutrition concerns. There has been increase in rice production in Bangladesh over the last few decades, but catastrophic climate impact has been affecting production. With the highest consideration for the development of agriculture and the welfare of the farmers, the government is continuing its all-out efforts for the overall development of the agricultural sector in the light of Vision 2041, 8th Five-Year Plan (July 2020 - June 2025), National Agriculture Policy 2018, National Agricultural Extension Policy 2020, National Agricultural Mechanization Policy 2020, Master Plan for Agricultural Development in the South, Sustainable Development Goals, Delta Plan-2100 and other planning documents (Bangladesh Economic Review, 2022). The initiative and progress are somehow facing difficulties due to negative impact of climate change and rise in agricultural input costs.

The history of SRI in Bangladesh dates back to 1999-2000 when the Government's Department of Agricultural Extension (DAE) and CARE-Bangladesh introduced

SRI to farmers in Kishoregonj district. The average SRI yields in that first *Boro* season was 6.5-7.5 t/ha, which was around 20% higher than farmer practice. This yield performance was observed to be encouraging to the farmers to take forward the SRI practice and dissemination continued to spread in the surrounding areas. The SRI movement formally started in Bangladesh in 2000, when Prof. Norman Uphoff visited Bangladesh and a meeting was held in BRAC Head Office with representation of some government and NGO organisations. Initially, an SRI working group was formed which later on turned into a Steering Committee and started trials on SRI in small scales with the participation of some government and non-movement organisations. PETRRA-IRRI provided funds to conduct participatory action research on SRI in 2002 in different parts of Bangladesh for two years. Oxfam also funded SRI trials in its river Basin Programme in northern Bangladesh from 2005 for four consecutive *Boro* seasons.

The SRI National Network (SRI NNB) was formed in 2006 to further strengthen promotion and coordination of the SRI programme. It was constituted with representatives from NGOs, Department of Agricultural Extension (DAE) and the Bangladesh Agricultural University (BAU) to support implementation of rice intensification. The partner NGOs were supported in collaboration with BRAC and Padakhep to train up and promote the improved technologies among the farming communities. The expert team of SRI NNB imparted training and provided field follow up support to the farmers' groups in different parts of the country. The financial assistance received from CIIFAD (Cornell International Institute for Food and Agriculture Development), Cornell University was also very useful for the SRI NNB to take forward the SRI programme. Later on, RDA and ADRA joined the SRI NNB for promotion of SRI in Bangladesh.

Institutional arrangement of SRI initiatives in Bangladesh

As mentioned above, in January 2000, an SRI Working group was formed by representatives of different government agriculture related organisations and NGOs interested in SRI, in a meeting hosted by BRAC at its headquarters, where Prof. Norman Uphoff was present. Later, the group formed a Steering Committee, which was composed of BRRI, DAE, BRAC, CARE, and Syngenta Bangladesh Ltd. This brought together public sector, NGOs and other private sector development institutions. At a follow-up steering committee meeting, plans were made for a systematic two-year evaluation of SRI, which was funded by the PETRRA project managed by IRRI/ Bangladesh and financed by DFID. These studies have provided a thorough base of knowledge for understanding the advantages that SRI methods can provide.

The SRI Steering Committee started implementation of the River Basin Programme (RBP) of Oxfam in 2005. The project conducted SRI trials with the *char* dwellers in the northern part of the country during 2005-06 *Boro* season and continued for three consecutive *Boro* seasons. Each year, the results of the trials were encouraging as reflected by an increase in both area and farmer participation. Trials were also conducted during the fourth year with support from *Padakhep*, a partner NGO of Oxfam GB. SRI NNB provided training, monitoring and reporting support to the personnel of partner NGOs of Oxfam GB Bangladesh. SshRI cultivation guidelines (manual) and brochures have been printed adequately for distribution to the various organisations and farming communities.

The SRI Steering Committee, followed by the SRINNB organized a total of five national workshops during 2003 – 2010 where the participants from NGOs, DAE, BRRI, BAU and farmer leaders attended. The national workshops were graced by the agriculture minister and senior government officials. A number of papers were presented by researchers, extension specialists, and NGO officials. SRI farmers also narrated their experience. The workshop felt that a better understanding of the principles of SRI would be necessary to promote SRI methods in the country, and it was recommended, among other things, that an integrated and coordinated approach be followed involving farmers, researchers and extension workers (GO/NGO) in conducting SRI trials. It also recommended seeking donor assistance in undertaking SRI promotional activities. In 2012, a national dialogue was held at BRAC 'to review and evaluate the SRI trials and promotional activities in Bangladesh to find out impediments and scaling up promotion of SRI, and provide recommendations for promoting SRI in a co-ordinated manner' by BRAC and Bangladesh Rice Foundation. A follow up meeting was held at the Bangladesh Agricultural Research Council (BARC) where the recommendations of the dialogue were discussed and confirmed. One of the recommendations was that henceforth the participating organisations would provide their own fund in implementing their SRI programme and another recommendation was to seek fund from different sources. It was also resolved that SRI NNB would continue to monitor, evaluate and document the results of the partner organisations' SRI programme

All these SRI initiatives created awareness among the farming community to increase their farm productivity. Both government and NGOs have been working on crop intensification in an environmentally friendly manner. The recent impact of climate change has made the farming community, policy makers, extensionists to address the issue of salinity, excessive rainfall, early or late floods, cold effects and change in seasons with new initiatives.

Objectives of the new initiative

- Improve productivity and income of the rice farmers through intensification and integration of other cropping practices in an institutional approach.
- Conduct action research trials in the farmers' field to observe, learn and disseminate the findings among the farming community at local, regional and national level by the partner NGOs.
- Linkage and network development with the implementing partner organizations, research, academic institutions and relevant international agencies.
- Sharing of the results with the national and regional level policy makers, researcher and extensions agencies.

Methodology

The crop intensification initiative of SRI NNB followed farmer participatory action research approach (PAR) for involving the farmers to undertake field experiments, observation, analysis and adoption process to increase farm productivity and income. The farmers were organized into groups of around 25 members to plan, implement, observe and share findings with the community farmers, project staff and extension personnel. The key programme objectives were to enhance benefits from sustainable increases in productivity, increase benefits from improved and equitable access to markets, strengthened resilience and adaptive capacity, reduce gender disparity in access to and control of resources and decision making, improve policies and institution's role to directly contribute to build up farmers' capacity in participatory research.

Sharing of crop intensification initiative and technical capacity development

SRI NNB organized and conducted a number of workshop and training events for sensitizing the government and NGOs those are working with agricultural productions on the importance of rice intensification to improve productivity in a sustainable manner. DAE, BRAC, Padakhep, POSD, Uttaron, ADRA, SAFE and some other organizations participated in learning and implementation of system of rice intensification among the farming community (see annex-1). The extension staff of these various organizations received training prior to train and assist the farmers for implementing SRI in their field. Though initially the journey was not smooth, application of action research approach and demonstration process was observed to be useful in learning and evaluating the performance of the crop intensification initiative with the farmers in various parts of the country.

Learning topics of the initiative

The learning topics were selected considering the existing problems of crop production and availability of feasible technologies from research institutions. The following learning topics were covered during the crop intensification training held at various location of the programming areas. In this respect detailed schedule was prepared combining field practices in the training sessions.

- Importance and opportunities for system of rice intensification in various locations of programming area
- Improved cultivation practices of rice production – seedling raising, transplanting, fertilization, irrigation management, Insect-pests and diseases management and challenges
- Identification/characteristics quality seeds
- Good quality seeds with selection, processing, preservation, germination test, etc.)
- Sources/availability of quality seeds (markets, organizations, etc.)
- Farmer-led research design for winter and monsoon seasons.
- Regular monitoring and evaluation of the action research performance.

Design of the Participatory Action Research (PAR) on SRI with farmer groups

The design of the PAR for crop cultivation was done in a manner to follow participatory process with considerations to ensuring **ownership**, **partnership**, **equity** and **scaling**. After receiving the technical training from SRI NNB resource team and other relevant research and extension resource persons, the farmer groups designed PAR trials for their own field. The respective partner NGO provided intensive field follow-up to support the farmers where the SRI NNB resource team visited from time to time to observe and encourage the farmers.

The respective partner NGO personnel attended on the job training events with the farmer groups to learn the facilitation process of the PAR process. This learning event created an opportunity to physically participate to implement the experiments with the farmers. The initial sessions helped them to building their understanding and confidence level as how to facilitate the implementation of the experiments with the farmers. This farmer and field staff learning environment created a congenial atmosphere among the farming community.

The farmers were supported by on-the-job training for practically doing and learning by the SRI NNB and respective NGO field personnel. The direct participation of the staff in field trials setting and subsequent follow-up encouraged the farmers to undertake the initiative with much care and management.

Implementation of PAR on SRI with the farmer groups

The technical information was accommodated into PAR module format in order to make it participatory and subsequent facilitation in the farmer groups. The programme personnel and the farmers worked jointly in setting up the experiments in the field. The following learning topics were facilitated with the farmer groups.

The farmers received on-the-job training on system of rice intensification process from the respective partner NGO staff in the real field situation. The training included from seed-to-seed production technology of rice cultivation in SRI practice. They learned about how to grow seedling for SRI field and transplanting of tender age seedling of around 2 weeks old in the main field. Farmers generally transplant around 6 – 7 weeks old seedling during the winter season as it does not grow fast during this season. But transplanting of 2–3 weeks old seedling in the rice field was a big challenge due to change in their long tradition of practice. The rice farmers had to face criticism of other neighbouring farmers about the poor visibility of the tiny seedlings in the transplanted field. It was observed that some SRI farmers damaged the transplanted field and replanted with 7-8 weeks old seedlings. It was, however, a miracle to them when they saw emergence of many tillers with vigorous growth of plants after the 3rd week of transplanting in the SRI field. The farmers applied adequate amount of organic manure and along with the chemical fertilizer. The farmers were happy to see the growth of the SRI rice field better than their traditional field. Finally, they noticed higher grain yield and straw in the SRI field.

SRI practice in farmers' field: Farmers were cultivating rice in traditional methods since long but after experiencing higher yield and income, they have adopted this practice in their farming system following wider plant spacing, application of organic manure, using mechanical weeders, and AWD as means method of irrigation. The popularity of SRI is increasing rapidly among the farmers due to its higher production, better market price and also due to nutritive grains size, shiny color and more biomass production for the cattle. Farmers have adjusted the principles of SRI in their rice production practices.

3. Findings of SRI trials and demonstrations

PETRRA-IRRI project: Substantial increase in rice yield was found in the PETRRA-IRRI project. The trials were conducted in various locations in different districts by the partner organizations. The result was encouraging, as seen in **Table-1.**

Table-1: Yield (t/ha) status in SRI and farmer's practice by organisation, *Boro* 2002-03

Particulars	BRAC	POSD	SAFE	Syngenta
SRI method	8.3	6.8	7.7	7.1
Farmers existing method	5.8	5.6	6.5	5.0

Source: PETRRA-IRRI report 2004.

Oxfam GB Bangladesh: SRI trials were done in the River Basin Project areas of Oxfam during 2005-6 *Boro* season in three districts (Kurigram, Gaibandha and Lalmonirhat). Results showed average yield of SRI and non-SRI plots were 6.6 and 5.3 ton/ hectare. SRI plots had 25% higher yield. Profitability of SRI was also 78% higher. Trials continued for four consecutive *Boro* seasons showing better results.

BRAC: BRAC joined the SRI programme as a partner from the beginning of the SRI initiative. Initially, they started demonstration of SRI method with few farmers. Thereafter, they participated in PETRRA-IRRI funded SRI sub-project during 2002-2004 undertaken by the SRI steering committee as a partner organization. This also showed more benefits under the SRI method of rice production. SRI trial status revealed that SRI farmers received higher production (22%) and income (30%) more that the farmers' normal practice (**Table-2**).

Table-2: Comparative costs, returns and BCR under SRI and farmers' normal practice (2007)

Method of production	Yield / ha (kg/ha)	Gross revenue*/ ha (taka)	Total cost/ha (taka)	Gross margin/ha (taka/ha)	BCR
SRI	7483	93, 537.50	36, 038.13	57, 499.37	2.60
Normal practice	6134	76, 675	32, 730.38	43, 944.62	2.34

Source: BRAC SRI demonstration report 2007.

Under the Agriculture and Food Security Programme of BRAC, SRI demonstration project was undertaken in 12 districts of Bangladesh from northern and southern parts of the country. It was a 3-year programme during the dry season from 2013 to 2015. Mainly small and marginal farmers were organized into block production system. A total of 52 blocks were formed. In three years, a total of 6,693 farmers were brought under the SRI programme. Benchmark survey was conducted to select the interested farmers in SRI programme. A comparative study was conducted between SRI, non-SRI (BRRI recommended method) and farmer's practice. Both HYV and Hybrid rice varieties were used in the SRI programme. In 2013 BRRI-28 rice variety yielded 16% higher under SRI than non-SRI and 52% higher than farmer's practice. Hybrid rice *Shakti*-2 variety showed 5% higher yield in SRI practice over non-SRI and 17% over the farmer's practice. In 2014, Hybrid rice variety (*Sathi*), SRI yield was 7% higher than non-SRI and 29% higher than farmer's practice. In case of BRRI Dhan-28 SRI yield was 5% higher than non-SRI and 27% higher than under farmer's practice. In 2015, BRRI-28 yield under SRI 8% higher than non-SRI and 21% higher than in farmer practice. Hybrid *Sathi* SRI yield was found 11.5% higher than that of non-SRI and 20% higher than under farmer's practice.

Lastly, the Monash University of Australia, in collaboration with BRAC Research and Evaluation Division (RED), conducted an action research programme on SRI in a number of locations in Bangladesh to determine the effectiveness of SRI on yield and income of the farmers. The study found that the SRI results were positive for increasing yield and income of the participating farmers. Another significant result of the study was that farmer participation increased with increase of the intervention period.

SRI by Rural Development Academy (RDA), Bogura: Experiments were conducted at RDA demonstration farm during three crop seasons of 2012-13. In *Boro,* BRRI *dhan*

28 was used in both SRI and farmers' practices. In SRI technique, 14 days old seedlings were transplanted (single plant) and in farmers' practice 28 days old seedlings were transplanted in January, 2013 with spacing of 25 cm x 25 cm. In *Aus*, *Parijat* variety was used under both SRI and farmers' practices. In SRI technique, 14 days old seedlings were transplanted (single plant) and under farmers' practice 17–20 days old seedlings were transplanted during May-June, 2013 with spacing of 25 cm x 25 cm. In T. Aman, *BRRI Dhan 49* was used in both SRI and farmers' practices. In SRI technique, 14-day old seedlings were transplanted (single plant) and in farmer' practice 20 days old seedlings were transplanted on 28August, 2013 at the spacing of 25 cm x 25 cm.

Highest yield of 6.00 t/ha of *Boro* was obtained from the SRI trial plot against 4.86 t/ha under farmers' practices[2]. The yield was 25.92% higher in trial plots (SRI) compared to farmers' practices (**Table-3**). Higher gross return (TK 119,985/ha) and gross margin (Tk. 42,602/ha) were also recorded from SRI trial plots. Gross margin of SRI over farmers' practice was 24,511 Tk/ha.

Table-3: Yield and yield contributing characters of *Boro* under different management practices at RDA, Bogura during 2012-13

Treatment	Plant height	No. of effective tiller/ hill	Length of pani-cle (cm)	No. of grains/ panicle	1000 grains wt (g)	Grain yield (t/ha)	Straw yield (t/ha)	Yield increase over FP (t/ha	Yield increase over farmers practice (%)
Trial plot (SRI)	110.88	24.32	26.69	172.50	26.08	6.00	6.55	1.26	25.92
Farmers' practice	108.75	22.05	24.87	165.07	23.73	4.86	5.96		
t value	4.32	5.40	5.11	5.12	6.55	6.23	5.0		

Source: Report on Comparative Performance of SRI and Farmers' Practice During Boro, Aus and Aman Rice seasons 2012- 2013, RDA Bogura

Later on, RDA undertook a five-year project with larger coverage to introduce modern farming technologies in 200 sites in 40 districts for increasing rice and other crops, to increase irrigation water use efficiency, and improve the soil fertility through utilization of *Trichoderma* enhanced composting and improved mechanization, following SRI principles. The results were highly encouraging.

Currently, RDA has been implementing a two-year project (2022-2023) in five sub-districts of five districts with funding support and research collaboration of the National Graduate Institute for Policy Studies (GRIPS), Japan, to assess the impact of mechanized SRI in Bangladesh relative to conventional SRI and as well as standard rice management practice. SRI practice may expand faster if it is found feasible.

ADRA Bangladesh: ADRA Bangladesh has been implementing SRI in Bangladesh for about a decade in Mymensingh and Manikganj regions of the country to improve food security of the farming community in collaboration with Department of Agricultural Extension (DAE) of Ministry of Agriculture following Participatory Action Research (PAR) approach with the farming community

ADRA programme staff provided training to farmers and organize SRI demonstration in participation of the rice farmers. The farmers observed the method of demonstration in the field and the result was shared during crop harvest time with the community farmers. The farmers observed the yield performance of the SRI and control field. The higher yield of the SRI field encouraged the farmers for adoption of SRI method in their own field. The SRI plots were maintained with alternate wetting and drying irrigation water and used manual rotary weeders. The overall yield from the SRI field was around 25% higher than the control plots, whereas production cost almost same but the farmers opined that they might be able to reduce production cost due to use less irrigation and seedlings in the SRI field.

The farmers of Mymensingh area experimented SRI practice under ADRA WEP project and they found 25% in yield increase in the SRI fields compared to farmer practice (**Table-4**).

Table-4: Rice variety and yield per hectare from SRI demonstration plot during 2016 – 2017

Union	Village/Area	# of Farmer	Land Area	Rice Variety	Yield in MT/ Hector		Diff in MT
					SRI practice	Farmer practice	
Gouripur S	Bakerkanda	40	2.26	BRRI-Dhan-28	7.20	4.75	2.45
Bokainagor	Betendor	19	1.93	BRRI-Dhan-28	7.11	5.95	1.16
Bokainagor	Batta/Pathantola	22	1.94	BRRI-Dhan-28	6.95	6.00	0.95
Ochintapur	Dariapur/Chorakona	28	1.90	BRRI-Dhan-28	7.20	5.62	1.58
Gouripur S	Palandor	10	0.40	BRRI-Dhan-28	6.75	6.06	0.69
Ramgopalpur	Sreedor	15	0.75	BRRI-Dhan-28	6.86	5.20	1.66
Moilakanda	Surjokona	4	0.16	BRRI-Dhan-28	6.63	4.76	1.87
Total/Average		**138**	**9.34**		**6.96**	**5.48**	**1.48**

Source: WEP Gouripur, Mumensingh

Experimentation and adoption of climate smart Agriculture (CSA) approach

The farmers have been experiencing the negative impact of climate change for about a decade or so by facing early flood, excessive and untimed rainfall, heavy cold effects, etc. It is directly affecting their crop production and incurring yield loss. In this situation they started thinking of experimentation, evaluation and adaptation of CSA technologies for addressing the negative impact of climate change. The farmers started looking for options as how to integrate additional crops to creasing rice field productivity and income. SRI NNB supported the farmers to try with CSA technology in their rice field to increase production and income. The staff of partner NGOs were trained with the specific learning topics (see annex-2) to go for PAR and decide the effectiveness of the various technological options for the certain area's feasibility. The following sequence was followed while experimenting the technology in the field.

Integration of crop diversification initiative in the rice field

The objective of this initiative was to create an opportunity for the group farmers to learn on how to design and implement varietal trials with rice and vegetables (gourds, okra, red amaranth, Kangkon, etc.) to grow on plot dikes. The exercise allowed them to learn an ideal vegetable soil bed or pit preparation before sowing seed. The group farmers were explained the purpose of doing these experiments. The facilitator encouraged the farmers to follow proper plot preparation and seed sowing for the vegetables they already selected. This exercise helped the all the group participants to learn together for designing and conducting of action research of various vegetable during the different cropping season of the year to maximize cropping intensity and production. This initiative helped the farmers for learning and producing of different vegetables along with rice production.

The farmers organized learning sharing session to evaluate the performance in terms of yield and economic return. They mentioned to get enough for family consumption and making increased income for their family. A technical guideline was prepared and shared with the field personnel as how to implement the trial and demonstrations in the field

with the direct participation of the farmers. The initiative ensured famers participants in all steps of implementation process to develop ownership of the initiative among the farmers.

Dike cropping: Producing of various vegetable crops in the rice and other crop field dikes getting popularity for utilizing the space of rice field dikes. Farmers have been growing various suitable vegetable during the monsoon and winter season on the rice field dikes.

The productivity of rice field may be increased by intensification of feasible and economically viable cropping opportunities. A farm family will continue to receive higher rice yield through adoption of SRI practice and at the same time will harvest vegetable for family consumption also may generate income from the sale proceeds. Farmers experienced producing of creeper vegetables like gourd, beans, spinach and other vegetables that can be grown on some trellis support. They mentioned that the crop field dikes are enriched with nutrition for which they produce more. Farmers also mentioned that they can consume vegetable from the dikes round the year if planned properly.

Some farmers have little widened their dikes by taking land from inside their plot, which allowed more space for growing vegetable in profitable manner. Presently considering vegetable land scarcity in the homestead area or even interference of large trees, farmers found dike cropping as feasible option to produce vegetable in a successful manner. This type of vegetable production is climate smart technology that suits quite well to grow in the winter season without any bag or tower and during the rainy season it can easily withstand erosion in case of excessive rainfall or waterlogging for some time. Farmers found it useful for them as they can produce vegetables without interrupting the rice production in their field. This type of vegetable production technique is getting popularity for the farmers who can't grow vegetable properly in the homestead area due to shade of large trees or scarcity of land.

Vermi-compost: Vermi-compost was found to be very useful and an essential element for crop production among the farmers. Some farmers were trained to produce vermi-compost in a proper manner and make business out of it. The compost performance was measured with and without compost, where the farmers were impressed at the higher yield in the vermi-compost applied field. Now vermi-compost evolved as an agri-enterprise by the producers to make packets and selling to the farmers. Advertising strategy has been done in the farmers' field day and other social events to popularize vermi-composting for higher production. This environment friendly approach is getting remarkable acceptance among the farming community and growing up as an enterprise. A good number of farmers are now producing vermi-compost considering its high demand and reasonable market price for earning revenue.

Lessons learnt and innovations in SRI Bangladesh

Adjustments and modifications considering Bangladesh context:

- **Seedling age:** During the winter boro season, it was not possible to maintain seedling age below 15 days for transplantation due to its poor growth. The farmers have to wait for another week or more for seedling uprooting and transplantation.
- **Planting spacing:** Farmers in some cases made adjustment in plant spacing after seeing the results at different spacing conditions. This adjustment they made considering the soil fertility and duration of the rice variety.
- **Irrigation management:** The farmers take irrigation on seasonal contractual basis and accordingly they have tendency to take more water in the transplanted field due to the fear that if any mechanical problem of the pump machine arises, they may not get water during needs. Hence, it remained as a barrier to comply with the SRI principle but farmers have been realizing this issue and trying to address it.

Mechanization in SRI practice:

- RDA Bogura has been experimenting mechanized transplanter for transplanting single seedling method of rice production. The positive results of the findings might be promoted to reduce farmers' transplanting time.

SRI NNB Progress at institutional level and future plans

There has been progress at the institutional level to understand and take forward SRI initiatives with the Government and NGOs. Top-level officials of the Department of Agricultural Extension (DAE) are now supportive to promote SRI among the farmers throughout the country. There has been consensus in the national and regional level workshops to take forward SRI practice country-wide by combing the issues of climate change impacts. The future plan of SRI NNB is to address SRI and climate change impacts in a co-ordinated effort with the research and extension agencies with government and NGOs on the following aspects.

i. There is strong need to move forward to improve our rice production system. Since SRI has shown advantages in ensuring higher production and distinct cost economies, so we need to show its suitability to our farmers in Bangladesh.

ii. The appropriate strategies need to be identified and experimented in the different areas of the country to address the emerging problems that have been hindering crop production and farmers' livelihoods.

iii. GO-NGO collaboration should be strengthened to promote SRI in a right manner. We must all help farmers' organisations to adopt SRI in an appropriate way

iv. Collaboration to be strengthened with the research institutions to provide the appropriate technologies to the affected farming communities with consideration to their own agro-ecological and socio-economic conditions.

v. The group approach of irrigation management, use of mechanized seed transplanter and harvester would be considered to promote in the next SRI programmes.

vi. Training of farmers and field workers on SRI practice and technologies to address climate impacts should be provided in a planned manner to the implementing partners in collaboration with SRI NNB.

vii. SRI NNB will ensure training, monitoring and reporting support to the personnel of implementing partner NGOs for learning and practicing of SRI. In this respect necessary guidelines (manual) and brochures to be prepared and printed adequately for distribution to the various organisations and farming communities.

Conclusion

Though SRI practice was initiated about two decades ago in Bangladesh it did not expand much throughout the country. Farmers to farmers' extension took place in localized proximity. Institutional management support and resource allocation is inevitable to expand the benefits of SRI among the farmers. It is expected that farmers might exercise the SRI principles in other crops as well. A vibrant initiative with proper action research approach might expedite the learning and expansion of SRI practice among the farmers. The recent impact of climate change is an emerging concern among the farmers for adequate crop production due to change in temperature, rainfall, cold effect, salinity in the coastal region and flood prone areas (flash and seasonal). Participatory action learning opportunity combining the research institutions and extension agencies might yield better to support the farming communities to withstand the climate change negative impacts.

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Learnings from SRI Upscaling Experience in Bihar, Tripura and Odisha

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Abstract

Despite showing positive results over a decade by millions of farmers across India, System of Rice Intensification (SRI) and now called as System of Crop Intensification (SCI) has not received adequate appreciation through upscaling and investments policy. SRI however, was featured as an innovation to be up scaled in the 12th Five Year Plan. Recently, It has been considered as one of the technologies to increase the production under Niti Ayog's policy paper (2017) on doubling farmers income. The schemes like SAGY, NFSM, NRLM, etc. also promote SRI as one of the agriculture based livelihood enhancement techniques. Some of the states have been on forefront to adopt SRI in their government schemes and diverted the funds from existing schemes for SRI demonstration, promotions, training, upscaling, etc. The strategy in each state differs in the way civil societies, research institutes, academics, etc. played a role in promotion of SRI. Based on the differential approaches used by states, rainfed conditions and experience of promotion for almost a decade, three case study states, Bihar, Odisha and Tripura were chosen for this analysis. The learning from each state has been drawn to understand - factors instrumental in upscaling and success, reasons of de-adaptation and accordingly recommendation are drawn. .

Keywords: Policy analysis, System of Rice Intensification, Government schemes

Introduction

The rainfed and smallholder farmers are more vulnerable to climatic vagaries, low productivity and volatile markets putting the household food security at stake. Public interventions by way of capital investment, research, and extension in agriculture in India have largely been guided by the concerns of aggregate food sufficiency. But lack of appropriate policy interventions in the context of rainfed and smallholder farmers has affected the production system adversely. To address this complex crisis, agroecological innovations such as the System of Rice Intensification (SRI) has already shown great potential at being a climate-smart method to produce more grain, while reducing water, seed and agrochemical use and more useful for small and marginal farmers. Despite showing positive results over a decade by millions of farmers across India, SRI (now called as SCI) has not received adequate appreciation through upscaling and investments policy. SRI however, was featured as an innovation to be upscaled in the 12th Five Year Plan. It has also found its place, recently, in SAGY, NFSM, NRLM, Niti Ayog's policy paper on doubling farmers' income as one of the techniques to improve crop production. But adaptation under these schemes is to a limited scale particularly in the rainfed regions of the country. In this paper we try to understand the various drivers and hinderances to upscaling of SRI through government schemes. The cases of three states were studied to understand how SRI scaling up efforts were carried out in these sampled states in last decade.

Methodology

Based on literature review and discussions with local organizations, the three states – Tripura, Bihar and Odisha were chosen based on the criteria – (a) Agro-climatic zone (b) Rainfed area and social demographic profile (c) Who led the strategy (government, civil society organizations, academia, research institute etc.) (d) main schemes under which SCI/SRI was promoted (e) If differential strategies adopted by implementor. Tripura represents the case of scaling up of SRI through government-led efforts, Bihar represent the case of CSO-led efforts whereas in Odisha mainly research institutes and academia was instrumental in introducing SRI in the state.

Quantitative data collection

a) Secondary data collected from State wide MIS systems on year-wise budget, coverage, allocations for various components, etc.

b) CSO level data on expenditure, coverage, cost-benefit analysis etc.

Quantitative data collection

a) Desk review of policy documents, scholarly articles, case studies by CSO etc.

b) Structured and semi-structured interviews from Macro level (State level) to micro level (community) – 9 interviews from state level actors, 13 from district/block level and 9 interviews with community level workers

c) Focus group discussion in 8 village/communities

Key highlights of Results and finding

	Tripura	Bihar	Odisha
History	• Initiated in 2002-03 with 44 demonstration @0.2ha by SARI • 2008-09- area under SRI 50000 ha (250,000 farmers) • Initiated under State Perspective Plan (2001-10) to address food grain shortfall • Two pronged strategy - SRI and Hybrid rice	• 2002 PRADAN initiated, 2007 - PRADAN undertook 128 demonstrations under JEEVIKA • District, State level consultation, CM, Krishi Mantri got interested • 2009-10: 5 farmers per district under ATMA, • 2011 SRI year declaration by CM • 2011 PRAN constituted Climate-Resilient Agricultural Training Center	• XIMB, OUAT, DWM and CSOs initiated • State level dialogue in 2007, SRI learning alliance 2007 • RKVY, SRI village programme under RKVY in 2008-09, inclusion in BGREI • MKSP shaped by PRADAN
Strategy	• Extensive training of government officials during 2010-2014 • Farmers training, exposure, farmers' schools, community nurseries • Village level workers (VLW) & PRIs were backbone • Incentivizing farmers for demonstration, handholding till 3 years	• JEEVIKA - Trained VLRPs, SEWs (VLRPs as resource person to UP_NRLM l incentive based model) (women on forefront) • Handholding by CSOs (PRAN in 38 districts) • Other than Rice - introduction of machines for improving line sowing	• Initial years from 2007-2010, SRI demonstration promoted by incentivizing farmers • SRI Village in partnership with CSOs • Later Line transplanting was introduced and promoted largely and now DSR, stress tolerant variety • Extension system of existing RKVY/BGREI was instrumental • VAW and Krishi Sathi's played role of farmers' training etc
Major Schemes	• NFSM: 30% of budget is for demonstration under SRI, Rs. 9000/ha (include input cost like seed, fertilizer, IEC material) • RKVY: HYV, Hybrid seeds. • ATMA: Trainings • Farm mechanization : Seeders, weeders, Power weeders	• JEEVIKA-BRLSP programme of State Rural Livelihood Mission (2006-2017) Major investment on VLRPs and capacity building (40%) • RKVY plan 2011-17 (Rs. 1274 crore on SRI) & BGREI - Incentivize farmers Rs. 3000/acre for setting up demonstration.	• RKVY SRI village 3.23 lakhs per village (30 villages) (Total outlay of Rs. 100 lakhs, 1500 acres) • RKVY/BGREI (2010-11) - Rs. 1300/acr ~ Rs. 8.2 corers • BGREI only 3% of outlay under Crop Production system • NFSM (2016-18) Rs. 2.7 corers/ year

	Tripura	Bihar	Odisha
Coverage	• 2006-2014, % share of SRI area and production has increased from 7% to 41% • 2015-19: average 100,000 ha under SRI (out of average 270,000 ha area under Paddy) (35%) but trends are decreasing with 25% steep from 2015-16 to 2018-19 • Adaptation - Transplantation, spacing and weeding	• 2011-12 - SRI year with coverage of 3.5 lakh hectares • JEEVIKA - 250,214 (SRI), 272,317 (SWI) • RKVY/BGREI - 366,000 Ha total from 2011-19 (But more de-adaptation in RKVY/BGREI • Adaptation - Spacing, Weeding. Now more focus is on DSR)	• RKVY 2007-08 - 1557 acres, SRI village 2008-09 - 1500 acres • RKVY/BGREI - 2010-11~18000 ha • BGREI (LT) 2015-16 ~ 100,000 ha • NFMS (2016-2018) ~ 3000 ha per year • Adaptation-Line transplantation takes over the SRI after 2011-12.

Conclusion

Policy and Practice changes

(a) Investment on Community based para-workers like in case of extension support system in the form of VLW (Tripura) and VLRP (JEEVIKA-BRLSP)

(b) Investment on capacity building programme – creation of knowledge extension system, extensive training of government officials (as in case of Tripura), Training of VLW (as in case of Tripura) and VLRPs (as in case of Bihar), extensive training of farmers through VLRPs, etc.

Research

(a) Revisit package of practices, typology specific changes, and improved SRI adaptation, consideration for farmer’s adaptability

(b) Farm mechanization as per the suitability of economic condition of farmers, local conditions, soil parameter, water parameter, etc. need to be developed.

Policy vision

(a) SCI works for small and marginal farmers who have family labour to invest and are not migrating (seasonally) from the region.

(b) It is very important that the lessons learnt from farmers’ field, farmers’ innovation coupled with scientific support, systemic changes at several levels of policy implementation and community-based extension/ knowledge system has to be incorporated into the new vision for policies. There is a sufficient knowledge and empirical evidence to rework the strategy of SRI/SCI promotion. The policy adaptation of SRI/SCI requires considerable change in extension systems and approaches deviating from target driven strategies.

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Scaling Up the System of Rice Intensification in 13 West African Countries

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Abstract

RICOWAS, the largest SRI scaling-up project to date, will be implemented over four years in 13 West African countries, starting in January 2023. RICOWAS can be considered a follow-on project to the SRI-WAAPP project, which was implemented from 2014-2016 and reached 50,048 farmers growing rice using the SRI method at 1,088 sites on 13,944 hectares across 13 countries, with 56% and 86% SRI yield increases for irrigated and rainfed lowland systems, respectively, over conventional rice production. The objective of RICOWAS is to improve climate resilience and increase the rice system productivity of smallholder rice farmers across West Africa using a climate-resilient rice production approach. The project aims to reach at least 153,000 rice growers with indirect benefits to an estimated 1.5 million people. Given the highly diverse nature of rice systems and climate zones in West Africa, RICOWAS will apply the conceptual framework for SRI with four interactive crop production principles, i) encourage early and healthy plant establishment, ii) minimize competition among plants, iii) build up fertile soils rich with organic matter and beneficial soil biota, and iv) manage water carefully to avoid both flooding and water stress. These principles remain the same no matter where SRI is applied and provide the foundation for adaptation to local conditions. With SRI at the center, RICOWAS additionally integrates agro-ecozone specific Sustainable Land and Water Management (SLWM) practices to maximize the adaptation potential of the vulnerable rice production systems throughout West Africa, calling the new approach Climate-Resilient Rice Production (CRRP).

Keywords: Sustainable Land and Water Management (SLWM), agroecology, climate-resilience, regenerative agriculture

Background of SRI in West Africa

In 2010, West Africa produced 7.9 million tons of milled rice and imported an additional 5.7 million tons to satisfy demand. The ECOWAS Rice Commission estimates that by 2025 yearly rice consumption in West Africa will increase to 24 million tons (value of 12 billion USD), triple the 2010 production. The ECOWAS States – through their “Rice Offensive,” supported by the National Rice Development Strategies – target self-sufficiency in rice production by 2025 (ECOWAS, 2012; Fofana *et al.,* 2014). Key risks for rice production in West Africa stem from increasing climate variability with exacerbated dry spells, droughts, and heatwaves, as well as greater likelihoods of floods, shortage of irrigation water, strong winds and storms, and changes in pest and disease pressures – all of which can lead to substantial rice yield reductions or crop failure (Riede *et al.,* 2016; Sultan & Gaetani, 2016; Sylla *et al.,* 2016).

The System of Rice Intensification (SRI), an agro-ecological, climate-smart and low-input methodology for increasing rice productivity, can play a crucial role in closing the rice production gap in West Africa. Developed in Madagascar and practiced today in more than 60 countries, the SRI methodology allows increased yields, often by 50% or more, while using 90% less seed, 30-50% less water, and decreased amounts of agro-chemicals (Styger & Uphoff, 2016). SRI trials in West Africa began in 2000. Larger-scale expansion occurred first in Mali, starting in 2007. Between 2010-2012, Mali SRI practitioners provided technical training to their peers in Benin, Burkina Faso, Ghana, Nigeria, Senegal and Togo. By 2012, an estimated 2500 farmers practiced SRI in ten countries of West Africa.

Given the growing interest in SRI across the region, the regional project **"Improving and Scaling up the System of Rice Intensification in West Africa"** (SRI-WAAPP) was commissioned and supervised by the West and Central African Council for Agricultural Research and Development (CORAF) as part of the West Africa Agriculture Productivity Program (WAAPP), supported by the World Bank under the institutional umbrella of the Economic Community of West African States (ECOWAS). The project was coordinated by the National Center of Specialization on Rice, Institute of Rural Economy (CNS-RIZ/IER), Mali, and the SRI-Rice Center, Cornell University, USA. The SRI-WAAPP project ran from 2014 to 2016 in Benin, Burkina Faso, Côte d'Ivoire, The Gambia, Ghana, Guinea, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo (Styger & Traore, 2018). By the end of the project, 50,048 farmers – of whom 33% were women – grew rice using the SRI method at 1,088 sites on 13,944 hectares across the 13 countries. The project trained 33,514 people, mostly farmers, including 1032 technicians. The number of institutions working with SRI increased from 49 to 215. The average SRI yield for irrigated rice was 6.6 t/ha compared to 4.23 t/ha for conventional rice (N=292 sites), a 56% increase. For rainfed lowland systems, SRI yields averaged 4.71 t/ha, compared to 2.53 t/ha for conventional rice (N=441), an 86% increase. The estimated total additional quantity of rice produced with SRI at the SRI-WAAPP sites compared to conventional rice during the 2015/2016 growing season alone was 31,458 tons of paddy, or 20,113 tons of milled rice, representing a value of 10.07 million USD dollars (Styger &Traore, 2018).

The RICOWAS project

The RICOWAS project was designed to build on the achievements of the SRI-WAAPP project. RICOWAS will be the largest SRI scaling-up project to date, implemented over four years from 2023-2027 in the same 13 West African countries as SRI-WAAPP. Funded by the Adaptation Fund (AF), the Sahara and Sahel Observatory (OSS) will oversee overall project implementation. CNS-RIZ/IER in Mali will provide regional technical coordination in partnership with the Climate-Resilient Farming Systems program at Cornell University. At the country level, national research and extension institutions will be in charge of project execution in collaboration with NGOs and farmer organizations, and with technical and scientific partners from the public, private, and civil society sectors (Sahara and Sahel Observatory, 2021). The objective of RICOWAS is 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 reach at least 153,000 rice growers and indirectly benefit 1.5 million people. Figure 1 shows the RICOWAS project intervention zones in the 13 countries.

Figure 1: RICOWAS project intervention zones of the 13 participating countries.

Regional SRI scaling-up approach developed by the RICOWAS project

Rice production systems in West Africa range from rainfed upland (43% of rice area) and rainfed lowland (40% of rice area) to irrigated systems (17% of rice area), and to the lesser-known mangrove, deep-water, and recession rice systems (5% of rice area). Rice is planted in all climate zones, from the arid desert climates in northern Senegal, northern Mali, and Niger to rainforest regions in Liberia, Guinea, and Sierra Leone (Diagne *et al*., 2013). Given the highly diverse nature of rice systems and climate zones in West Africa, it is important that all stakeholders share the same understanding of SRI. During the SRI-WAAPP project, a new conceptual and operational framework for SRI was implemented for the first time (Styger, 2017). The same framework will also be used by the RICOWAS project. How the conceptual framework is applied to different rice systems, as well as to other crops, is illustrated in Figure 2.

The conceptual framework identifies **four interactive SRI principles** that define the SRI methodology. They are i) encourage early and healthy plant establishment, ii) minimize competition among plants, iii) build up fertile soils rich with organic matter and beneficial soil biota, iv) manage water carefully to avoid both flooding and water stress. These principles remain the same no matter where SRI is applied and provide the foundation for the practices that are adapted to local conditions. SRI was originally developed for irrigated rice. But when farmers understood the synergies created when applying the SRI principles together, they continued to adapt cropping practices to local conditions. The SRI practices can therefore vary for different i) rice systems (rainfed lowland, rainfed upland, irrigated systems, mangrove systems, recession systems), ii) agro-ecozones and climate zones, as well as iii) for other crops, especially monocotyledons with good tillering potential.

Expanding the SRI method with the Climate-Resilient Rice Production approach

The RICOWAS project adopts a new comprehensive approach, entitled **Climate-Resilient Rice Production (CRRP)**. CRRP is based on the SRI methodology in combination with location-specific Sustainable Land and Water Management (SLWM) practices, and if indicated with Integrated Pest (and disease) Management (IPM). CRRP is used as an adaptation measure to different and location-specific climate threats. The approach recognizes that the foundation of climate-resilient rice systems lies in integrated soil and water management, keeping soils structurally intact and regenerating them with organic matter, both keys to developing healthy soils. Storing water within a plot and at the landscape level, and being able to add or remove water from rice fields as needed, are key to developing sustainable water management approaches (Sahara and Sahel Observatory, 2021).

Findings from the locally adapted practices implemented in the 13 countries will be pooled, and best practices synthesized for the different climate zones and rice systems. Using an iterative and circular approach, these best practices can be improved and fine-tuned over the life of the project. This highly participatory process integrates inputs from farmers, researchers, and technicians, and will also draw on successful ideas and experiences from other parts of the world. The RICOWAS project will use a modular approach for trainings and technical manuals, covering CRRP topics as adapted to different climate zones and rice systems. This approach allows a common understanding of CRRP at the regional level while developing and adapting innovations at the local level. The project will also provide access to tools and equipment that support the adoption of SRI and SLWM. The project will build on current institutions, strengthening their institutional and human capacities according to opportunities and needs. It will also rely on national decision-making and leadership in the implementation of the project. CRRP champions – including farmers and technicians – will be encouraged to participate in the project, based on their engagement and commitment to CRRP. RICOWAS will promote national networks and build on the regional community of practice for CRRP that started under the SRI-WAAPP project. (Sahara and Sahel Observatory, 2021)

Adopting a climate zone and regional approach

Each of the four climate zones of West Africa crosses between five and ten of the 13 countries, and most countries are spread across more than one climate zone as shown in Figure 3 (CILSS, 2016). A regional and climate zone approach for scaling-up climate-resilient rice production has multiple advantages: i) a larger group of

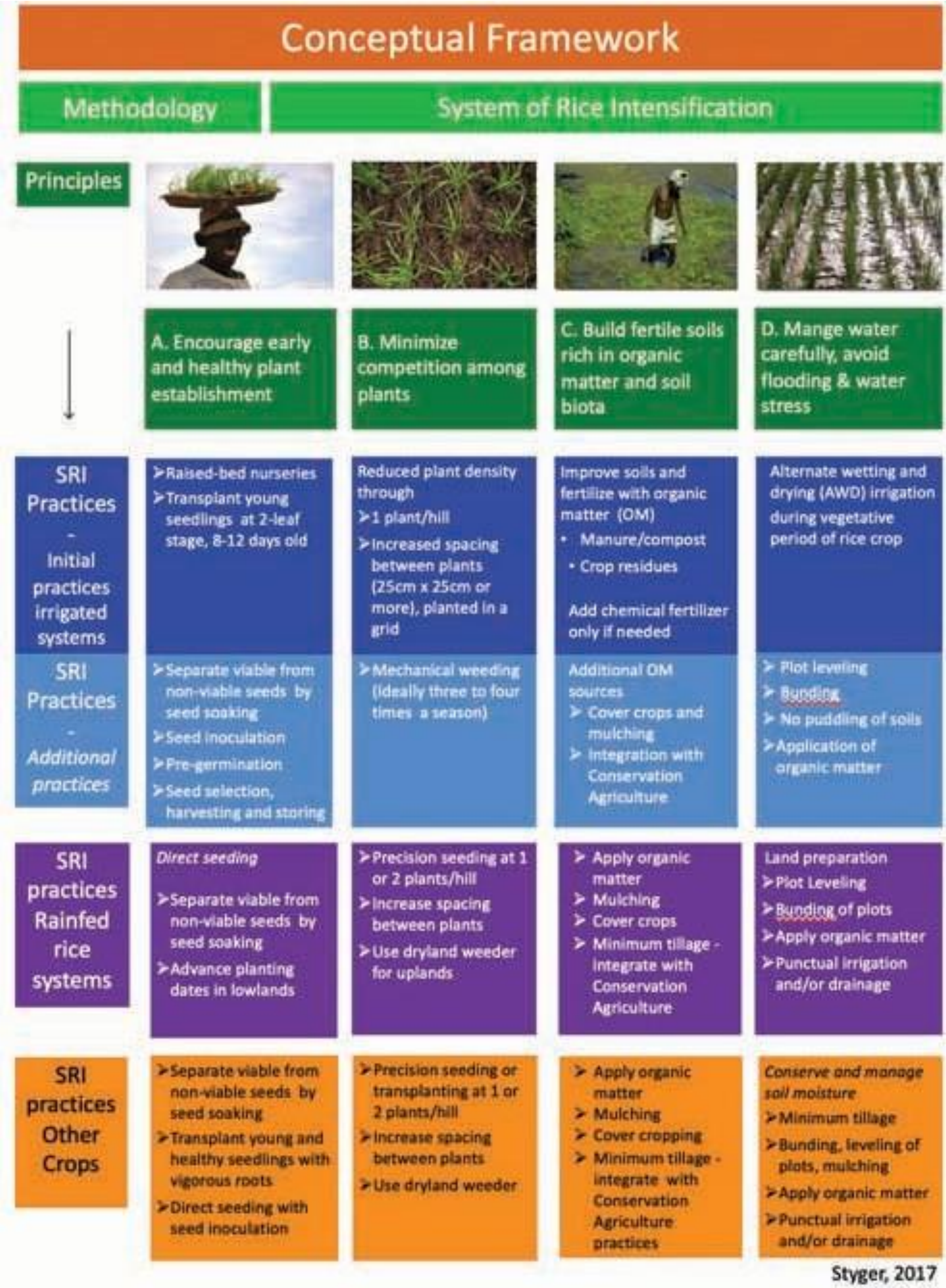

Figure 2: Operational conceptual framework for the System of Rice Intensification (SRI) and the System of Crop Intensification (SCI) (Styger, 2017)

people from several countries can collaborate on the same topics, ii) the innovation process can be accelerated, and iii) locally adapted innovations developed in one country can easily be shared with other countries working in the same climate zone and/or rice systems. The map of the project zones (Figure 1) clearly depicts how smaller project zones at the border of one country can fuse into larger zones when combined with the border zones of their neighboring countries.

Figure 3: Bioclimatic regions of West Africa (CILSS, 2016)

Conclusions

The RICOWAS will be the largest SRI scaling-up project to date, implemented in 13 West African countries. Given the highly diverse rice systems, the RICOWAS project will build its technical approach on i) a simple conceptual framework with four SRI principles that provide guidance on adapting cropping practices to local conditions, and on ii) expanding the implementation approach beyond SRI by integrating principles and practices from other agro-ecological approaches, summarized in the Sustainable Land and Water Management approach. By doing so, the project harmonizes the operational approach, as everyone shares the same understanding. It also facilitates data collection, comparisons, and learning across rice systems and climate zones. Most importantly, RICOWAS will favor the implementation of location-specific soil regenerating and agroecological practices and will facilitate effective innovation development with a focus on rice productivity increase and climate adaptation. The implementation approach developed by RICOWAS might also serve as a model for other SRI scaling-up projects in other parts of the world.

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Theme II

Breeding Cultivars, Land Races, Ideotypes, Management Practices, Pest and Disease Dynamics of SCI

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Breeding and Deploying Multiple Stress-Tolerant Maize Varieties in the Tropics

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Abstract

Maize is the key crop for food, feed, and nutritional security of millions of smallholder farmers and consumers in the developing world, especially in sub-Saharan Africa (SSA), Asia, and Latin America. CIMMYT and partners have adopted innovative approaches over the last one decade to develop, evaluate, and deliver elite stress-resilient and nutritionally enriched maize varieties with relevant client-preferred traits, especially in the stress-prone tropics. Effective integration of modern breeding tools/strategies, including high-throughput and precision phenotyping, doubled haploid (DH) technology, and genomics-assisted breeding, are integral part of these efforts leading to impressive genetic gains, while enhancing the pace, precision, and efficiency of breeding pipelines. Through extensive public-private partnerships, CGIAR-derived climate-resilient and multiple stress-tolerant improved maize varieties are being deployed in over 13 countries in SSA, four countries in South Asia, and several countries across Latin America. Certified seed production of CGIAR-derived improved stress-tolerant maize varieties was estimated to cover approximately 7.2 million hectares in SSA in 2022, reaching an estimated 7.2 million households, and benefitting ~44 million people. In the past five years, a total 20 high-yielding drought + heat stress-tolerant maize hybrids were released in South Asia, including four new hybrids in 2022 – BWMRI-2 in Bangladesh; Rampur Hybrid-12 in Nepal; and IMH-222 and IMH-223 in India. In collaboration with seed company partners, certified seed production of climate-resilient maize hybrids scaled-up from a baseline of just 70 MT in 2018-19 to 1026 MT in 2021-22, and deployed in about 50,000 hectares in various stress-vulnerable targeted ecologies in Bangladesh, India, Nepal and Pakistan, reaching ~128,200 farm families. Experiences of CIMMYT strongly indicate that besides strengthening the seed sector, adoption of progressive seed laws and regulations, are vital for improving smallholder farmers' access to climate-resilient improved seed. Policy support and institutional innovations are also required for overcoming key bottlenecks affecting maize seed value chain.

Keywords: Climate resilience, Multiple Stress, Maize, Tropics, Variety, Modern tools

Introduction

Achieving sustainable food and nutritional security, i.e., the basic right of the people to produce and/or purchase the nutritionally balanced food they need, without harming the social and biophysical environment, has to be the funademental goal of any nation. Over the last seven decades, India made immense progress towards food security of the population. Since 1950, the population almost tripled, but food grain production had more than quadrupled. India is now among the largest producers of rice, wheat, pulses, fruits, vegetables, milk, cotton, horticultural crops, dairy and poultry, aquaculture, and spices. Agricultural production in India is valued at US$ 401 billion in 2017, which is more than that of the USA (US$ 279 billion).

Despite this impressive progress, there is no scope for complacency. It is estimated that by 2030, India's population would be 1.52 billion; by 2050, it would be approximately 1.7 billion, which will be the highest in the world and about 400 million more than China, the most populous nation today (Singh, 2019). By 2050, India needs to step up production of all agricultural commodities by around 30 per cent in food grains and to more than 300 percent in vegetable oils to meet the needs of increased population and rising living standards (Singh, 2019). Also, by 2050, to meet the diverse demands of the population, it has been estimated that land productivity has to be increased by 4 times, water productivity by 3 times, and labour productivity by 6 times (Chand, 2012). All this has to be achieved in the context of changing climates, more fargile natural resources, and by staying within the planetary boundaries i.e., without major environmental and ecological footprints.

Climate change is for real, and certainly not fiction, as is unfortunately still believed by some in the world! The negative impacts of frequently occuring climatic extremes/ variabilities on agricultural production are most often felt by the resource-constrained smallholders in the tropics, be it in Africa, Asia or Latin America. Abiotic stresses, especially drought, heat, flooding/waterlogging, soil acidity, and combinations of various abiotic stresses have a huge negative impact on the rainfed crop yields. For instance, in South and South East Asia, more than 80 percent of the maize-growing area is rainfed and prone to various climatic extremes/variabilities. While we tend to focus mostly on abiotic stresses in the context of climate change, it is equally important to consider the changing spectrum of pathogens and insect-pests, due to increase in temperature (Deutsch *et al.,* 2018; IPPC Secretariat, 2021; Skendžic *et al.,* 2021).

Building climate resilience in the smallholder farming systems, therefore, requires implementation of an intenisve multi-disciplinary and multi-institutional strategy. This should include extensive awareness creation and widespread adoption of climate-resilient crop varieties and climate-smart agronomic management practices, strengthening of local capacities, and much stronger focus on sustainability. An array of agricultural production technologies and practices, including stress-tolerant improved crop varieties, conservation agriculture practices, and agroforestry systems, that aim to mitigate climate-induced risks and foster resilience have been developed through national and international AR4D initiatives over the past two decades. In addition, institutional interventions that seek to mitigate risk and build resilience through other mechanisms could play a complementary role to climate-smart agricultural production technologies/practices (Hansen *et al.,* 2019).

Breeding Multiple Stress-tolerant Improved Maize Varieties for the Tropics

The International Maize and Wheat Improvement Center (CIMMYT) and partners in Africa, Latin America and Asia are intensively engaged in developing and deploying climate-resilient improved maize varieties adapted to the tropics (Cairns and Prasanna, 2018; Prasanna *et al.,* 2021; Chivasa *et al.,* 2021). CIMMYT has used two major approaches for developing sources of abiotic stress tolerance that have been widely used in maize breeding programs in SSA, Asia and Latin America. The first was constitution of drought-tolerant populations for undertaking recurrent selections and derivation of elite inbred lines. The DTP-Y, DTP-W, and La Posta Sequia are examples of such populations. The second approach was full-sib recurrent selection under managed drought stress within elite populations to increase the frequency of drought tolerance alleles in germplasm already adapted to the lowland tropics (e.g., Edmeades *et al.,* 1999; Prasanna *et al.,* 2021a). Both approaches have generated several inbred lines that have become important sources of drought and heat tolerance in maize, especially in the tropics (Cairns *et al.,* 2012). Thus, population formation and improvement have resulted in an increase in the frequency of drought-adaptive alleles and identification of superior sources of drought tolerance (Edmeades *et al.,* 2017).

Besides constitution of appropriate maize populations for implementing recurrent section for improving drought stress tolerance, CIMMYT also has established an extensive phenotyping network for maize breeding in the tropics along with managed stress screening protocols (Prasanna *et al.,* 2021a); identified and used suitable secondary traits (e.g., anthesis-silking interval or ASI); and implemented focused breeding programs to continuously develop products (inbred lines, improved OPVs, and hybrids) that can perform well under both optimal and stressed environments (Cairns and Prasanna, 2018; Prasanna *et al.,* 2021a). CIMMYT's maize product advancement process typically includes not only regional on-station trials of promising pre-commercial hybrids coming out of the breeding pipeline vis-à-vis internal genetic gain checks and commercial checks but also extensive regional on-farm varietal trials to ascertain the performance of the promising pre-commercial hybrids under farmer-managed conditions. This also provides opportunity for the socioeconomics team to assess farmers' product as well as their trait preferences. The best entries coming out of this rigorous process are then announced on the CIMMYT website, and further allocated to interested public/private sector partners for varietal registration, scale-up, and delivery in the target geographies.

Accelerating Improved Varietal Development using Modern Tools/Technologies

CIMMYT-Maize Teams in Africa, Asia and Latin America use an array of modern tools/technologies for accelerating improved varietal development and for increasing genetic gain for grain yield in stress-prone tropical environments (Prasanna *et al.,* 2021a). These tools include the doubled haploid (DH) technology (Prasanna *et al.,* 2012; Chaikam *et al.,* 2019), low-cost and high-throughput phenotyping using proximal and remote sensors (e.g., Makanza *et al.,* 2018a,b), genomics-assisted breeding (e.g., Nair *et al.,* 2018), and breeding information management system, including decision-making tools. With the rapid reduction in genotyping costs, new genomic selection technologies have become available in several crops that allow the crop breeding cycle to be greatly reduced, facilitating inclusion of information on genetic effects for multiple stresses in selection decisions (Xu *et al.,* 2017).

Through dedicated maize DH facilities in Kenya and Mexico, CIMMYT Global Maize Program produces annually over 100,000 DH lines (up from less than 5000 in 2011) and selects the best out of these lines in breeding pipelines. CIMMYT team has also developed and deployed superior second-generation haploid inducers for tropics using marker-assisted breeding (Chaikam *et al.,* 2018). In December 2021, CIMMYT has established a Maize Doubled Haploid Facility at ARS-Kunigal in Karnataka, India, in partnership with UAS-Bangalore. This facility will provide DH development service not only to CIMMYT maize breeders, but also to those from the NARS and small- and medium-enterprise (SME) seed companies in South Asia.

Deploying Climate-resilient Maize Varieties in the Tropics

An array of elite maize varieties with drought tolerance, disease resistance and other farmer-preferred traits have been developed by CIMMYT and deployed by seed companies across sub-Saharan Africa (SSA), Asia and Latin America. Between 2007 and 2021, CIMMYT and partners in SSA released more than 300 climate-resilient maize varieties in 13 African countries. In 2021, more than 171,000 tons of certified seed of CGIAR-dericed multiple stress-tolerant maize varieties were produced and commercialized by over 100 small- and medium-enterprise seed company partners across SSA, covering an estimated 7.2 million hectares, and benefiting about 7 million farm households.

Tesfaye *et al.,* (2017, 2018) highlighted the potential benefits of incorporating drought, heat and combined drought and heat tolerance into improved maize varieties in the climate-vulnerable tropical environments. Asia is now beginning to emulate the success story from Africa in terms of extensive deployment of drought-tolerant and drought + Heat-tolerant improved maize varieties through intensive public-private partnerships. Through the USAID-funded Heat Tolerant Maize for Asia (HTMA) project, a large heat-stress phenotyping network, comprising 23 sites in four Asian countries (India, Bangladesh, Nepal and Pakistan) has been established. Several CIMMYT-derived drought-tolerant and heat-tolerant CIMMYT-derived elite maize varieties have been released during 2016-2018 through public and private sector partners in South Asia, and several more are in pipeline.

For new climate-resilient crop varieties to contribute towards smallholders' adaptation to climate variability, it is important to further strengthen the seed systems. Delivering low-cost improved seed to smallholder farmers with limited purchasing capacity and market access requires stronger public-private partnerships, and enhanced support to the committed local seed companies, especially in terms of information on access to new products, adequate and reliable supplies of early-generation (breeder and foundation) seed, and training on quality seed production, quality assurance/quality control (QA/QC), and seed business management. Proactive management of product life cycles by seed companies benefits both the farmers and businesses alike, contributing to improved food security and adaptation to the changing climate (Chivasa *et al.,* 2021).

Protecting Agri-food Systems from Devastating Pathogens and Insect-Pests

Pathogens and insect-pests have severe and cross-cutting negative impacts, particularly affecting farmers' incomes, and livelihoods. Their capacity to rapidly evolve and proliferate pose a huge challenge. There is a significant need for implementation of development and implementation of multi-disciplinary, multi-institutional, and sustainable strategies for devastating crop diseases and pests, to counter the threat to food and nutritional security, and the livelihoods of populations (Prasanna *et al.,* 2022b).

Two most recent examples of transboundary pests/pathogens severely affecting maize smallholders are the maize lethal necrosis (MLN) in Africa, and the fall armyworm (*Spodoptera frugiperda*) in Africa and Asia. MLN is a complex viral disease, emerging as a serious threat to maize production and the livelihoods of smallholders in eastern Africa since 2011, primarily due to the introduction of maize chlorotic mottle virus (MCMV). CIMMYT, in close partnership with national and international partners, implemented a multi-disciplinary and multi-institutional strategy to curb the spread of MLN in sub-Saharan Africa, and mitigate the impact of the disease (Prasanna *et al.,* 2020; Prasanna, 2021).

Fall armyworm (FAW) has been prevalent in the Americas for several decades but was reported for the first time in West Africa in 2016. Within two years, FAW incidence had already been reported in more than 40 countries across Africa, and over 15 countries across the Asia-Pacific (Prasanna *et al.,* 2021b). The pest was reported for the first time in India in mid-2018, and subsequently reported in several other Asian countries. FAW attacks primarily the maize crop and has potential to feed on more than 80 other crops, including sorghum and sugarcane. Indiscriminate and unguided use of toxic synthetic pesticides is reported across Africa and Asia for FAW control, which poses serious threat to environment, animal and human health, besides affecting the natural enemies of the pest. Therefore, it is extremely important to develop, test, and urgently deploy science-based, integrated pest management (IPM) technologies/management practices, including host plant resistance (both native genetic resistance and transgene-based resistance) to FAW (Prasanna *et al.,* 2022), environmentally safer synthetic pesticides, biopesticides and botanicals, besides low-cost cultural control and agro-ecological approaches (Prasanna *et al.,* 2018, 2021b). A set of three first-generation FAW-tolerant CIMMYT maize hybrids have been announced in 2021 for Africa (https://maize.org/cimmyt-announces-fall-armyworm-tolerant-elite-maize-hybrids-for-africa/). South Sudan and Zambia have recently released these three hybrids, while several more countries are expected to release the FAW-tolerant maize hybrids in 2022-2023. Breeding for native genetic resistance to FAW has also been initiated by CIMMYT and partners in South Asia.

Conclusions

We need to collectively address an array of challenges, including adaptation to the changing climates, alleviating extensive malnutrition, improving soil health, and protecting agrifood systems from devastating diseases and insect-pests. Intensive multi-institutional and multi-disciplinary efforts are required to cocreate and deploy innovative and sustainable technologies that can improve crop productivity, reduce production costs, and improve the incomes and livelihoods of smallholder farmers. Building climate resilience warrants effective integration of climate-resilient crop varieties, climate-smart agronomic management practices, and effective implementation of policies to help reduce environmental and ecological footprints of agricultural practices.

Scientific institutions must enhance the the pace, precision and efficiency of breeding programs through judicious and effective integration of modern tools/strategies, including high-density genotyping, high throughput and precision phenotyping, speed breeding, molecular marker-assisted and genomic selection-based breeding, and knowledge-led decision-support systems. Seed systems need to be further strengthened to become more market-oriented and dynamic, and for providing smallholders with greater access to affordable climate-resilient and nutritionally enriched improved seed. Understanding the smallholder farmers' constraints for adoption of modern technologies, enhancing affordability and access to quality agricultural inputs, and improving their linkages to the input and output markets should be accorded top priority.

Technologically, we are living in exciting times. Genomics-assisted breeding, genome editing, speed breeding, remote sensors, satellite imagery, drones, artificial intelligence, machine learning, decision support tools, and information and communication technologies, are only a few of the innovations that one can mention that are impacting various spheres of life, including agriculture. Breeding programs should be constantly appraised and revised by incorporating new innovations. Furthermore, the efficiency and effectiveness of the breeding programs should be monitored by employing metrics designed to measure the impacts of breeding outcomes (= improved varieties) on the ultimate users – the farmers.

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ANGRAU's Contribution to the State and National Rice Baskets

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Abstract

ANGRAU is a pioneer in rice research in India. It has the credit of releasing 123 rice varieties in 58 years of its inception which include 91 HYVs, 30 pure line varieties and 2 hybrids. ANGRAU has the credit of developing first BPH tolerant rice variety MTU 5249 (Vajram) way back in 1986. Developed two rice hybrids for first time in the country in 1993 – APHR1 and APHR 2. Out of 45 mha of rice area in India, ANGRAU rice varieties occupy 14 mha of area, producing 38 mt of production accounting for 33.15% of total rice production in India. By cultivating ANGRAU rice varieties, a revenue of Rs 62317 crores is generated annually in the form of returns accounting for 2.22 percent of India's Agricultural GVA.

Keywords: Rice Varieties, MTU, APHR1, APHR2, Popular, Breeder seed

Introduction

Acharya N.G. Ranga Agricultural University (ANGRAU), Guntur, Andhra Pradesh has been serving and catering to the needs of farmers across the country and the state. In the last 58 years of its existence, it has the credit of developing 123 rice varieties, released at the state and national level, including 30 pure line selections in the pre-green revolution era, 91 high yielding rice varieties and two hybrids by different rice research stations located at Maruteru, Nellore, Bapatla, Ragolu, Nandyal and Machilipatnam through crop improvement programs (**Figure 1**). ANGRAU also has the credit of development and release of the first Brown Plant Hopper resistant variety, Vajram in 1986 in the Country. It was also the first to develop and release rice hybrids in the country, in 1993, namely, APHR-1 and APHR-2.

In 2022, ANGRAU has released four rice varieties through Central Variety Release Committee (CVRC) and three rice varieties through the State Variety Release Committee (SVRC). The CVRC varieties, namely MTU Rice 1273 and MTU Rice 1293 are short duration introgressed lines of the Mega Rice Variety, MTU 1010 of 115-120 days' duration with non-shattering nature and tolerance for BPH and blast. MTU 1293 is also tolerant to salinity. These varieties have long slender grain with kernel length >6mm and are highly suited for export under non-Basmati category. MTU Rice 1310 and MTU Rice 1321 are high yielding medium duration, medium slender grain type varieties with high head rice recovery and suitability for raw rice. The SVRC varieties, MTU Rice 1318 is highly non-lodging and has become popular as non-lodging Swarna. It has replaced more than 2.0 lakh hectares of Swarna area in the State of Andhra Pradesh and is poised to become a mega rice variety in the coming years. MTU Rice 1232 is highly tolerant to submergence and flash floods even up to one month, while MCM Rice 103 fulfills the long demand for 140 days' duration, fine grain, salinity tolerant variety.

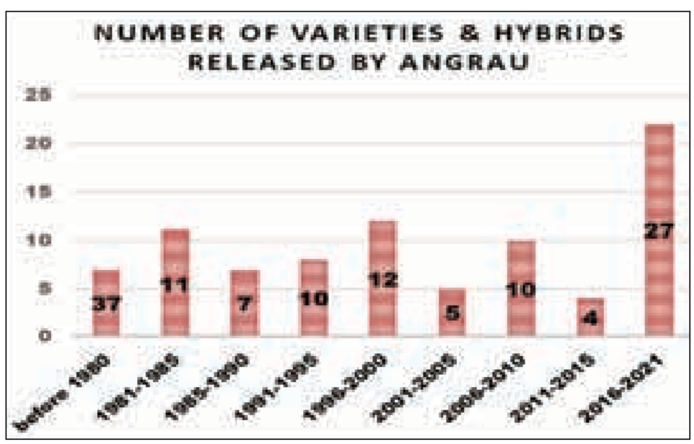


Figure 1: Details of rice varieties / hybrids released by ANGRAU

ANGRAU Rice Varieties – National Scenario

ANGRAU rice varieties are cultivated across different states of the country and the details are presented in **Table 1**. Swarna (MTU 7029), Samba Mahsuri (BPT 5204) and Cottondora Sannalu (MTU 1010) receive more than 100q GOI breeder seed indent each year and are in much demand. These three varieties account for 60 per cent of the total ANGRAU rice varieties breeder seed indent. Among these, Cottondora Sannalu (MTU 1010) and Samba Mahsuri (BPT 5204) have the highest average annual cultivation area in the country (3.24 and 2.79 million hectares, respectively) and with an annual contribution of Rs. 13,705 and Rs. 8,587 crores in the country's rice production economy. It is also estimated that because of these varieties, an average of Rs. 652.6 and 587.5 crores of additional income are generated annually to rice farming community. Likewise, Swarna (MTU 7029), Vijetha (MTU 1001) and Nellore Mahsuri (NLR 34449) contribute a per cent share of 3.32, 2.89 and 1.84, respectively, to the country's total rice revenue.

Other rice varieties released in the recent years and in increasing demand at the national level are Chandra (MTU 1153) and Tarangini (MTU 1156) with more than 70q breeder seed indent from GOI and other indentors. These varieties are mostly cultivated in the states of Chhattisgarh, Madhya Pradesh, Odisha and West Bengal for export purpose under non-Basmati category in view of their long slender grain with kernel length more than 6 mm and convenient duration of 115-120 days. The variety, Pushyami (MTU 1075) is being grown in more than 30,000 hectares in West Bengal and 50,000 hectares in Odisha because of its high yield potential and resistance to Brown Plant Hopper (BPH). Similarly, Bheema (MTU 1140) is popularly grown for its submergence tolerance in West Bengal in more than 40,000 hectares while, MTU Rice 1223 is grown in rainfed uplands of Chhattisgarh in more than 1 lakh hectares.

Maruteru Samba (MTU 1224) and Maruteru Mahsuri (MTU 1262) are grown for their fine grain in Odisha and Telangana in an area of about 1.20 lakh hectares annually. Indra (MTU 1061), another predominant rice variety of Andhra Pradesh state after Swarna (MTU 7029) and Samba Mahsuri (BPT 5204) is popular in the state of Telangana for its salinity tolerance, high head rice recovery and suitability for raw rice. Nellore Dhanyarasi (NLR 3354) and Nellore Mahsuri (NLR 34449) are popular in Tamil Nadu and are being grown in more than 70,000 hectares for their grain quality and tolerance to pests and diseases. Sravani (MTU 1239) is grown in Chattisgarh in about 1.30 lakh hectares while Sujatha (MTU 1210) is popular in the states of Odisha (50,000 ha), Telangana (10,000 ha) and West Bengal (20,000 ha).

Table 1: ANGRAU rice varieties are cultivated across different states of the country

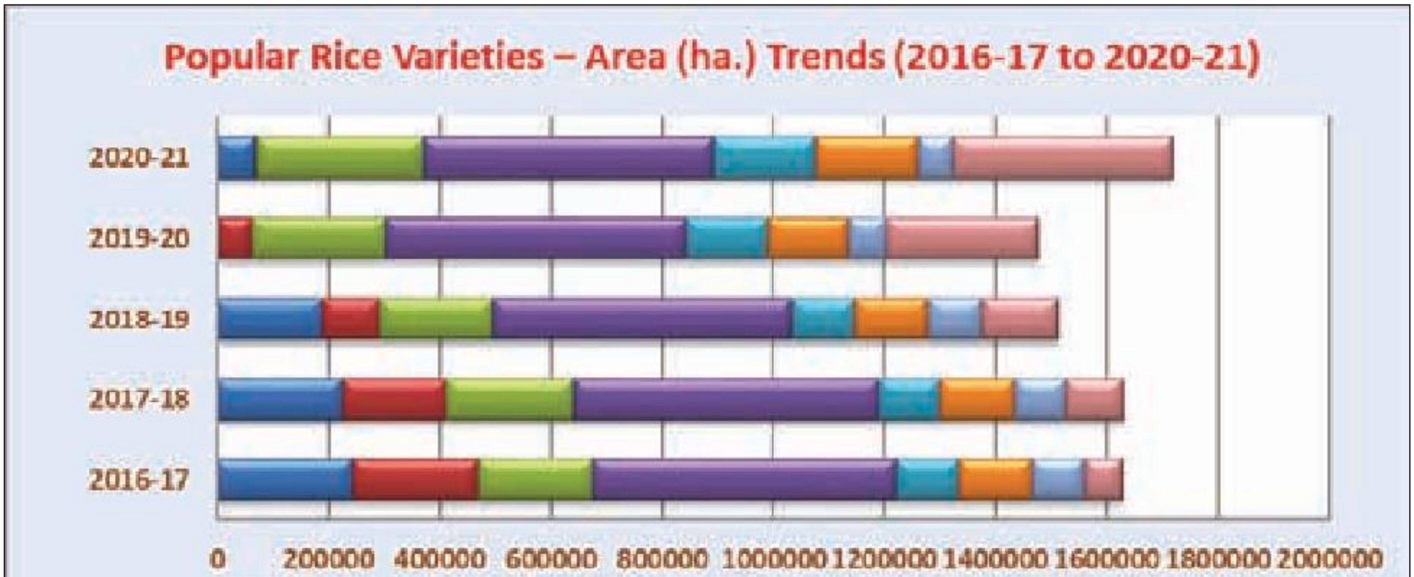
State	ANGRAU rice varieties being cultivated		Per cent area under ANGRAU rice varieties
	Number	Details	
Chhattisgarh	7	MTU 1010, MTU 7029, MTU 1001, MTU 1153, MTU 1156, MTU 1223, MTU 1239	85.05%
Maharashtra	4	MTU 1010, MTU 7029, MTU 1001, MTU 1153	11.34%
Odisha	6	MTU 1156, MTU 1153, MTU 1075, MTU 1224, MTU 1262, MTU 1210	8.45%
Tamil Nadu	2	BPT 5204, NLR 34449	7.95%
West Bengal	10	MTU 7029, MTU 1153, MTU 1140, MTU 1156, MTU 1001, MTU 1075, MTU 1210, NLR 3354, MTU 1223, MTU 1006	6.30%
Karnataka	3	BPT 5204, MTU 1001, MTU 1010	6.26%
Uttarakhand	1	MTU 7029	4.17%
Madhya Pradesh	2	MTU 1153, MTU 1156	2.55%

Source: GOI Breeder Seed Indents for 2022-23 (https//www.seednet.gov.in)

ANGRAU Rice Varieties – Andhra Pradesh Scenario

ANGRAU rice varieties occupy lion share in the state of Andhra Pradesh. During Kharif season 15.57 lakh hectares out of 17.42 lakh hectares of total rice grown area is under ANGRAU varieties. Similarly, 6.21 lakh hectares out of 7.62 lakh hectares of Rabi rice area is under ANGRAU varieties. An output of 123.14 lakh tones was produced by cultivating ANGRAU rice varieties in Andhra Pradesh, which accounted for 88 per cent of the State's total rice production in 2021-22. ANGRAU rice varieties, Sri Dhruthi (MTU 1121), Swarna (MTU 7029) and Samba Mahsuri (BPT 5204) are most commonly grown with 5.03, 3.5 and 3.34 lakh hectares respectively, during 2021-22. Other important ANGRAU rice varieties occupying more than 1.0 lakh hectares in the state are Indra (MTU 1061) and Nellore Mahsuri (NLR 34449) (**Figure 2**).

The GOI breeder seed indents for 2022-23 reveals maximum indent of 799.25q for 33 ANGRAU rice varieties accounting for 23.41 per cent of the total GOI paddy breeder seed indent (**Figure 3**). ANGRAU has also been consistently ranking first, in comparison to other Rice Research Institutes and State Agricultural Universities with respect to GOI breeder seed indent, since 2015. Further, 26.8 per cent of the ANGRAUs rice varieties are receiving regular indents for breeder seed from GOI. Apart from the Central Indents received for Breeder Seed, ANGRAU also receives indents from Seeds Men Associations, Seed Production Societies, Agencies and Progressive Seed Growers accounting for more than 2000 quintals of Breeder Seed every year pertaining to more than 35 ANGRAU rice varieties resulting in generation of 2.5 to 3.0 crores of revolving fund.



	2016-17	2017-18	2018-19	2019-20	2020-21
MTU 1010	242788	224154	188689	2021	68947
MTU 1001	226678	189554	104124	62447	3098
MTU 7029	204506	227333	202995	238811	297630
BPT 5204	547978	547623	538420	540167	523027
NLR 34449	110324	110324	112683	146720	182450
MTU 1061	134283	134283	131194	144444	184139
MTU 3626	93066	93066	97263	68545	64093
MTU 1121	68254	103073	137253	272960	394266

Figure 2: Trends in Area occupied by popular rice varieties of ANGRAU (2016-17 to 2020-21)

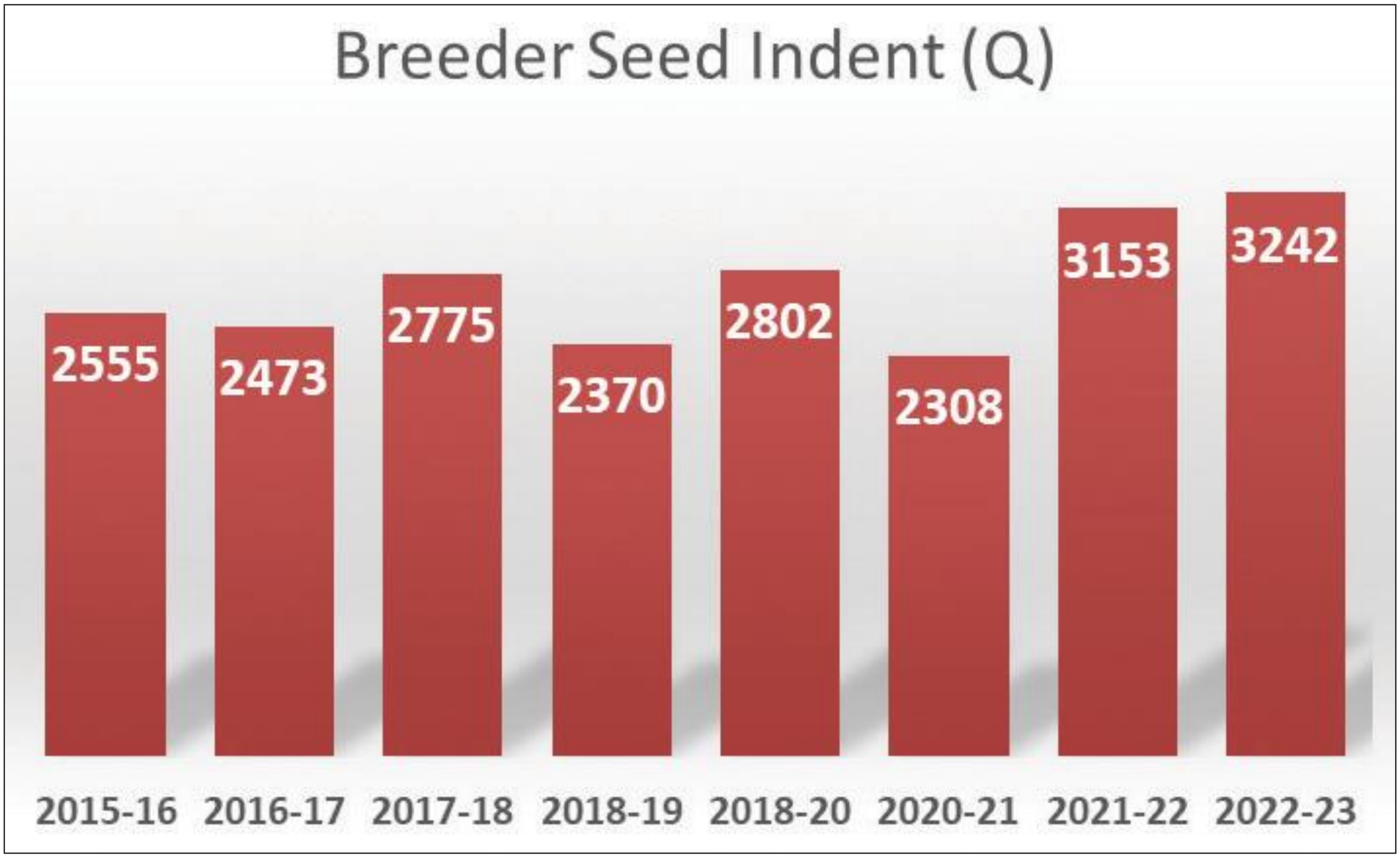


Figure 3: Breeder seed indents of ANGRAU rice varieties by GOI, ICAR and AP

Conclusion

It is estimated that 14 million hectares of rice area of the country is under ANGRAU rice varieties resulting in approximately 38 million tonnes of average annual production accounting for Rs. 62,317 crores of revenue generation annually, equivalent to 33.15 per cent of the total revenue generated from rice production, leading to about 2.22 per cent contribution to the country's Agriculture GVA. ANGRAU rice varieties also account for 33 per cent of the total non-basmati rice exports form the country, resulting in annual export revenue of Rs. 8,073 crores. ANGRAU rice varieties have the credit of being consumed by one of every three Indian families with rice as their staple food in the country and nine out of every ten families in the state of Andhra Pradesh. The State rice farmers are estimated to have earned an amount of Rs. 20,243 crores through the cultivation of ANGRAU rice varieties.

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Improvement of Local Speciality Rices as a Boon to Health, Wealth and Export Diversity: Case of Kalanamak Rice

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Abstract

A blessing from Lord Buddha some 3,000 years ago, and now a heritage rice of Uttar Pradesh, India is valued for its aroma, taste and nutritive quality. Its cultivation declined from 50,000 ha to less than 2,000 ha and was at the verge of extinction. No attention was paid for improving Kalanamak and it survived as landrace due to the mercy of the farmers. PRDF collected, catalogued and conserved 250 accessions of Kalanamak, and the best one, through Pureline selection, was released in 2007 and notified in 2010 as KN 3. Mutation breeding using gamma rays and EMS gave many academically interesting mutants but no high yielding dwarfs. Hybridization of KN 3 with Swarna Sub1 and Improved Sambha Mahsuri yielded varieties like Bauna Kalanamak 101, Bauna Kalanamak 102 and Kalanamak with shorter duration and 50% higher yield, released and notified in years 2016, 2017 and 2019 respectively. Protocol for organic production with higher yield was developed and certification under PGS arranged. Kalanamak is sugar-free with 49 to 52% Glycemic Index, 11% protein, 3 times higher Iron and 4 times higher Zinc. It is unique rice to have Vitamin A in form of Beta Carotene. Kalanamak is backed by Geographical Indication and PPV&FRA, and selling at five times higher price of common rice tripling farmers' income. Now exported to Singapore, Nepal and Dubai has opened door to prosperity and added diversity to Basmati for export. This success story can be repeated for other land rices of speciality status.

Keywords: Aroma, Mutation Breeding, Glycemic index, export, farmers inccome, Organic

Introduction

Kalanamak rice variety is an epitome of best aromatic rice cultivated and consumed in North-eastern part of Uttar Pradesh (Chaudhary and Tran, 2001). Locally, this heritage rice is even classed superior to Indian mystic rice Basmati. However, over centuries of cultivation and farmers' way of handling seed, neglect by research institutions and double onslaught on economic front by High Yielding Varieties (HYV), its area reduced from 50,000 ha to less than 2,000 ha (Table 1). Deterioration in "grain quality" and loss of aroma happened due to spontaneous mutation and out-crossing, non-scientific seed production and cultivation, in changed environment and processing practices. However, by continued researches done at Participatory Rural Development Foundation (PRDF) during 1998 to 2021, varieties and technologies were developed to save Kalanamak and revert to old glory. Exact history of its cultivation is not recorded but it is believed that Kalanamak was given to farmers of Bajaha jungle in Siddharthnagar district of Uttar Pradesh some 3,000 years back (Chaudhary and Tran, 2001) by Lord buddha.

Materials and Methods

We collected 250 germplasm accessions of Kalanamak rice and the Accession No. 3 was handled by Pureline selection method of breeding and released as KN3. It was crossed with Swarna Sub_1 and segregating generations handled through pedigree method of breeding to develop semi-dwarf variety Bauna Kalanamak 101. KN3 was also crossed with Improved Sambha Mahsuri to develop variety Bauna Kalanamak 102. Variety Kalanamak Kiran was developed from the cross KN3 x Swarna Sub_1 and notified in 2019 as Kalanamak Kiran by the Central Variety Release and Notification Committee of Government of India. These varieties were tested multi-location by the AICRIP trials in whole country and at RATDS by Department of Agriculture in U. P. Grain qualities were tested at NRRI Cuttack, ICAR-IIRR Hyderabad, IICT Hyderabad and R-FRAC, Lucknow.

Organic Protocol on KN3 variety was developed with inputs like green manure, poultry manure, Bhumi Shakti, FYM, *Trichoderma, Pseudomonas*, Herbozyme, Amrit Pani, Decomposer in various combinations. Multi-location trials were conducted in Gorakhpur, Mahrajganj and Siddharthnagar districts of U. P. The best combinations were recommended to produce Organic Kalanamak Rice. Participatory Guarantee System (PGS) of the NCONF , Ghaziabad was used to certify the product as "PGS India Green" and "PGS India Organic".

Results and Discussion

Initial research to improve Kalanamak

Initial research on Kalanamak started with the collection of its germplasm (Chaudhary *et al.,* 2010; Chaudhary and Mishra 2010) and mutation breeding (Chaudhary, 1979). Using 42 morpho-agronomic characters, accession were described, catalogued (Chaudhary *et al.,* 2010), and the collection was deposited in the National Gene Bank at ICAR- NBPGR New Delhi (Chaudhary, 2005; Chaudhary *et al.,* 2010; Chaudhary, 2016). The mutants were mostly of academic nature (Chaudhary and Chauhan, 1979; Mishra and Chaudhary, 2011) but none were found superior to existing varieties (Chaudhary *et al*., 2012).

Purification and release of first Kalanamak variety

U. P. Council of Agricultural Research (UPCAR) financed extensive collection of Kalanamak from all possible sources. These sources included National Gene Bank of NBPGR, New Delhi; N. D. University of Agriculture and Technology, Faizabad; Central Rice Research Institute Cuttack, and farmers of North-Eastern U. P. PRDF tested 250 collections to find out that some of the collections were non-aromatic although the grain appearance was identical to aromatic Kalanamak accessions. Some accessions had mixtures of scented and non-scented Kalanamak in various proportions. One of the pureline selections developed from the collection of Siddharth Nagar district was tested as KN3-27-3-3 and released by U. P. State Variety Release Sub-Committee and notified by the Central Variety Release Committee in 2010 as KN 3 (Chaudhary, 2009). Due testing was done at Regional Agricultural Technology Demonstration and Testing Station (RATDS) of U. P.

Development and Release of Bauna Kalanamak 101

Bauna Kalanamak 101 was developed out of a cross Kalanamak KN 3 with Swarna Sub_1 and tested as UPCAR-KN-2-19-14-1-1. PRDF had proposed a number of semi-dwarf breeding lines of Kalanamak for testing at RATDS during the years 2012 to 2015 in state trial called "Paddy Standard Varietal Trial: local aromatic, irrigated". The average yield superiority of UPCAR-KN-2-19-14 was 46.41 over its check Kalanamak KN3. The State Variety Release Sub-Committee released it in 2016. The Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops approved in its 75th meeting and notified it in its Gazette No. 3-51/2016-SD.IV dated 23rd December 2016 with the name "Bauna Kalanamak 101".

Development and Release of Bauna Kalanamak 102

Bauna Kalanamak 102 was developed out of a cross Kalanamak KN 3 with Improved Sambha Mahsuri and tested as UPCAR-KN-1-5-1-1-1 at RATDS of Department of Agriculture U. P. during 2012, 2013 and 2014. It was released and notified during the year 2016 as Bauna Kalanamak 102. With plant height of 95cm, it is non-lodging and suitable for combine harvesting. Based on the overall test, the test entry UPCAR-KN-1-5-1 (Bauna Kalanamak 102) yielded 32.37 quintal / ha. That way it out-yielded the check variety Kalanamak KN3 by 30.37%. It is 10 day early in maturity than Kalanamak KN3. In AICRIP trials conducted by Indian Institute of Rice Research (ICAR - IIRR), Hyderabad in Kharif 2014, the mean yield was 3198 kg/ha as against 2792 of Kalanamak KN3, and flowering duration earlier by 11 days across India. In the year 2017 it was released by U. P. State Variety Release Committee of Department of Agriculture, and notified by Government if India as "Bauna Kalanamak 102" (Chaudhary *et al.,* 2018).

Development and Release of Kalanamak Kiran

Selected out of cross of Kalanamak KN3 and Swarna Sub_1, it was tested at RATDS of Department of Agriculture as PRDF-2-14-10 (Kalanamak Kiran), was tested at RATDS during 2013 – 2016. It stood at first rank with average yield of 32.95 quintal / ha. It out-yielded the check variety Kalanamak KN3 by 26.58 %. Its aroma content was confirmed by the Indian Institute of Chemical Technology (IICT), Hyderabad confirmed its aroma equal to KN3. It is semi-dwarf, lodging resistant and suitable for harvesting by combine harvester (**Table 1**). Bauna Kalanamak 102 has the same level of Iron and Zinc as its original parent Kalanamak It was notified by the Government of India Gazette of India under Gazette No. 3220 (Part II (3) dated 06 08.2019.

Table 1. Area (estimate of PRDF) during 1960 to 2021 under Kalanamak varieties in 11 districts covered under Geographical Indications (GI)

Sl. No.	Year	Estimated Area (ha) of Kalanamak	Remark on technologies
1	1960	50,000	Traditional area under Kalanamak
2	1970	40,000	Traditional area under Kalanamak
3	1980	10,000	Spread of HYV rice
4	1990	2,000	Spread of HYV rice
5	2000	2,000	Spread of HYV rice
6	2010	3,000	Notification of Kalanamak KN3
7	2015	10,000	Demonstration of Kalanamak KN3
8	2016	20,000	Notification of Bauna Kalanamak 101
9	2017	25,000	Notification of Bauna Kalanamak 102
10	2018	35,000	Release of Kalanamak Kiran
11	2019	40,000	Notification of Kalanamak Kiran
12	2020	45,000	Notification of Kalanamak Kiran
13	2021	50,000	Notification of Kalanamak Kiran, Govt support for publicity, exhibition and marketing
14	2022	70,000	Support from government, consumers and traders to the available technologies.

Protocol for Organic Production of Kalanamak

Protocol for producing organic Kalanamak rice was developed based on the multi-location and multi-year trial. A manual was prepared for farmers (Chaudhary and Mishra, 2016). Using *Trichoderma and Pseudomonas* in combination showed synergistic effect and increased the yield. Additional treatments with green manure, BGA, PSB were added for farmers of different area. Plant protection measures using Waste Decomposer, *Amrit Paani* etc were also perfected. Gorakhpur and four other districts have been selected under the Organic Crop Production scheme under *Paramaparagat Krishi Vikas Yojna* (PKVY). PRDF as the Regional Council of National Centre of Organic Farming (NOF) Ghaziabad of the Ministry of Agriculture and Farmers Welfare certifies it under Participatory Guarantee System (PGS) system and give labels of “PGS- INDIA - GREEN” and “PGS- INDIA - ORGANIC” categories.

Morpho-agronomic Characters and Cultivation practice

Kalanamak is highly photoperiod sensitive variety with short basic vegetative phase. It heads during mid October. Morpho-agronomic characters and grain quality characters of Kalanamak make it very suitable for production and consumption. Kalanamak should be produced only during Kharif season in its Geographic Indication area of 11 districts U. P. to maintain its grain quality. It should be cultivated like any other HYV but best is Organic Production techniques. Sheath blight and grain sucking pests need to be controlled using appropriate methods.

Grain quality

Kalanamak has Medium Slender grain. These have very high (70%) head rice recovery. Due to 19 – 20% amylose, cooked rice of Kalanamak remains soft and has excellent grain elongation (**Table 2**). In all India testing under AICRP, coordinated by Indian Institute of Rice Research (ICAR-IIRR), Hyderabad it was found to have all favourable grain quality characters (Table 3). Kalanamak varieties have the highest level of Iron and Zinc combined. Due to this reason, Kalanamak was the only rice variety from north India included in the **NutriFarm** Project of the centre and state of U. P. Kalanamak is the most nutritious of all rices in terms of protein, iron, zinc, Vitamin A as Beta Carotene (Chaudhary *et al.,* 2021) while being sugar free (**Table 2**).

Table 2. Grain quality characters of Kalanamak KN 3, Bauna Kalanamak 101, Bauna Kalanamak 102 and Kalanamak Kiran rice varieties *(analysed at NRRI Cuttack, NDUAT Ayodhyay, ICAR-IIRR Hyderabad and IICT Hyderabad, and R-FRAC, Lucknow*).

Sl. No.	Traits	Description of the variety			
		Kalanamak KN3	Bauna Kalanamak 101	Bauna Kalanamak 102	Kalanamak Kiran
1	Kernel length	5.76 mm	5.76 mm	5.76 mm	5.76 mm
2	Kernel width	2.18 mm	2.18 mm	2.18 mm	2.18 mm
3	L/B Ratio	2.64 mm	2.64 mm	2.64 mm	2.64 mm
4	Grain type	Medium slender	Medium slender	Medium slender	Medium slender
5	Kernel colour	White	White	White	White
6	1,000 grain weight	15 grams	15 grams	15 grams	15 grams
8	Hulling	80 %	80 %	80 %	80 %
9	Milling	75 %	75 %	75 %	75 %
10	Head rice	70 %	70 %	70 %	70 %
11	Alkali value	6 - 7	6 - 7	6 - 7	6 - 7
12	Volume Expansion Ratio	4.5	4.5	4.5	4.5
13	Gel consistency	80 mm	80 mm	80 mm	80 mm
14	Amylose content	21 %	22 %	22 %	21 %
15	Aroma	Highly aromatic	Aromatic	Highly aromatic	Highly aromatic
16	Iron (ppm) *	4.82	4.35	4.55	4.81
17	Zinc (ppm)*	16.97	14.35	14.55	16.37
18	Protein	10.64 %	10.50 %	10.64 %	10.64 %
18	Beta Carotene**	0.42 mg/100g	0.40 mg/100g	0.42 mg/100g	0.42 mg/100g

* All India average of 15 locations from AICRIP trials

** Analysis done at R-FRAC, Dept. of Horticulture, Govt. of U. P., Lucknow

Economics and Tripling Farmers' Income

Due to poor yield, poor quality and lesser income as compared to HYV rice, area under Kalanamak had declined before 2000. However, now with the availability of better quality varieties, those negatives have been annulled. Minimum Support Price (MSP) for fine paddy is around Rs. 2,000/ qtl but Kalanamak sells for Rs. 4,500/- and rice as high as Rs. ,35,000/- per quintal. It is being exported adding diversity to to lone Basmati from India. Common slogan that "Basmati for your eyes and Kalanamak for your palate" is popular in eastern U. P.

Conclusion

Improved varieties of Kalanamak rice namely KN3, Bauna Kalanamak 101, Bauna Kalanamak 102 and Kalanamak Kiran have been developed notified. Nucleus, Breeder, Foundation and Certified seeds of these varieties are available. Package of practices to produce common and organic Kalanamak rice been perfected. Hundreds of farmers are linked with the local and export markets on attractive terms for sales on long-term basis. Summarily, compared to Rs. 43,100 / ha net profit from common HYV rice, Kalanamak KN3 gives Rs. 69,375, Bauna Kalanamak

Rs. 126,250 and Organic Bauna Kalanamak Rs. 1,38,000 net profit per hectare. Consumers are assured of quality. Other local germplasm with speciality status can repeat the same story of Kalanamak.

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System of Crop Intensification in Ragi for Sustained Productivity to Meet the Challenges in Climate Change

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Abstract

System of crop intensification is one of the important concept to improve the productivity and to sustain the income of the farmers in long run. The doubling of farmers' income is the talk of the day to help them in their livelihood in spite of various constraints face in the field. Climate change is another challenge in the years to come for the farming sectors. Field experiments were conducted from 2016 to 2019 to evaluate the establishment technique in ragi (SRgI) wherein the experiment was laid out in Factorial Randomized Block Design, replicated thrice. The treatment consists of three establishment techniques *viz.,* Spacing: S_1 (22.5 X 22.5 cm), S_2 (25 X 25 cm) and S_3 (30 X 30 cm), Number of seedling: N_1 (one seedling per hill) and N_2 (two seedlings per hill) and Age of seedling: A_1 (12 days old seedling), A_2 (15 days old seedling) and A_3 (18 days old seedling) and control (22.5 X 10 cm, two seedlings per hill and 18 days old seedlings). The results revealed that single seedling with 12 days' age under wider spacing (30 X 30cm) was the suitable establishment technique to meet the challenges of increased production in millets. It was found that SRgI technique could result in single stroke harvest of ragi, avoiding multiple harvests. The results from the previous research of SRgI was considered, as a tool for mitigating climate change strategies *viz.,* high temperature and low rainfall. The experiments were taken up (2019-21) under Factorial Randomized Block Design, replicated thrice. The treatments consist of two factors *viz.,* Date of sowing: S_1 (Sowing on June 1st week), S_2 (Sowing on June 2nd week), S_3 (Sowing on June 3rd week) and S_4 (Sowing on June 4th week); and Variety: V_1 (TRY1), V_2 (CO14), and V_3 (CO 15). SRgI method of planting was adopted *i.e.,* single seedling with wider spacing. From the reference of the pertaining data, it can be deduced that early sowing of variety TRY 1 and CO 15 on 1st and 2nd week of June respectively could increase the production of ragi, minimize the risk of pest incidence and reduce the cost of production thereby support as a resistant crop to mitigate the climate change concepts projected in near future keeping in view of the System of Crop Intensification and its benefits.

Key words: System of Ragi Intensification(SRgI), climate change, resilient crop, small millets.

Introduction

Finger millet (*Eleusine coracana* L. Gaertn) is one of the promising food potential for ensuring food and nutritional security of our country. Finger millet is an ecologically sound crop having flexibility and resilience to a variety of agro-climatic adversities. As the crop requires very less moisture and nutrient demand, it is largely cultivated among small farmers. With respect to area and production in our country it has the pride of place in having the highest productivity (1661 kg ha^{-1}) among the millets (Seetharam and Krishne Gowda 2007). The combined potential of millets as both resilient crops for resource constrained farmers and as a nutritious foodstuff for growing populations, millets are slowly being rediscovered by the agricultural research and development community. Also in view of celebration of International year of millets 2022–23; Ragi is promoted in large sale to meet the future challenges of farming community. The modern agronomic approaches like suitable variety, planting and time of planting were imperative in boosting the yields. Crop geometry is a very important factor to achieve higher production by better utilization of resources (Uphoff *et al.,* 2011).

System of Ragi Intensification (SRgI) is called as 'Gulli ragi' in local language at Karnataka which applies the same kind of management practices as used in SRI (System of Rice Intensification), to grow ragi with often doubling the yield without dependence of seed, variety and other inputs. Yield enhancement in finger millet is possible when cultivated with SCI, because there is less competition among plants and weed, where plants can utilize resources efficiently (Bhatta *et al.,* 2017). System of rice intensification is a proven technique in elevating rice production. Integrating SRgI techniques for millet cultivation also shows similar results under long term study conducted by All India coordinated Small Millets Improvement Project from 2016-2021.

A major problem in Ragi cultivation is crop establishment technique; faced by farmers which decides the population. The reason behind the success of SRgI is the uniform establishment, flowering and maturity which facilitate single stroke of harvest and enable reduction in cost of cultivation especially with respect to labour consumption involved in multiple harvest.

Methods

Field experiments were conducted from 2016 to 2019 to evaluate the establishment technique in ragi (SRgI) at Karaikal region. The experiment was laid out in Factorial Randomized Block Design, replicated thrice. The treatment consists of three establishment techniques *viz.,* Spacing: S_1 (22.5 x 22.5 cm), S_2 (25 x 25 cm) and S_3 (30 x 30 cm), Number of seedling: N_1 (one seedling per hill) and N_2 (two seedlings per hill) and Age of seedling: A_1 (12 days old seedling), A_2 (15 days old seedling) and A_3 (18 days old seedling) and control (22.5 x 10 cm, two seedlings per hill and 18 days old seedlings).

Similarly, during 2019-2021 various experiments were taken up under Factorial Randomized Block Design, replicated thrice to study the mitigation of climate change with SRgI as a tool. The treatments consist of two factors *viz.,* Date of sowing: S_1(Sowing on June 1st week), S_2(Sowing on June 2nd week), S_3 (Sowing on June 3rd week) and S_4 (Sowing on June 4th week); and Variety: V_1 (TRY 1), V_2 (CO 14), and V_3 (CO 15). SRgI method of planting was adopted *i.e.,* single seedling with wider spacing.

Results and Discussion

The pooled result revealed that LAI, DMP, number of tillers m^{-2}, number of ear heads m^{-2} and number of fingers earhead^{-1} were maximum with single seedling and wider spacing (30 x 30 cm) along with an age of 12 days old seedlings. Also the yield characters like thousand grain weight, harvest index were better and resulted in higher average grain yield of 1200 kg ha^{-1}. It was also found that SRgI technique could result in single stroke harvest of ragi, avoiding multiple harvests.

It was proved that wider spacing, young seedlings was the better option to have higher yield attributes in finger millet. Similar findings of number of seedlings per hill attributed exceedingly to the production of commendable number of ear head hill^{-1}, finger earhead^{-1}, finger length and 1000 grain weight as reported by Gnanamurthy (1980). Highest fingers earhead^{-1} was registered for the treatment with wider spacing (30 x 30 cm) along with an age of 12 days old seedlings as compared to other treatments (Fig.6) as envisaged by Vijayavalli (2015).

Therefore, the farmers can adopt square planting with single seedlings at the younger age to enjoy a high remuneration in finger millet production as alos envisaged by Shukla *et al.* (2014). From the forgoing long term investigation, it can be concluded that SRgI practice [*i.e.* Single seedling with wider spacing (30 x 30 cm) along with 12 days old seeding ($S_3N_1A_1$)] could increase the production strategy of ragi and help to meet the challenges and sustain the nutritional security which will be the best option to obtain maximum remuneration by the farming community.

Also the high temperature prevailing during June to September and poor rainfall distribution at Karaikal region is another predicament factor that hinders the ragi production. The late sowing leads to reduction in the yield; however, this variation can be minimized by sowing a variety which has relatively less reduction in yield. This not only benefits maximum yield but also reduce cost spent on plant protection.

The results from the previous research of SRgI was considered, as a tool for mitigating climate change strategies *viz.,* high temperature and low rainfall experiments were designed to meet the challenges in climate change to evaluate the suitable variety and transplanting window of ragi using SRgI technique from 2019-22.

The pooled results obtained from the year 2019 to 2021 indicated that, plant height , thousand grain weight, straw yield and grain yield (1638 kg ha^{-1}) were superior in variety TRY 1 sown at the 1st week of June (S_1V_1). Also TRY 1

(V_1) a saline resistant genotype performed better at all four sowing windows (**Table 1 & Table 2**). The variety CO 15 when sown at 2nd week of June was next superior treatment (S_2V_3) which brought about 1229 kg/ha of average grain yield. The finding also depicted that late sown crop was susceptible to pest occurrence especially stem borer.

Table1. Effect of date of sowing and variety on grain yield of ragi

Treatment	Grain yield (kg ha^{-1})			
	V_1 (TRY 1)	V_2 (CO 14)	V_3(CO 15)	Mean
S_1 (Sowing on June 1st week)	1638	1094	848	1193
S_2 (Sowing on June 2nd week)	1098	671	1221	994
S_3 (Sowing on June 3rd week)	976	546	591	704
S_4 (Sowing on June 4th week)	1026	916	518	820
Mean	**887**	**605**	**596**	
	SE d		CD	
S	426.7		2030.9	
V	655.7		2380.1	
SXV	1311.3		3593.1	

Table 2. Effect of date of sowing and variety of ragi on straw yield of ragi (kg ha^{-1})

Treatment	Straw yield of ragi (kg ha^{-1})			
	V_1 (TRY 1)	V_2 (CO 14)	V_3(CO 15)	Mean
S_1 (Sowing on June 1st week)	2900	2117	1644	**2220**
S_2 (Sowing on June 2nd week)	1089	1329	1221	**1213**
S_3 (Sowing on June 3rd week)	1378	969	1013	**1120**
S_4 (Sowing on June 4th week)	1500	1726	1124	**1450**
Mean	**1287**	**1151**	**938**	
	SE d		CD	
S	689.7		3283.0	
V	2340.5		8496.2	
SXV	4681.1		12826.2	

Conclusion

From the reference of the pertaining data, it can be deduced that early sowing of variety TRY 1 and CO 15 on 1st and 2nd week of June respectively could increase the production of ragi, minimize the risk of pest incidence and reduce the cost of production in Karaikal region thereby support as a resistant crop to mitigate the climate change concepts projected in near future keeping in view of the System of Crop Intensification and its benefits.

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Microbial Inoculation can Enhance SRI Performance and Reduce Biotic and Abiotic Stresses in Rice

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Abstract

Microbes play crucial roles in plant survival and fitness by mobilizing soil nutrients, enhancing plant performance by producing phytohormones, and protecting plant from biotic and abiotic stresses. SRI crop management system, extrapolatable to improve production of other crops beyond rice, aims to create the best growing environment above- and below-ground and to mobilize various services from microbes to increase factor productivity. Inoculating crop plants with effective microbial agents, either in consortia or separately, enhances rice crop performance in various ways. This paper presents results from field experiments and offers some explanation of mechanisms accounting for the higher productivity and performance of SRI rice plants with augmentation of microbial agents in soil.

Keywords: *Trichoderma, Bacillus*, microbial ecological services, biotic and abiotic stresses

Introduction

Plant growth-promoting microorganisms (PGPMOs) play significant roles in soil fertility, plant productivity, and plant health by enhancing plant growth and alleviating the impact of biotic and abiotic stresses such as pests and diseases, water and nutrient deficiencies, and unfavorable environmental stresses. PGPMOs can colonize plant tissues, organs and cells as endophytes, among other things influencing phytohormone production and the plants' expression of genetic potential. Within the rhizosphere around plant roots and within plant roots, they can fix nitrogen and solubilize phosphates, thereby reducing the costs of production and curtailing environmental pollution by curbing reliance on agrochemicals (de Souza *et al.,* 2015).

A major explanation for this is that the recruitment of microorganisms in plant rhizospheres is influenced by the composition of nutrients in root exudates. For example, exudates that are rich in sugar, amino acids, and micronutrients will be more attractive to microbes, and this will enhance their ecological services for plants (Hayat *et al.,* 2017). Also, plants that are healthy and at a particular physiological stage can produce root exudates that are more alluring to microbial communities than can unhealthy plants (Habig *et al.,* 2015).

The System of Rice Intensification (SRI) is an evolved set of crop-growing practices that creates a more favorable soil environment, conducive for greater physiological yield. SRI methods improve soil physical, chemical, and biological qualities by favoring the use of organic materials for soil amendment and by aerating the topsoil with a simple mechanical rotary weeder when soil oxygen content gets reduced by the puddling of rice fields. This aeration enhances the abundance and activity of beneficial microbial communities, most of which are aerobic. It also reduces the generation and emission of methane (CH_4), which is produced by anaerobic methanogens.

Continuous flooding of paddy fields as practiced in conventional rice production has several deleterious effects for rice root systems such as creating a hard pan that limits their depth of growth, reducing oxygen supply and causing root necrosis over time, and accumulating toxic chemicals such as short-chain fatty acids in rhizospheres, produced by anaerobic respiration related to hypoxia. The impact of these factors results in a deformed root cortex, creating air pockets (aerenchyma) in the roots (Kirk & Bouldin 1991), and reducing root respiration due to hypoxic soil conditions. These lead to root systems that are unfavorable for colonization by beneficial microbes such as arbuscular mycorrhizae, which thrive only under aerobic soil conditions.

SRI creates a better soil environment for the growth and colonization of microbial agents in soil in one side and makes rice plants at the optimum physiological stage to exudate better root and shoot leaches attractive for beneficial microbes. The combination of these has a synergistic impact in crop yield and physiology (Khadka & Uphoff 2019).

Roles of microbial agents in rice performance

The soil contains a vast ocean of microbes. Among them, some microbes have a better ability to decompose organic matter in the soil (more saprophytic ability), while others are more competitive within rhizospheres in their ability to colonize roots, while some other microbes are pathogenic for plants. These characteristics of microbes can vary among the different strains or isolates found within the same species and genus. Therefore, it is always advisable for purposes of inoculation to select microbial isolates or groups of isolates that have better rhizosphere-colonizing ability and that can provide better ecological services for the target plants. For example, we have previously reported (Khadka *et al.,* 2022) on the differential roles of *Bacillus* spp. and *Trichoderma* spp. strains in promoting root and shoot growth of rice seedlings under controlled environmental assays (**Figures 1 and 2**).

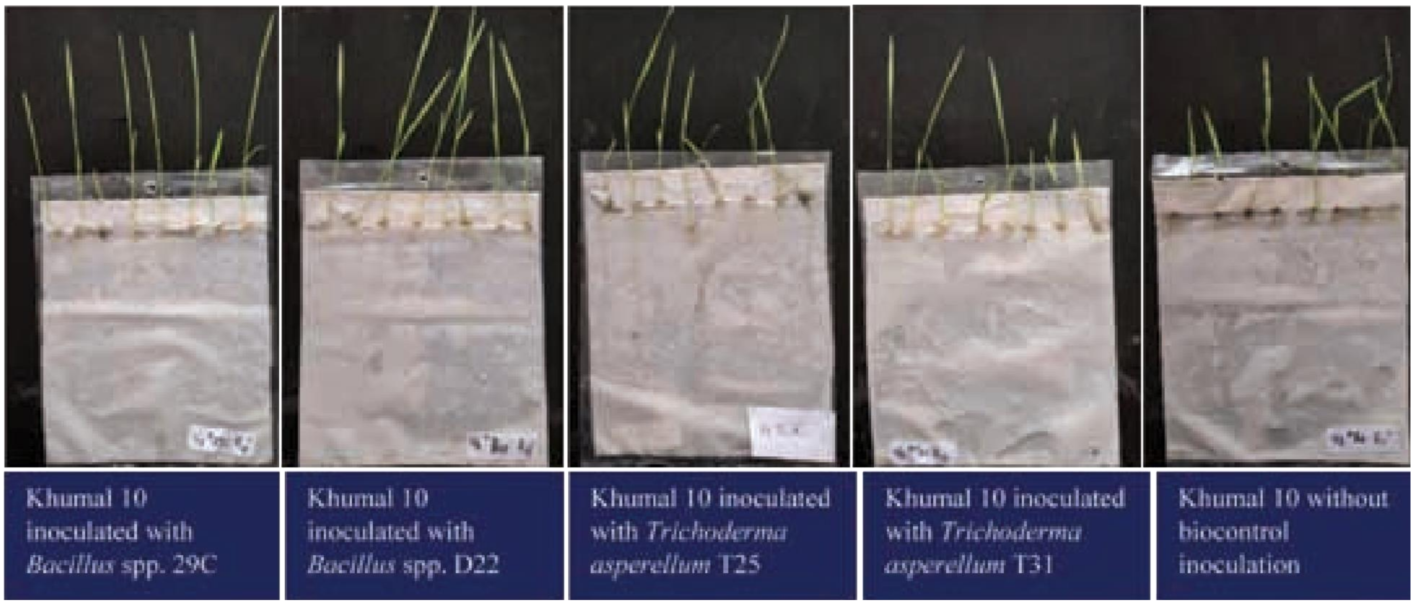

Figure 1: Effect of different strains of Bacillus spp. and Trichoderma spp. in root and shoot growth of rice seedlings

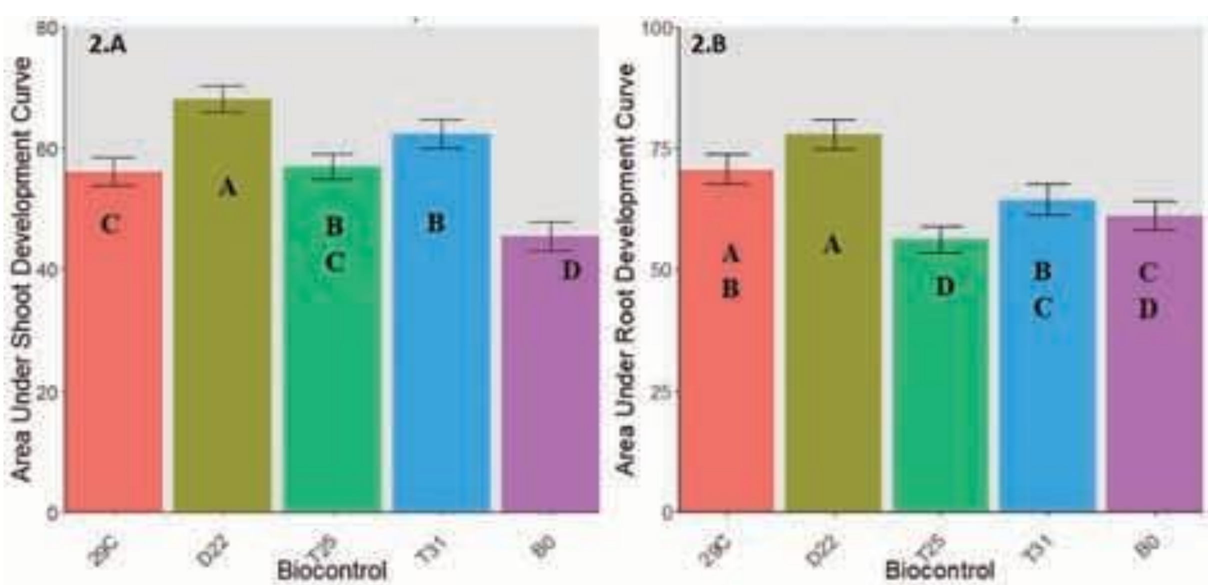

Figure 2: Effect of different strains of *Bacillus* spp. (29C and D22) and *Trichoderma* spp. (T25 and T31) in root and shoot growth of rice seedlings. B0 = no inoculation.

The inoculation of rice plants with different strains of either *Bacillus* spp. and *Trichoderma* spp. stimulated the plant root and shoot growth differently (**Figures 1 and 2**) The root and shoot growth were significantly higher in plants grown from seeds inoculated with *Bacillus* spp. D22 and 29C compared to the non-inoculated control (B0). Inoculation with *Trichoderma asperellum* T25 and T31 increased shoot growth, but did not change root growth as much compared to the non-inoculated control. Shoot growth was increased by 19%, 33%, 20% and 27% by microbial inoculation with 29C, D22, T25, and T31, respectively.

These results indicate that a symbiotic association of microbes changes the rice phenotypes, including their growth greatly. These changes will have an impact on the yield and quality of grains.

System of Rice Intensification enhancement by microbial inoculation

The System of Rice Intensification (SRI) promotes the optimum environment for rice growth by applying its principles through optimizing practices that create a congenial environment for growth of soil microbes and plants, so rice plants can achieve the best plant architecture close to the ideotype for maximum yield. For example, SRI management provides a better soil environment for soil microbial communities by providing more soil organic matter (SOM). Diverse populations of microbial communities thrive better in an area where there is a higher soil organic matter, because SOM supplies greater variety of nutrients, enhances soil resilience in a fluctuating soil environment, with varying pH, drought, temperature, and salinity thereby protecting microbes from environmental shocks.

At the same time, higher soil OM is important for plant growth so that healthy plants can leach nutrient-rich exudates into the soil as a source of microbial food. SRI practices include planting rice seedlings at an early age with and wider spacing which reduces inter-plant competition for space, light, and soil niches, optimizing the use of available resources. The practices enhance the architecture of both roots and shoots, making roots more robust, deeper, and well-distributed in the soil, and tillers more horizontal while leaves are more vertical, to intercept more light. compared to conventional transplanting. The higher number of feeder roots means they provide higher ecological niches for microbial colonization. SRI practices not only increase productivity but also increase soil biodiversity.

Conventional transplanting of seedlings into standing water creates suffocation of plant roots due to a limited supply of oxygen, and there is synthesis of ethylene and short-chain fatty acids due to anaerobic soil respiration in the rhizosphere region of rice resulting from continuous flooding which is deleterious to beneficial microbial colonization. SRI practices promotes more aerobic soil conditions due to alternate drying and wetting of rice paddies, and active soil root aeration by rotary weeders, which creates hospitable environments for soil microbial colonization.

Better performance of rice is achieved when rice seedlings are inoculated with beneficial microbes in SRI compared to conventional practice. Khadka and Uphoff (2019) concluded that the efficacy of *Trichoderma* inoculation is better in combination with SRI practices than in conventional rice growing. Doni *et al.,* (2017) also reported on how SRI growing conditions provided a better environment for *Trichoderma* and rice interaction compared to conventional rice crop management. They observed higher rice growth, nutrient uptake, physiological traits and yield with SRI management inoculated with *Trichoderma asperellum* SL2 compared to *Trichoderma*-inoculated rice with conventional management**.** The conventionally- grown rice tends to inhibit microbial services to rice physiology and yield compared to SRI rice due to anaerobic conditions and less organic matter in the soil. Therefore better crop yield along with a healthy, resilient and sustainable rice system could be achieved by fortifying SRI rice with appropriate microbial communities. This study also indicated production and inoculation of *Trichoderma* can be managed profitably by farmers themselves.

Environmental protection

Microbes have significant roles in soil ecology, environment and crop productivity. The flooding of rice fields is the second largest contributor to methane production in the agricultural sector. This could be reduced by adopting SRI practices since they promote alternative wetting and drying which greatly reduces methane production.

At the same time, beneficial microbes protect the crops from a variety of biotic stresses including fungi, bacteria, viruses, and even insects through the activation of plants' defense systems, direct production of antibiotics that are lethal to plant pathogens, directly parasitizing pathogens, or suppressing them competitively by occupying ecological niches and utilizing their resources (Harman *et al.,* 2021). Furthermore, several endophytic bacteria are recognized to directly contribute in biological nitrogen fixation, and this may have substantial potential to reduce the application of nitrogenous fertilizer which is becoming one scarcest resource currently due to the increasing energy demand. The application of SRI combination with an appropriate microbial agent could provide better yield without depending on expensive fertilizers, and protect crops from varieties of ailments caused by soil and environmental fluctuations, pests and pathogens.

Thus, SRI rice fortified with suitable microbial agents could solve contemporary environmental issues by curtailing the use of agrochemicals such as fertilizers, and pesticides, reducing global energy demand and consumption in production and transportation of agrochemicals and their environmental costs and contamination that they cause to soil and water.

Conclusion

The use of microbial agents in crop production is gaining greater attention in research and application due to its multiple benefits in the farming system. The combination of SRI and appropriate microbial agents could provide sustainable solutions for multiple issues of crop production. However, the selection of appropriate microbial agents which are active root colonizers and provide better ecological services to plants is equally important.

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Breeding Climate Smart Sugarcane Varieties for Diversified Uses

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Sugarcane is a tropical crop grown in over 100 countries, with Brazil, India, China and Thailand being the major producers. Sugarcane in India dates back to pre-vedic period (2000BC) and the country is also one of the principal centers of origin of the *Saccharum* complex (*Saccharum, Erianthus, Sclerostachya, Narenga, Miscanthus*). Presently, this crop is the prime source of raw material for all major sweeteners produced in the country, while the crop is also emerging as a crop of diversified products. Sugarcane's attention is all the more relevant now when India in its mission for energy security, has achieved a 10% blending of bioethanol with petrol during 2022, while aiming to achieve 20% blending with petrol in 2025. The export of sugar has reached an all-time high of 10.8 MT during 2022, and sugar emerged as the single largest export commodity from the agricultural sector.

Though inter-specific hybridization is the mantra of sugarcane improvement, deleterious effects of climate, human activities and growing importance of the crop for the production of sugar, ethanol, energy, several non-food products, value-added products, fertilizers, other bio-fuels, chemicals and products with high nutritive, industrial and pharmaceutical value necessitates development of climate smart sugarcane varieties and varieties for special needs suitable for specific regions. This adds to the importance of research attention to preserve, characterize and utilize accessions of the Saccharum complex in a systematic way. The wealth of germplasm with potential sources to every stress or combinations of stresses is the strength that sustained sugarcane over a century and for future needs. Like every country engaged in sugarcane improvement retaining a collection of sugarcane clones, which evolves over time with new additions, Indian collection grew over years and now ICAR Sugarcane Breeding Institute houses the largest germplasm collection in the world. In several countries, some early generation progeny derived from *S. spontaneum* have provided good biomass yields, particularly in ratoon crops.

With plateauing of yield experienced during 1970s after a remarkable achievement which heralded a sugar revolution since 1918 in India and also in Indonesia through successful inter-specific hybrids between *Saccharum officinarum* and *S. spontaneum*, which formed the founding clones for variety development worldwide, genetic improvement became a professionally directed and scientific endeavor since 1980. Enhancement of sugarcane germplasm through pre-breeding is a long term research activity, involving collection of new germplasm accessions from natural stress affected regions, maintenance of new and available genetic resources, characterization for different stresses and varied uses based on agronomic, cytological, molecular, anatomical and morphological parameters and utilization. Genetic diversity present in the sugarcane germplasm, among different Saccharum species and related taxa, represents a large reservoir of genes to develop new varieties and hybrids for any character or ecosystem. In India, this is addressed through a national active germplasm assembled at ICAR Sugarcane Breeding Institute at its research centre at Agali near Coimbatore to facilitate wide hybridization under national sugarcane research system to supply fluff of wide crosses to 24 research stations spread across the length and breadth of the country. This initiative unlocks the genetic potential through making available the best parents characterised as donors of the different stresses as outcome of several years of focused research on trait specific germplasm.

A recent assessment of success through harnessing wild resources of leading countrie,s the Indian success has been creditable. While many countries experimented with a large number of germplasm accessions, success in terms of released varieties has been limited to a handful of ancestor clones from *S. officinarum, S. spontaneum and S. barberi* . The reasons for low success rate in comparison with large efforts of over 30 years in Australia were listed by Roach (1984, 1989). Inferior traits in the wild donor clones, difficulties in selecting and combining the appropriate desirable portions of both the wild type and the recurrent parents during subsequent selection cycles have been the major bottlenecks. The Indian experience showed that totally 91 different sources were successfully incorporated into the commercial pool (Hemaprabha *et al.,* 2021). However, reports of many novel creations have been developed from Saccharum complex including Sorghum, bamboo and maize have been encouraging through bridge crosses and other innovative approaches.

Cytoplasm of wild species is another source of novel genes, and different cytotypes of S. spontaneum also could be successfully incorporated to commercial level through repeated backcrossing. Cytoplasm of *Erianthus* was incorporated utilising *S. spontaneum* as a bridge species to create novel cytoplasmic lines in addition to *S. spontaneum*. Premachandran *et al.,* (2012) reported successful development of new cytoplasm substitution lines in sugarcane with the cytoplasm from *S. spontaneum* and *E. arundinaceus*. The F_1 hybrids involving intergeneric hybrids of *S. spontaneum x E. arundinaceus* and *S. spontaneum x E. bengalensis* were backcrossed up to BC_5 stage to get novel hybrids of commercial status. Chromosome contribution from *Erianthus* was confirmed through Genomic In Situ Hybridization (GISH). Two Co canes thus developed are Co 15015 with *E. arundinaceus* cytoplasm and Co 16018 with *S. spontaneum* cytoplasm and are under AICRP testing. Further evaluation of hybrids under CYM series could identify hybrids with high drought tolerance potential (Mohanraj *et al.,* 2018). Intergeneric hybridization at ICAR-SBI has come of age with the release of three varieties from intergeneric hybrids as immediate parents viz. Co 06022, Co 06027 and Co 06030, and quite many hybrid derivatives in advance stages of evaluation.

Several significant findings on trait enhancement using *S. spontaneum* are as providing good sources of resistance to diseases such as sugarcane mosaic, red rot, sugarcane yellow leaf virus, pests and multipests, environmental stress such as cold tolerance, waterlogging tolerance, high temperature, salinity, alkalinity and drought. Linkage drag has been a bottleneck to hastening noblilization process, though some alleles with more favourable effects than in existing commercial materials may exist in *S. spontaneum*. Hence, breeders identify favourable alleles in advanced backcross populations as well as in the donor germplasm with the aid of DNA markers or molecular cytological tools.

In addition to using sugarcane juice for varied uses, wild members of Saccharum complex which have high fibre and low sucrose content are desirable in breeding programs for increasing biomass production, ratoonability, better adaptability to varied climatic conditions, which would further enhance bioenergy production systems. Energy canes with harvestable biomass as high as 279.01 t/ha/year (SBIEC11001) and cane fibre as high as 31.86% (SBIEC 13001) have been developed. Recently an energy cane SBIEC14006 has been commercialized. Since the energycanes are capable of growing in the marginal land with low rainfall, salinity, alkalinity, water logging or hilly slopes, barren lands available around the mill can be profitably utilized. Establishment of energy plantations in a corporate or community mode by bringing groups of farmers will ensure the uninterrupted supply of quality and economically feasible raw materials throughout the year (Govindaraj, 2021).

Second generation ethanol from Lignocellulosic biomass of sugarcane is one of the preferred feedstocks for biofuel production to compensate for the future fossil fuel demand. With a high level of adaptability to biotic and abiotic stress and a lignin content of about 23%, Erianthus species is considered as an exemplary bioenergy crop. Lignolytic enzymes such as lignin peroxidase, laccase, dye-decolorizing peroxidase, ascorbate oxidase, ferroxidase, nitrite reductase and ferroxidase enzymes are considered for developing enzymatic pretreatment options. Kasinathan and aruchamy (2016) described the laccase extracted from Haloferax volcanii strains for treatment of Erianthus biomass to determine lignin breakdown and lignin modified wild clone will be ready in the near future .

Thus sugarcane crop and wild relatives and derived hybrids suited to diverse ecological and environmental situations and being able converters of solar energy provide a varied range of applications for the future requirement and situations. Concerted efforts of multispecialty experts from research and industry with the farmer’s / enterpreneur’s participation are needed to harness the best out of this wonder tropical plant.

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Impact of Rice Cultivation Methods on Insect Pest Incidence and Their Management

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Abstract

Under the influence of fluctuating global climate scenario and limited resources of water availability, different methods of rice cultivation like System of rice intensification (SRI), Direct seeded rice (DSR), Alternate wetting and drying (AWD) and Aerobic rice have become popular as alternatives to conventional transplanting method. Due to these shifting cultivation situations, insect pest profiles have also undergone changes with associated influence on beneficial insects and other natural enemies. Multi-location studies carried out under All India Coordinated Rice Improvement Project (AICRIP) have revealed significantly less incidence of major pests like stem borers, planthoppers in SRI compared to normal rice transplanting method. Overall, the SRI method leads to more robust plant health with enhanced capacity to resist pest attacks. In case of DSR, AICRIP studies have consistently revealed higher incidence of all the insect pests in the normal transplanted method compared to DSR. However, few reports have indicated association of insect pest outbreaks with higher seed rate and plant densities. Limited studies have shown that AWD also has the potential to minimize the incidence of insect pests and diseases compared to irrigated rice. However, soil borne pests, particularly root-knot nematode can be more damaging under aerobic conditions. Field cum laboratory studies carried out at ICAR – IIRR on impact of cultivation systems on the rich insect biodiversity in rice have revealed association of higher total abundance and greater richness of beneficial insect species with SRI management.

Keywords: Insect pests, Prevalence, Establishment methods, Arthropod diversity, IPM

Introduction

Rice is the world's most important food crop, providing a major source of food energy for more than half of the human population. Rice cultivation methods are continuously evolving to meet the challenge of sustaining rice production under changing global climate scenario. With limited resources of water and other inputs, different methods of rice cultivation have emerged, of which, System of Rice Intensification (SRI), Direct seeded rice (wet direct-seeded rice -wet DSR) and dry direct-seeded rice -dry DSR)), Alternate wetting & drying (AWD) method of rice cultivation and Aerobic rice have been potentially promising. These methods provide potential alternatives to the conventional transplanting method of rice cultivation under limited sources of water, land, and other inputs.

Since the onset of the green revolution in rice in the country, insect pests have been the prime biotic stresses exerting considerable pressure limiting rice production. In India, the rapid increase in rice area under high-yielding varieties, mono and continuous culture of rice accompanied by enhanced use of inorganic fertilizers has led to increased incidence of insect pests and diseases. The number of insect pests considered important in paddy cultivation increased from three in 1965 to more than 15 in 2009 (Gururaj katti *et al.,* 2009). Among these, six major insect pests are prevalent in different rice cultivation systems in India. Of them, stem borers have been recorded to cause consistently more damage to the rice crop. Three species, yellow stem borer (YSB), *Scirpophaga incertulas* Wlk. followed by pink stem borer (PSB), *Sesamia inferens* and White stem (WSB) borer, *Scirpophaga innotata* are widespread across rice cultivation systems and regions. Planthoppers are also key pests and are widely distributed across all the rice ecosystems. Two types of planthoppers are commonly observed in India with brown planthopper (BPH) being more dominant than white-backed planthopper (WBPH) in occurrence and distribution. Gall midge (*Orseolia oryzae* Wood-Mason) is another important pest confined mainly to irrigated or rainfed rice including shallow upland and deep-water rice. Similar to stem borer, gall midge is also one of the important hidden pests of rice as most of the pest life cycle is completed within the rice plant. Among the foliage pests of rice, leaf folder (*Cnaphalocrocis medinalis* Guenee) is an important one having the ability to cause severe defoliation. Leaf folder infestation can result in yield loss when the flag leaf is severely affected during the early reproductive stage of the rice crop. In addition to the above, there are a few pests of regional significance such as rice hispa, whorl maggot, case worm, and cutworm/swarming caterpillar which are sporadic but can cause considerable losses depending upon time and place of occurrence.

Rice cultivation methods vary depending on the availability of water resources (**Figure 1**). In recent times due to limited water resources, improved rice cultivation methods like SRI, DSR, AWD and Aerobic rice have become popular (Kumar *et al*., 2009 & 2013). Under these changing cultivation scenarios, insect pest patterns have also altered over time and space with concomitant influence on beneficial insects and other natural enemies.

Experiments have been carried out at ICAR-IIRR farm and multi-locations under the All India Coordinated Rice Improvement Project (AICRIP) since 2005 to know the influence of the cultivation systems on insect pest incidence as well as insect biodiversity. This paper highlights the salient findings of these studies with a view to provide significant leads for successful insect pest management in these diverse scenarios of rice cultivation. Results of a case study to assess farmers' experiences in pest incidence and pest management practices adopted in SRI compared to conventional practices have also been described to focus the efforts towards the development of need-based location-specific IPM.

Waterlogged / low lying	Normal Transplanted rice	Direct seeding/ AWD	Saturated / SRI	Aerobic
Stem borer, Case worm, Swarming caterpillar	Stem borer, Gall midge, Leaf folder, BPH, WBPH, GLH Gundhi bug, Whorl maggot, Hispa, Caseworm	Stem borer, Leaf folder, GLH, BPH, WBPH, rodents	Hispa, thrips, defoliators like leaf folder, stem borer, leaf mite	Soil borne pests like nematodes, root aphids
MORE WATER →				**LESS WATER**

Figure 1. Insect pest incidence vis-à-vis rice cultivation methods influenced by water resources

Insect pest scenario in different rice cultivation systems *vis a vis* conventional method of cultivation

System of Rice Intensification (SRI)

System of rice intensification (SRI) developed in Madagascar in 1980's has gained wider acceptance in many countries including India due to its advantages over conventional method *viz.*, water and seed saving, high yield and less dependent on chemicals (Uphoff, 2003). The components of SRI include the use of young seedlings, careful transplanting of single seedling per hill, wide spacing, controlled irrigation, aerated soil conditions and enrichment of soil through *in situ* incorporation of weeds and the use of organic manures (Gopalakrishnan *et al.,* 2014; Surekha *et al.,* 2015).

Multi-location studies have revealed the incidence of YSB, leaf folder, gall midge, case worm, BPH, WBPH, whorl maggot, and thrips in both SRI and normal methods of rice cultivation (Padmavathi *et al.,* 2009). The incidence of dead hearts (DH) and white earheads (WEH) caused by stem borer has been relatively lower in the SRI method compared to the normal transplanting method at various locations. However, leaf folder incidence was found higher in SRI method at few locations, whereas the incidence of caseworm and gall midge has been at par in both the methods of rice cultivation. In case of planthoppers, BPH and WBPH numbers have been higher in normal cultivation than SRI method (**Table 1**).

Table 1. Insect Pest incidence in Normal and SRI methods of rice cultivation

Method/Treatment*	Per cent damage						Number per hill	
	SBDH	SBWE	LFDL	WMDL	GMSS	CWDL	BPH	WBPH
SRI	9.8	15.5	21.0	12.5	2.7	7.1	9	15
Conventional/ Normal	12.6	25.5	12.9	5.6	4.5	7.8	249	28
Locations	6	6	2	5	3	2	3	3

* Replications - 7

Among various cultivars grown in both methods of rice cultivation, white earheads were found significantly low in IR 64 grown under the SRI method followed by Swarna, Annada, and Krishnahamsa varieties. Scented varieties like Sugandhamathi and Vasumathi were infested more than non-scented varieties (**Figure 2**).

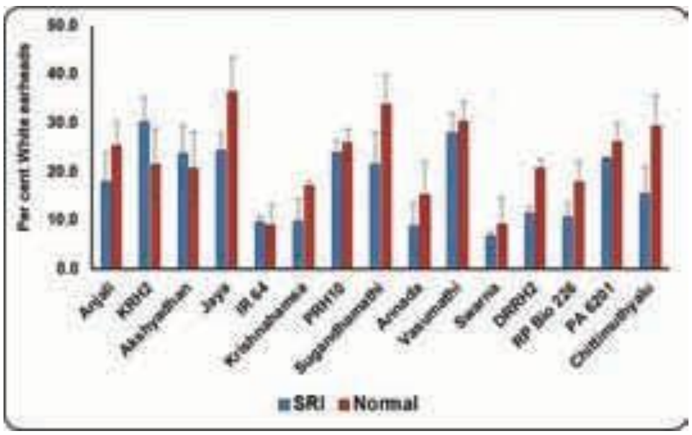

Figure 2. Incidence of YSB in different cultivars grown under SRI and Normal methods of rice cultivation

With the introduction of the System of Rice Intensification (SRI), a new dimension has been added to the changing pest scenario. Ideally, the SRI method leads to healthier and more vigorous plants having better capacity to resist pest attacks. However, the initial management of pests immediately after planting can pose a problem for the farmers. The freshly planted and tender seedlings may not be able to withstand severe hispa and thrips damage as it may severely affect the plant growth. Stem borer is another pest that may create havoc at this stage, if not properly managed. Similarly, wider spacing adopted in SRI cultivation may favour increased hispa but reduce gall midge incidence in the early stages. In the tillering stage, vigorous plant growth with a cluster of tillers may attract defoliators such as cutworms, ear-cutting caterpillars, and leaf folders (Padmavathi *et al*., 2009). However, a significant increase in the number of tillers and leaves should be able to compensate for the loss due to defoliation. In later stages, SRI cultivation may reduce BPH incidence due to increased aeration resulting from wider spacing.

Direct-seeded rice (DSR)

Direct seeding is done in two ways *viz.,* wet-seeded rice and dry-seeded rice. In general, direct-seeded rice is affected by similar pests and diseases as transplanted normal rice. Multi-location studies revealed the incidence of stem borer, leaf folder, gall midge, whorl maggot, hispa, BPH, and WBPH at many locations in both the methods of cultivation, *viz*., normal method and DSR. However, under some conditions, a high seed rate (80-120 kg ha-1) is being recommended for the establishment of DSR and studies have indicated association of an outbreak of insect pests with high rice plant densities. High seed rate causes nitrogen deficiency, reduces tillering, and increases proportions of ineffective tillers, leading to a greater chance of crop lodging accentuated by attack due to planthoppers. Higher pest incidence has also been reported because of dense canopy and less ventilation around plants (especially in broadcast-sown rice with a high seed rate). In another related scenario, higher population densities of leafhopper, *Nephotettix cincticeps* and leaf folder have been reported in machine-transplanted rice than in DSR.

AICRIP studies have consistently revealed higher incidence of all the insect pests in the normal transplanted method as compared to DSR (**Figure 3**).

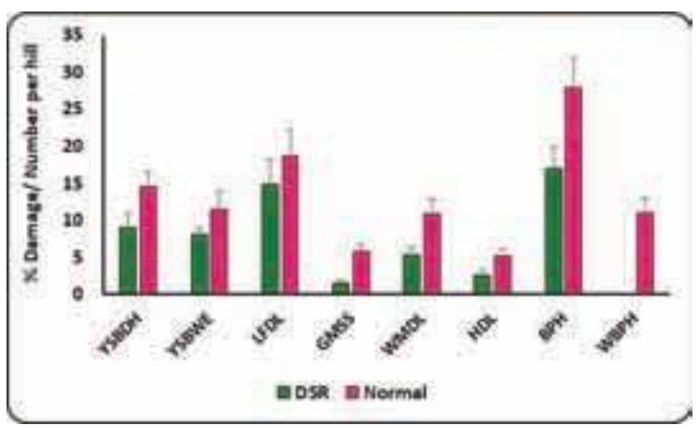

Figure 3. Insect pest incidence in DSR and normal methods of rice cultivati on

Alternate wetting & drying (AWD) method of rice cultivation

Alternate wetting and drying (AWD) is a water-saving technology that lowland (paddy) rice farmers can follow to reduce their water use in irrigated fields. In AWD, irrigation water is applied to flood the field a certain number of days after the disappearance of ponded water. Hence, the field is alternately flooded and non-flooded. The number of days of non-flooded soil in AWD between irrigations can vary from one day to more than 10 days depending on the soil type. AWD also has the potential to minimize the incidence of insect pests and diseases compared to the conventional method.

The intermittent irrigation with AWD in rice has been effective in decreasing insect pest (92 %) and disease (100%) infestation (Bouman, 2007; Bouman *et al.,* 2007; Chapagain and Yamaji, 2010). In a study from Bangladesh, the incidence of stem borer, rice bug, and brown planthopper was reported in the AWD method of rice cultivation (Hasan *et al.,* 2016). Out of 108 farmers who practiced the AWD method, no occurrence of insect pests was reported by 63% of farmers compared to the conventional method. It was found that the stem borer infestation in the AWD method was less (5.6%) compared to the conventional method (27.8%). However, further studies are needed to unravel the relationship between the paddy water environment and insect pests/diseases.

Aerobic rice system (ARS)

ARS is a new production system in which rice is grown under non-puddled, non-flooded, and non-saturated soil conditions. Few studies carried out so far have indicated that the incidence of pests and diseases in the aerobic rice production system is less than in irrigated rice. However, soil-borne pests, particularly root-knot nematode can be more damaging under aerobic conditions (Arayarungsarit, 1987; Nishizawa *et al.,* 1971; Padgham *et al.*, 2004; Soriano and Reversat, 2003).

Factors contributing to change in pest scenario

A number of factors have contributed to the continuing changes in the pest scenario, of which major ones are: a) planting modern varieties over an extensive area, b) growing varieties that do not possess resistance to major pests, c) cultivating rice throughout the year providing a permanent food source to the pests, d) imbalanced use of fertilizers, particularly the application of high levels of nitrogen and e) increased and misplaced emphasis on insecticides use resulting in their indiscriminate application leading to pest resistance, resurgence, secondary pest outbreaks, and other detrimental side effects.

Impact of cultivation methods on insect biodiversity

Earlier studies have revealed that cultivation systems have an enormous impact on insect biodiversity measured by the guild composition of insects captured in the rice field plots subjected to varying cultivation systems including the conventional normal transplanting method. The guild composition includes the proportion of insects that feed on plants (phytophages) as well as natural enemies like predators, parasitoids and other insects that prey upon and regulate the phytophages. The extent of the impact of any cultivation system on the natural interplay of these beneficial agents determines the suitability of cultivation practice to protect the ecological, economic and ultimately the social interests of rice farmers. Earlier studies, are few, scattered and provide only a limited view of the impact of alternative rice cultivation systems such as SRI and DSR.

The present study encompassing the field cum laboratory studies carried out at ICAR – IIRR involved detailed investigations into guild composition associated with changing pest profiles under differing rice cultivation scenarios with special reference to the SRI method.

Under these studies, the guild composition of captured insects revealed that the proportion of insects that feed on plants (phytophages) was higher where conventional cultivation methods had been used, while predator, parasitoid and other insects that prey upon and control phytophages were more in numbers in SRI-method plots. This indicated that there was a higher total abundance and greater richness of beneficial insect species associated with SRI management. The phytophages counted included yellow stem borer, spotted stem borer, two species of leaf folders, stink bugs, hispa, skipper, leaf and plant hoppers. The predators included spiders, coccinellids, staphylinid beetles, predatory bugs, carabid beetles, damsel, and dragon flies. Parasitoids included braconids, ichneumonids, and chalcids (**Figure 4**). Not surprisingly, conventional methods, which include continuous flooding of plots, showed more aquatic arthropods compared to SRI-

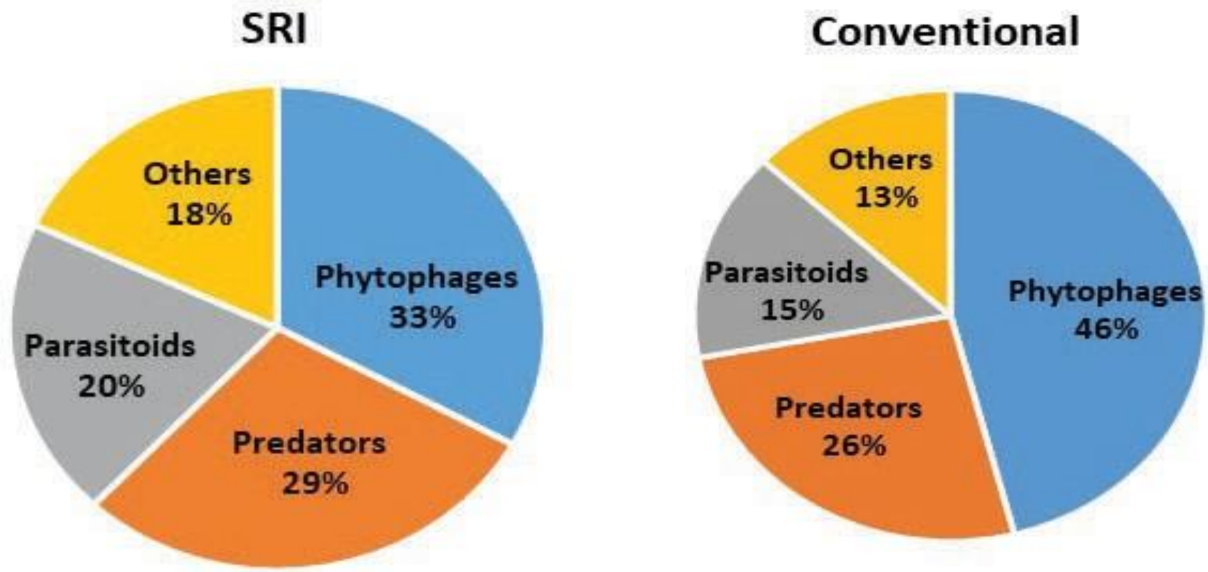

Figure 4: Guild composition in SRI and Conventional method of rice cultivation

method plots. Karthikeyan *et al.,* (2010) and Jayakumar and Sankari (2010) have also reported high spider populations with SRI, while Devi and Singh (2015) have reported higher species diversity and greater Shannon Index with SRI compared to conventional methods.

Integrated Pest Management (IPM)

Rice farmers have been mostly relying on a single tactic of chemical control for managing pest problems, hence it has become imperative to develop an effective and holistic system of tackling pests to make it more environment-friendly, economically viable, and socially acceptable for the farmers. This can be achieved through integrated pest management (IPM), which is an approach to promote natural, economic and social farming techniques through the effective blending of appropriate tactics like growing pest-resistant cultivars (host plant resistance), suitable cultural practices (cultural control), use of eco-friendly pesticides (chemical control), conservation of in situ natural biological control (biological control) and other novel pest control techniques like the use of pheromones, etc. Under the changing cultivation scenarios coupled with global climate alteration patterns, IPM technology development strategies have also evolved to address the twin challenges of altered pest profiles and transforming cultivation systems. This has been made possible by the concerted multi-location research efforts under AICRIP to develop holistic pest management modules appropriate for each cultivation system.

Farmers Experiential Learning study on pest incidence and management under SRI method compared to conventional practices – A Case Study

As a case study to highlight the ecological, economic and social implications involved in carrying out such studies under farmer situations, a field survey was conducted with the aim of assessing farmers' experiences in pest incidence and pest management practices adopted in SRI compared to conventional practices.

Among the insect pests of rice, whorl maggot, rice hispa, stem borer, green leaf hopper and leaf folder were recorded in both methods. Around 70% of farmers did not take up any control measure in SRI whereas, in the normal method, they undertook at least one spraying of chemical pesticide. These included endosulfan, monocrotophos, and quinalphos. Among the SRI adopters, 35% of farmers used indigenously prepared mixtures such as Pancha kavya, Amrita jalam, Pancha jalamrutam, and neem for protection against insect pests.

In the SRI method, the benefit-cost ratio was 1.77 and 1.76 in Katkur and Bonakallur villages, respectively. In conventional paddy cultivation, insecticides accounted for 5% of the cost of cultivation (Padmavathi *et al.,*2008). In the SRI method, this cost is reduced. Moreover, reduction in the usage of pesticides helps in the conservation of natural enemies in the rice ecosystem, protects human and animal health, and reduces environmental pollution.

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Theme III

Resource Use and Conservation in SCI (Natural Farming, Organic Farming, Conservation Agriculture etc.), Climate Resilience and Ecosystem Protection

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Sustainable Agricultural Intensification and Climate Smart Agricultural Practices for Improved Food and Climate Security

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Abstract

The grand challenge of increasing production and access to nutritious and safe food to meet growing populations under threat to climate change and climate variability requires systems and transdisciplinary approaches towards agri-food systems. Sustainable agricultural intensification (SAI) focuses on increasing agricultural production from existing farmland without any adverse environmental impacts. There are three major components of SAI which include: (i) genetic intensification (e.g., focused on improving yields, resistance to pests and diseases, tolerance to abiotic stresses, increasing nutritional quality of food products, and using precision breeding, genetics, and genomics tools); (ii) ecological intensification (e.g., focused increasing diversification, farming, cropping and agroforestry systems, resource use efficiency, integrated water, nutrient and pest management); and (iii) socio-economic intensification (e.g., focused on markets, value addition, income generation, policy, creating enabling environment, and building social capital). Climate-smart agricultural (CSA) practices emphasize greenhouse gas emissions, water footprint, and focus on both adaptation and mitigation strategies. Few selected SAI and CSA practices include minimum and no-tillage; cover crops; crop diversity and genotypes selection for effective water use and stress tolerance; diversification (crop mixtures and rotations; perennials, agroforestry systems; forage crops; dual purpose crops); and nutrient recycling from livestock. Overall, developing adoption and scaling of these practices will require convergence of biophysical and social sciences, participatory approaches, public and private sector engagement and commitment of resources from all donor agencies for research and development, human and institutional capacity building.

Keywords: sustainable agricultural intensification; climate-smart agriculture; food security; climate resilience; diversification.

Introduction

Today about 820 million people around the world do not have access to food and about 2 billion people suffer from malnutrition (undernutrition, obesity, and micronutrient deficiency). Furthermore, our agri-food production systems are under the threat of climate change and climate variability. At the present trend of greenhouse gas emissions, global surface temperatures will continue to increase rapidly. It is projected that the global population will reach more than 9.5 or 10 billion by 2050. Meeting the demands of the growing population will require increasing food production by 55 to 60%. The increased food production must come from existing farmland as we do not have more land to bring into agriculture, and it is not desirable, as it will cause irreversible loss to our natural resources and biodiversity.

Focusing on productivity will continue to be important for addressing food and nutrition insecurity. The goal of our agri-food systems must be to increase food production using environmentally sustainable, economically viable, and socially acceptable ways. This can be achieved by using sustainable agricultural intensification (SAI) and climate-smart agricultural (CSA) practices. The SAI emphasizes the provisioning of safe, nutritious, and healthy food at all times to all people from existing farmland without damaging our natural resources and ecosystem health. The CSA practices are those which are intentional in minimizing greenhouse gas emissions, water footprint and include both climate adaptation and climate mitigation strategies. The SAI has several components, that can be broadly divided into three. First: genetic intensification that is focused on increasing yields; building tolerance to biotic and abiotic stresses; improving nutrition using both traditional methods and novel genomic and gene editing tools. Second: Agroecological intensification that is focused on diversification; farming systems; integration of legumes and perennials; improved agronomy; resource use efficiency; integrated nutrient, soil, water and pest management strategies. Third: Socio-economic intensification focused on developing new markets; access to markets; policy interventions; understanding barriers of adoption; building social capital; creating enabling environments; and institutional building. The use of innovations in digital and geospatial tools; artificial intelligence; mechanization; nanotechnology; precision agriculture; entrepreneurship; private sector partnership; and engagement of women and youth will be critical. Overall, it covers, interactions of genotype, environment, management and social aspects including human and social aspects.

Status of SAI Practices

Pretty *et al.,* (2018) did a global analysis and measured progress towards sustainable intensification by farms and hectares, using seven sustainable intensification sub-types: conservation agriculture, integrated crop and biodiversity, integrated pest management, pasture and forage, trees, irrigation management and small or patch systems. From 47 sustainable intensification initiatives at scale (each >10,000 farms or hectares), it was estimated that about 163 million farms (29% of all worldwide) are practicing forms of sustainable intensification on 453 million ha of agricultural land (9% of worldwide total). They concluded that that sustainable intensification may be approaching a tipping point where it could be transformative. They also analysed the growth in social groups that focused on sustainable agriculture and land management systems (Pretty *et al.,* 2020) using the same seven sustainable intensification types. It was observed that across 122 initiatives in 55 countries the number of social groups has grown from 0.50 million (in 2000) to 8.54 million (in 2020). The area of land transformed by the 170–255 million group members was 300 million ha, mostly in less-developed countries (98% groups; 94% area). They concluded that together with other movements, these social groups could now support further transitions towards policies and behaviours for global sustainability.

Few Selected Examples of SAI and CSA Practices

These are few specific successful examples of SAI and CSA practices which have multiple advantages and help with both increasing overall system productivity, minimize environmental damage, and greenhouse and water footprint. These practices also help with reducing waste, re-using and recycling, and efficiently using all resources including both above and below ground. They are not in any order of importance or preference but include diverse examples from around the globe.

No-Till Crop Production System: Zero or no-tillage (no-till) crop production systems reduce soil erosion, improve soil health, enhance soil microbial diversity, and improve soil water quantity and quality (e.g., decrease sedimentation and pollution of water streams and lakes) and decrease greenhouse gas emissions. Long-term studies show that no-till produces equal yields and is more sustainable and enhances soil and water quality and a healthy environment. However, improved and better access to mechanization tools for planting under no-tillage are needed. In addition, weed management options including diverse herbicides, crop rotation systems, and integrated weed management practices would be needed. No-till crop production also leaves and provides crop residues that provide continuous soil cover to minimize evaporation water loss and improve soil organic matter and microbial activity.

Cover Crops: Several species of cover crops (e.g., legumes and grasses) can be grown in summer and winter seasons to provide continuous soil cover. Cover crops provide multiple benefits to farming systems. They minimize soil erosion, improve physical and biological properties, and enhance microbial communities and activity. Cover crops also break the cycle of pests and diseases and add organic matter and nutrients to soils. The selection of cover crop species that thrive in the target environment and farming needs critical investigation. The choice must consider the availability of soil water and nutrients and its potential impact on the following crop grown in rotation. Cover crops that have added value for grazing or biomass will have greater potential for adoption.

Crop Diversity and Genotypes for Effective Water Use and Stress Tolerance: Crop species vary in the amount of water required for their productivity and response to irrigation. Having the right crop species (e.g., life cycle, tolerance to drought and other abiotic stresses), and matching crop species with available soil moisture and rainfall pattern is critical for the longer-term sustainability of water resources. Crops with various water requirements and rooting depth and soil profiles can improve resource use efficiency. Drought stress-tolerant crop species (for example sorghum, millets, mung beans, and cowpea) not only lower water needs but also can withstand moderate drought stress. Many droughts tolerant and water use efficient cultivars and/or hybrids are available in different crop species.

Perennial Crop Production Systems: Traditionally perennial crop production systems were an integral part of crop production farming systems. However, new intense farming systems moved away from that model. Perennial crops conserve resources better than annual crops and use fewer external inputs and provide environmental sustainability. Some annual crop species are being developed into perennial plants. There are some successful examples (e.g. rice, sorghum and kernza) that are showing progress. However, longer-term sustainability and economic viability need further investigation. In addition, further research is needed on potential adoption and their suitability inappropriate land use (e.g. particularly in marginal areas vs. intensive production systems).

Agroforestry Systems: Integrating selected trees and woodlands into farming systems offers ecological, nutritional, and economic benefits. These systems do not compete with the crops – but are complementary and provide nutrients, improve soil nutrition, minimize soil erosion, sequester carbon, and provide ecosystem services through wildlife, water, and air quality. In the longer term, these systems enhance environmental and ecosystem services. These systems can also support livestock and benefit crops when used in an intercropping system. Agro-forestry systems also provide greater diversification and address nutritional needs and income to producers. There are many examples of leguminous trees and shrubs from Africa. In addition, the multi-layered systems of the crop with different heights, morphology, and phenology are popular in Asia.

Crop Rotations and Integrated Management of Pests, Diseases, and Weeds*:* Crop rotations play a key role in managing pests, diseases, and weeds. These pressures are less in crop mixture and crop rotations because insects, pests, and weeds are or can be specific to hosts and crop diversity will break their lifecycle. In addition, having trap crops can also concentrate the pest in particular areas and can be controlled more effectively than if pests are spread across. Push-pull technology where a certain plant species pushes the pest away from the main crop and a trap crop pulls pests towards them have enormous potential to manage pests in a particular cropping system. The use of these methods will minimize herbicides and pesticides and enhance environmental sustainability. Further, the use of integrated pest and weed management practices which includes both biologicals and chemicals (diverse chemical and mixtures) must be used to avoid the development of resistance. Such practices can also enhance natural predators that are efficient in managing pests within the limits.

Forages Crops for Enhanced Animal Nutrition: Sustainable farming systems that incorporate crops and livestock systems need to target forage and pasture crop species to enhance nutrition. Inadequate quality of forage or animal feed not only decreases the productivity of livestock but also the quality of its products. Animals grazing on nutritious forages improve the quality of livestock and quality food that is nutritious, healthy, and safe for humans. Furthermore, improved forage production systems will also minimize the water and carbon footprint of meat production. In recent years' dual-purpose crop varieties (e.g., pearl millet, sorghum, cowpea, soybean, groundnut) are available where grain is human consumption and biomass is animal feed. Some of these varieties are biofortified and have a higher nutrient density in grains and biomass to address the nutritional needs of animals and humans.

Diversification of Pastures and Grazing for Nutrient Recycling: Legume pastures particularly improve soils through biological nitrogen fixation from nodules in the roots. In addition, the leaves of legumes also contain nitrogen that can improve soil quality. Both depleted soils and soils with excess nutrients are not beneficial to the ecosystem. Appropriate pasture management is critical for creating nutrient balance and nutrient availability of the different grazing systems (natural grasslands and legumes) and the combination of livestock species. In addition, effective pasture plant species can also enhance the quality of livestock production and subsequent human nutrition and health.

Soil and Nutrient Management Practices that Minimize Nutrient Loss and Pollution: Methods that will optimize the use and increase input use efficiency (particularly water and nutrients) are critical. Implementing nutrient stewardship principles of the 5 Rs which include – the right source of nutrients, applied at the right rate, at right time, at the right place, and using the right methods to enhance efficiency and sustainability. Using these principles will not only allow us to investigate biological sources of nutrients and minimize our reliance on external inputs but also increase efficiency. These options include the integrated use of both inorganic and organic sources (e.g. legumes, annuals and perennials, biomaterial, composts) of nutrients for economic and environmental benefits.

***Integrated and Efficient Water Management Practices*:** Managing and effectively utilizing water is key to increasing water productivity. In-situ water capture (harvesting) methods such as tied ridges, contour ridges, and the use of live mulches must be considered to increase the infiltration of rainwater and decrease water runoff, soil erosion, and nutrient losses. Further using watersheds and slopes to collect rainwater and store it in ponds and using it for irrigating commercial crops is an effective method to improve water productivity. Stormwater and wastewater from industries and households must be utilized for irrigation. For irrigation technologies, using the principles of 5 R: right source – groundwater, surface water, collected water (ponds), or in-situ water harvesting or recycled water; right rate (how much to irrigate) – depending upon the season, crop needs, soil type, and stored soil moisture; right time – when to irrigate during the crop cycle (most sensitive stages such as planting, pre-flowering, flowering, and grain filling); right method – sprinklers, drip irrigation, sub-surface irrigation; and right place – soil depth, slope and depth. Using these methods will not only increase water use efficiency and water productivity.

***Nutrient Recycling from Livestock to Crop Production Systems**:* Manure from livestock contains highly valuable nutrients (N and P) that are essential for crop production. Using manure as a source of fertilizer will minimize the dependence of crop production on fossil fuel-intense inorganic fertilizers. In addition to the direct value of manures, the by-products can also be used for certain commercial products including the production of biogas. However, the balance of manure production and nutrient recycling needs for crop production and its integration requires proper management and planning to make it environmentally safe and sustainable.

Conclusions

The SAI and CSA practices provide holistic solutions to challenges of food, nutrition and climate insecurity. Development, adoption and scaling of best management practices will require integration and convergence of biophysical and social sciences, transdisciplinary and participatory approaches, public and private sector engagement, dedicated support and commitment of resources from all donor agencies, and public support for innovation, human and institutional capacity building. In addition, agricultural research and education organizations must restructure, change and adapt to find local solutions to global challenges and develop a dynamic workforce that deals with societal broader issues and can find local solutions to global problems. Finally, researchers and educators must directly and effectively engage with policymakers and citizens to show the value of research and development and return on investments.

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Precision Agriculture for Transforming Rice-Based Food Systems under Stress-Prone Environments

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Introduction

Rice is the major staple food for nearly 4 billion people worldwide and 800 million people in India. Despite considerable advancements in rice research and development, a number of issues and challenges have put rice farming in a precarious position. In Asia, rice is primarily grown in four different types of ecosystems: flood-prone, upland, rainfed lowland, and irrigated. But the primary hotspots for the concurrent occurrence of abiotic (drought, submergence, and/or salinity) stresses are the rainfed rice ecosystems in South and Southeast Asia. Abiotic stressors can affect about 16.33 million hectares (m ha) of rainfed arable land in India, including salinity (3.79 m ha), flood (5.36 m ha), and drought (7.18 m ha) (3.79 m ha). Resource-poor small and marginal farmers in these areas mostly depend on the rice-based cropping system (RBCS) for their food and livelihood. But the productivity of fragile rainfed environments often becomes low due to multiple stresses along with different biophysical and socio-economic issues (Singh *et al.*, 2017). Emerging vulnerabilities to monsoon variability and climate change make rainfed agricultural systems contribute around 44% of the food production from about 56% of the net cultivated area in the country. Farmers are still faced with a problem that results in risk-averse input management and prevents them from taking advantage of the regular (non-stress) year because of the monsoon aberrations and extreme weather events that are becoming more frequent (Singh, 2021). Location intelligence through precision rice farming is needed to address the variability at different scales. As the first line defense against climate threats and vulnerabilities, it is imperative to deploy stress-tolerant rice varieties (STRVs). In addition, precision agronomy, including improved management interventions, provide numerous opportunities to unlock the untapped potential of improved rice genotypes and bring the resilience of rice-based food systems under stress-prone environments.

Major challenges

Rice production under both the irrigated and rainfed systems in Asia are still being impacted by climate change. To continue producing enough rice to feed the growing population, there are numerous challenges to address and overcome. The major challenges include degrading natural resource base (soil and water), low input use efficiency, extreme climatic vulnerabilities, inadequate farmers' awareness (traditionalism in rice farming and burning rice straw), labor migration from rural to urban areas (growing shortage and high wages), inclusion of women and young people (unemployed youths), fragmented and small landholdings, diminishing profit margins (low incomes of many rice farming households) and environmental concerns. There is an urgent need to address these emerging challenges for improving the livelihood, nutrition, and income of smallholder farmers and their families. The International Rice Research Institute (IRRI) has been working with R&D institutions (both national and international), farmers, extension agents, policymakers, and other stakeholders to deliver consolidated research and education support services for achieving the major Sustainable Development Goals.

Agronomic Innovations and Interventions

i) Drought management

Drought is the most important abiotic stress that affects about 23 m ha of rainfed rice in South and Southeast Asia. The drought-tolerant rice varieties (DTRVs) of short- to medium-duration groups yield about 0.8-1.0 t/ha under severe drought stress situations, where the majority of farmers' preferred varieties typically succumb and produce insignificant or nominal yields (Dar *et al.*, 2020). The DTRVs (DRR Dhan 42, DRR Dhan 44, DRR Dhan 46, DRR Dhan 47, Sahbhagi Dhan, Shusk Samrat, etc.) can withstand dry spells for up to two weeks during the active tillering stage and even produce more or less double the yields of popular rice varieties (Dar *et al.*, 2020). Even they can perform better than the currently grown popular rice varieties (Damini, Moti, Sarju 52, Lalat, Swarna, etc.) under normal conditions in drought-prone areas (Singh, 2021). DTRVs can efficiently withstand drought stress and exhibit about 9-20% higher rice productivity over the recommended dose of fertilizers (RDF) alone when supplemented with the exogenous application of nutrients (calcium, zinc, and iron), which are inadequate under moisture stress conditions (Lal *et al.*, 2019). Optimal nutrition is a powerful drought-escaping strategy that greatly influences the water circulation within rice plants. Foliar application of potassium can improve the source-sink relationship as well as grain productivity through the retention of chlorophyll pigments during water shortage (Kumar *et al*., 2017). Other management interventions include choosing the appropriate crop establishment methods, seed priming, integrated weed management, using soil conditioner (hydrogel), soil/dust/straw mulching, etc. (Singh *et al*., 2020). While the improved (drought-tolerant) varieties and best management practices (BMPs) can provide about 14 and 12% yield advantages over the farmers' preferred varieties and farmers' management practices (FMPs), respectively, combination of improved varieties and BMPs together can give about 20% yield gains over the farmers' varieties and their own management in rainfed upland areas.

ii) Submergence management

Submergence is another significant abiotic stress that affects nearly 15-20 m ha of rice fields in South and Southeast Asia (Singh, 2021). According to field trials, SUB1 introgressed rice varieties (Swarna-Sub1, Samba-Sub1, BINA Dhan 11, CR 1009-Sub1, IR 64-Sub1, etc.), even after 10-15 days of flooding, can yield about 1-3 t/ha more than their recurrent parents (Singh *et al*., 2009). Proper nursery management (sparse seed rate, balanced nutrition), use of healthier and sturdier seedlings (35-40 days old), and post-submergence nutrient management (20-20 kg additional N-K_2O/ha at 5-7 days after de-submergence) help improve better crop survival with an additional yield gain of 0.5-1.0 t/ha in the STRVs under flood-prone rainfed lowland environments. Only improved management can give about a 19% yield advantage over the FMPs in coastal rainfed lowlands, whereas the stagnant flood tolerant rice varieties (such as Amal-Mana) with matching management practices (MMPs) involving transplanting of 2 seedlings/hill at a spacing of 15 cm x 15 cm and application of nutrients at 50-30-15 kg N-P_2O_5-K_2O + 5 t FYM/ha) exhibit about 73% higher grain yield than the farmers' preferred varieties grown with the existing practice (Sarangi *et al*., 2016).

iii) Salinity management

Rice productivity often becomes very low (<1.5 t/ha) in salt-affected areas of Asia, which remain either under-exploited or unexploited due to the presence of excess salt and other soil-related problems (Singh, 2021). A number of rice varieties such as CSR 36 (Naina), CSR 43, CSR 46, CSR 60, Jarava, Luna Sampad, Luna Suvarna, DRR Dhan 58, Narendra Usar Dhan 2008, Gosaba 5, Gosaba 6, etc. have been identified or developed for growing on degraded soils, compared with normal soil areas, the salt-affected areas need precision management practices for rice cultivation. The major recommendations for growing salt-tolerant rice varieties in coastal areas include using adequate organic manure (FYM, green manuring with *Sesbania* or *Azolla* as a biofertilizer), higher nitrogen doses (100 kg N/ha) in the nursery, transplanting three to four seedlings per hill at a spacing of 20 cm x 15 cm, and applying 150-60-40-5 kg N-P_2O_5-K_2O-Zn/ha in the main field. While the tolerant rice varieties (such as CSR 43) provide about 16% yield gain over the farmers' preferred varieties (such as Ganga Kaveri, Moti and Narendra 359), the same STRVs with the appropriate management practices (MMPs) increase the grain productivity by about 8 and 16% over current recommendations (BMPs developed by the ICAR-Central Soil Salinity Research Institute) and FMPs, respectively. Combining the MMPs with improved varieties can exhibit about 35% higher yield than the farmers' varieties and FMPs (Singh *et al.*, 2016).

iv) Management of multiple stresses

Successive occurrences of abiotic stresses such as heat, drought, submergence, and/or salinity within the same cropping season have led to incremental rice yield losses at farmers' fields. The Bill and Melinda Gates Foundation (BMGF)-funded project, 'Stress-Tolerant Rice for Africa and South Asia' (STRASA), has assisted millions of farmers who grow their crops primarily in rainfed environments to achieve remarkably higher yields despite abiotic challenges like drought, flood, cold, salt, and iron toxicity. With the use of IRRI breeding materials, climate-smart rice varieties such as CR Dhan 801, CR Dhan 802 (Subhas), and DRR Dhan 50 have been developed to combat multiple stresses in India. The Nepal Agricultural Research Council has also released Bahuguni Dhan 1 and Bahuguni Dhan 2 for flood- and drought-prone areas. BRRI Dhan

78, released by the Bangladesh Rice Research Institute, can tolerate vegetative stage flooding and reproductive stage salinity. The multiple STRVs provide 4-5 t/ha yield under normal conditions and 2.9-4.0 t/ha under varying levels of abiotic stresses (Singh, 2021). Since climate change poses a big challenge to smallholder resource-poor farmers, giving them better access to Green Super Rice (GSR) varieties is imperative. Many farmers are highly reluctant to apply external inputs in harvesting more output due to unpredictable weather patterns. Promising GSR genotypes are highly input-efficient, and they can withstand multiple abiotic stresses. Advancing agronomy of new GSR genotypes would significantly boost rice production and productivity in stress-prone vulnerable areas (Singh, 2021).

v) Precise and mechanized direct-seeded rice

Direct-seeded rice (DSR) has been emerging as a cost-effective and climate-resilient alternative to puddled transplanted rice (PTR) in South and Southeast Asia. Despite its multiple benefits, several studies have questioned the medium- to long-term sustainability of DSR-based systems because of yield decline, early season flooding, low germination under anaerobic conditions, irregular stand establishment, intense weed problems, soil sickness (micronutrient deficiencies), etc. Recently identified anaerobic germination (AG)-tolerant lines (like IR 14-D-177, IR 15-D-1072, etc.) with an improved management package provide a ray of hope for the popularization of DSR in rainfed lowland and other suitable environments (Singh, 2021). Lal *et al.* (2018) reported higher grain yields of IR 64-AG (21%), IR 64-Sub1 (16%), and IR 64 (19%) with the tailored management practices. Screening of weed competitive cultivars and their better bet agronomy is an innovative strategy for precise DSR. Dry-DSR (drill-DSR and precision broadcast-DSR), in combination with integrated weed management (IWM) may offer a pathway for simultaneously reducing costs and markedly increasing productivity (Panneerselvam *et al.*, 2020). The herbicide-tolerant (HT) rice varieties can be a game changer in improving crop performance and facilitating wider adoption of DSR. There is also a need to assess the extent of water saving, system productivity and resource budgeting of rice-based production systems under different micro-irrigation systems (surface and sub-surface drip). However, DSR can be made robust, mechanized and precise for its multiple advantages at the system level, not only during the rice phase.

vi) Precision agronomy

One of the most recent advancements in precision agriculture is a data-driven agronomic intelligence system, which uses machine learning techniques to deliver soil and crop management recommendations for each location (even at the 250 m pixel level). This geographic information assists fertilizer producers in creating custom blended fertilizers to address specific regional soil fertility problems and positioning the fertilizers where a high response is anticipated. Seed, pesticides, and the market sector can all benefit from similar intelligence to reduce costs while increasing resource use efficiency. The IRRI has developed Rice Crop Manager as a decision-making tool that offers site-specific fertilizer recommendations in irrigated and stress-prone rice-based systems (Singh *et al.*, 2022). To improve yield benefits and reduce greenhouse gas (GHG) emissions in rice production, farmer-friendly tools like Green Seeker and leaf colour chart (LCC) are helpful (Singh *et al.*, 2022). Similarly, IRRI has developed a number of digital tools (such as Easy Harvest, GHG Emission Calculator, Rice Doctor, RKB, SeedCast, WeRise, etc.) to support the research and farm management requirements in the rice sector. In addition to preventing eutrophication and water resource pollution, nano-fertilizers are expected to improve crop performance in terms of ultra-high absorption, nutrient use efficiency, etc. Scaling of alternate wetting and drying (AWD), sprinkler and drip irrigation systems issue under rainfed environments. AutoMon^{PH} is an Internet of Things (IoT) solution that makes it possible to schedule irrigation, monitor and report in real-time, and compute methane emissions more easily. Laser land levelling improves crop establishment and uniform maturity, increases input use efficiency, boosts yield, reduces weed infestations, etc. For precise site-specific weed management, IRRI and collaborating partners are also developing an Android-based beta version of WeedApp. Geographic Information Systems (GIS) and related Earth-observing technologies like Remote Sensing (RS), Global Navigation Satellite System (GNSS), and Unmanned Aerial Vehicles (or drones) offer a variety of applications, including crop growth monitoring, modelling and forecasting, damage assessment, pesticide applications, rice-fallow mapping, data-driven dynamic agro-advisories *etc.*, which would help increase the productivity and sustainability of rice-based systems (Singh *et al*., 2022).

vii) System diversification, intensification, and optimization

Building the resilience of RBCS under climate change becomes sensible and cost-effective through crop diversification and intensification in space and time. The effects of harsh weather conditions, such as the unpredictable and variable monsoon in rice and the terminal heat stress in wheat, can be alleviated with proper crop management and timely crop establishment. Transformative gains in the wheat yields are achievable only when rice and wheat are managed as a coupled system in eastern India (McDonald *et al.*, 2022). It has been revealed that wheat yield becomes 8-10% higher when grown after DSR as compared to when grown after PTR (Kumar and Ladha, 2011). Food security, profitability, and climate resilience will benefit from the efforts to "keep time" through improved management of the annual cropping calendar both now and as a base for adaptation to progressive climate change (McDonald *et al.*, 2022). Short- to medium-duration STRVs can create new potentials for transforming rice-based systems through diversification, intensification, and optimization when combined with alternate crop establishment methods and scale-appropriate mechanization. As experienced with the Cereal Systems Initiative for South Asia, timely rice establishment along with shorter-duration STRVs like Sahbhagi Dhan (115-120 d) allows better utilization of residual soil moisture for the succeeding crop and permits mustard planting in early October, followed by mungbean or maize in spring. This results in an increase in system-level productivity by nearly 63% and system-level net income by 88–122%, compared with the current practice of long-duration rice varieties followed by late planting of wheat (Singh, 2021). When combined with the proper technological interventions and best management practices, the introduction of *rabi* pulses (lentils, Lathyrus, and chickpea) in rice fallows under *paira* (*utera*) conditions with residual moisture conservation not only aids in the conversion of mono-cropped areas into double-cropping systems but also expands the opportunities for improving system productivity, soil health, and diet nutrition (Singh *et al.*, 2020).

Conclusion

Rice production is highly vulnerable and unreliable to climate change. Risks and concerns are further intensifying due to knowledge gaps among the farmers who usually grow rice varieties with conventional practices, including suboptimal crop management. Compared with irrigated rice, rainfed rice typically confronts greater risks and hazards. The STRVs of short- to medium-duration groups aid in accommodating the diversified, resource-efficient, and remunerative crops in succession while offering farmers yield insurance. Being tolerant enough to endure weather aberrations and abiotic stresses, the STRVs become elastic to fit into the climate-resilient cropping systems and give significantly more grain yield than their recurrent parents with and without stress conditions. They can produce an additional yield of 0.5-1.0 t/ha when raised using tailored management practices. In conclusion, precision agriculture needs to be summed up as a holistic approach from the crop planning to the post-harvest processing phase of production, deploying improved genotypes, cutting-edge technologies, best-bet management practices and scale-appropriate mechanization with a view to enhance the system resilience, productivity, and profitability of the RBCS under stress-prone fragile environments.

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Climate Change: Impact, Issues and Strategies

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Abstract

Agriculture production of India has been continuously rising; however, India still continues to have an alarming figure of undernourished population. Global climate change is widely viewed as one of the most significant challenges society is facing today. Combined with increased competition for land, water and labour from non-food sectors, climate change and associated increase in climatic variability will exacerbate seasonal/annual fluctuations in food yield. There are many options to mitigate the negative impacts of climate change, to minimize risks to agricultural systems. Options range from change in crop management, such as sowing time, stress resistance varieties, change in cropping systems and land use, to adjust to new climates. Government of India through its various schemes are also helping the country to adapt and mitigate the vagaries of climate. CRIDA with the help of NICRA and its climate related studies are identifying and demonstrating various climate resilient technologies to Indian farmers.

Key words: Climate change, NICRA, Adaptation Stress resistance, Resilience

Introduction

The world population is expected to increase by a further three billion by 2050 and 90% of the three billion will be from developing countries that rely on existing land, water, and ecology for food and well-being of human kind. The Intergovernmental Panel on Climate Change (IPCC) in its sixth assessment report (AR6) had warned that 1.5℃ warming was likely to be achieved before 2040 itself. Climate change poses many challenges to growth and development in South Asia. The Indian agriculture production system faces the daunting task of feeding 17.5% of the global population with only 2.4% of land and 4% of water resources at its disposal. The global warming of 1.5°C and 2.0°C will be exceeded during the 21st century unless the predictions in the carbon dioxide and other GHG emissions occur in the coming years. The climate change is manifested in terms of rising temperature, more variable rainfall patterns, rise in sea level, increased frequency of extreme climatic events such as drought, floods, cyclones, heat wave, etc. Though climate change is a global phenomenon, the impacts are more inequitable in the sense that developing countries will be more affected. India, being a developing country, with a large population depending on agriculture will be more affected by climate change. Climate change affects agriculture directly through crop yields and indirectly by influencing water availability and changes in pest and pathogen incidence.

India is especially vulnerable to climate change due to its large population's reliance on agriculture, the excessive demand on its natural resources, and its comparatively ineffective coping mechanisms. The warming trend in India over the past 100 years has indicated an increase of 0.6°C, which is likely to impact many crops, negatively impacting food and livelihood security of millions of farmers. Reduced food grain yield, loss of vegetable and fruit harvests, fodder scarcity, shortage of drinking water for animals throughout the summer, forced animal migration, and severe losses in the poultry and fishing industries have all been reported, posing a threat to the rural poor's lives. As a result, increasing agricultural productivity is vital for maintaining food and nutritional security for all, particularly resource-poor, small, and marginal farmers who will be the most affected. Long-term climate change could have serious effects for the poor's livelihood security if adaptation is not planned. Other natural resource-based sectors are also important for the country's economic development. Field crops, horticulture, livestock, fisheries, and poultry are all strongly associated with various United Nations Sustainable Development Goals (SDGs), including zero hunger, nutrition, and climate action, among others.

Impact of Climate Change on Crop and Livestock Productivity

Studies on impacts of climate change on agricultural crop yields predicted that irrigated rice yields are likely to be reduced by 4% in 2020, 7% in 2050 and by 10% in 2080 scenarios. Studies conducted at the Indian Agricultural Research Institute and elsewhere indicated a yield loss up to ~9 per cent for wheat, ~12 per cent for irrigated rice, ~18 per cent for maize, ~12 per cent for mustard, and ~13 per cent for potato by 2040 under RCP 4.5 scenarios without adaptation as compared to the mean yield between 2000-2007 despite CO_2 fertilization effects (Naresh Kumar *et al*., 2020). On the other hand, rainfed rice yields in India are likely to decrease only marginally (<2.5%) in 2050 and 2080 scenarios. On an all India basis, yields of groundnut, soybean and cotton are projected to improve due to climate change. Similarly, chickpea yield is projected to improve (by 17-25%) in Haryana and central Madhya Pradesh but is projected to decrease by 7- 16 % in southern Andhra Pradesh in 2050 scenario. When late and very late sown wheat also were taken into consideration, the impacts are projected to be about 18% in 2020, 23% in 2050 and 25% in 2080 scenarios. *Kharif* groundnut yields are projected to increase by 4-7% in 2020 and 2050 scenarios where as in 2080 scenario the yield is likely to decline by 5%. However, a large spatial variability for magnitude of change in the productivity is projected. Climate change may likely to benefit potato in Punjab, Haryana and western and Central UP by 3.46 to 7.11% increase in production in 2030 scenario, but in West Bengal and southern plateau region, potato production may likely to decline by 4-16% by 2030. Climate change is projected to affect grain quality as well. Grain protein is projected to reduce by about 1.1 % in high CO_2 and low N input conditions in wheat (Asseng *et al*., 2018). In addition to protein, the concentration of minerals such as Zn and Fe is also likely to reduce in many crops.

Research work in CRIDA shows that high temperature and its interaction with elevated CO_2 (eCO_2) significantly affected physiological, biochemical, biomass and yield parameters of groundnut genotypes grown on Alfisols in Free Air Temperature Elevation (FATE) plots. There was significant variability between the selected groundnut genotypes for their performance including seed yield under eT and eT+eCO_2 conditions. The superior performance for seed yield of groundnut genotype K-9 at high temperature of >40^{o}C, while responsiveness to elevated CO_2 even at high temperature were due to their ability to maintain better pod and seed number as well as improved test weight indicating their role under these conditions. The eCO_2 significantly improved the total biomass pod number and pod weight of the selected groundnut genotypes even at high temperature. Among the four groundnut genotypes, the better performance of K-9 under high temperature was attributed to its capacity to accumulate significantly higher concentrations of osmotic solutes especially proline and total soluble sugars, which led to better RWC and increased cell membrane stability. This indicated that the presence of eCO_2 ameliorated the negative impacts of elevated temperature of >40^{o}C on this C3 leguminous oil seed crop.

Apart from Crop, the livestock sector is also projected to be significantly affected by climate change. Risks to plants and animals in home gardens in dry districts of West Bengal are becoming increasingly visible (Jana and Roy, 2020). The thermal stress affects the quantity and quality of milk, and reduces body weight of goats. It is estimated that this will reduce milk yield by 1.6 million tonnes in 2020 and >15 million tonnes in 2050 (NPCC report, 2012).

Adaptation strategies

Climate change is a long-term phenomenon and agriculture sector respond to evolving climate in different ways in terms of adaptation and coping mechanisms. Farmers have been adapting to climate variability and change over years though such an adaptation was not explicitly planned. Change of crop varieties, alteration of sowing dates, change of crop choice, investment in irrigation, etc. are some of the adaptation measures that we have adopted in response to climate variability and change. Insurance against weather induced risk is an important adaptation measure that helps farmers smoothen their income and consumption and enable them survive a risk. Contingent crop planning is another risk management component that aims at ensuring some income to the farmers in the event of any aberrations in the weather during the crop season. ICAR prepared district-wise contingency crop plans for all rural districts in India for coping with monsoon aberrations (www.agricoop. nic. in). For this to be effective, availability of seed of the appropriate crop and variety is a prerequisite.

National programmes for climate change adaptation

The National Mission of Sustainable Agriculture was launched in 2010 as part of the National Action Plan on Climate Change (NAPCC) to promote sensible resource management. It was one of eight missions under the NAPCC. The *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY) was created in 2015 to solve water resource challenges and provide a long-term solution that promotes Per Drop More Crop by promoting micro/drip irrigation for optimal water conservation.

In collaboration with the Indian Council of Agricultural Research and state governments, the *Paramparagat Krishi VikasYojana* mission was implemented to extensively utilise adaption of climates mart practices and technology.

Green India Mission was started by the Government of India in 2014 under the auspices of the NAPCC with the primary goal of protecting, restoring, and increasing India's declining forest cover, thereby reducing the negative consequences of climate change. The launching of the Prime Minister's *Phasal Bhima Yojana* with its better provisions was rightly launched to address the issue of changing climate.

To maintain soil health, the Government of India has created the Soil Health Card scheme, which aims to analyze cluster soil samples and advise farmers on their land fertility condition. In addition, Neem Coated Urea was created to reduce the overuse of urea fertilizers, protecting soil health and providing plant nitrogen.

Programmes such as the National Project on Organic Farming and the National Agroforestry Policy were implemented in 2004 and 2014, respectively, to incentivize farmers with increased financial benefits and ecosystem conservation. These policies attempt to provide plant nutrients in the form of organic amendments, boost soil carbon stock, and protect soil from erosion.

National Initiative on Climate Resilient Agriculture (NICRA)

To meet the challenges of sustaining domestic food production in the face of changing climate and to generate information on adaptation and mitigation in agriculture, the Indian Council of Agricultural Research (ICAR) launched a flagship network project 'National Initiative on Climate Resilient Agriculture' (NICRA) during 2011, presently renamed as National Innovations in Climate Resilient Agriculture. NICRA is by far the largest farmer-participation outreach programme ever attempted in the subject of climate change adaptation anywhere on the planet. The research organization is in charge of programme planning, coordination, monitoring, and capacity building at the country level (ICAR-Central Research Institute for Dryland Agriculture). Krishi Vigyan Kendra (KVK; Farm Science Centre) under the Division of Agricultural Extension of the Indian Council of Agricultural Research (ICAR), All India Coordinated Research Project for Dryland Agriculture (AICRPDA) centres, and Transfer of Technology divisions of various ICAR Institutions across the country are responsible in implementing the project at village level through farmers' participatory approach. The major objectives of the project are: to enhance the resilience of Indian agriculture to climatic variability and climate change through strategic research on adaptation and mitigation; to validate and demonstrate climate resilient technologies on farmer's fields; to strengthen the capacity of scientists and other stakeholders in climate resilient agriculture and to draw policy guidelines for wider scale adoption of resilience-enhancing technologies and options. The project is being implemented through 3 major components viz. Strategic research through network and sponsored/ competitive grants mode, Technology demonstration & dissemination and Capacity building.

Technology demonstration component (TDC)

The TDC is a participatory programme of NICRA involving farmers to demonstrate site-specific technology interventions on farmers' fields for coping with climate variability in climatically vulnerable districts, to generate awareness and build capacity of farmers and other stakeholders on climate resilient agriculture and to evolve innovative institutional mechanisms at village level that enable the communities to respond to climate stresses in a continuous manner. The Krishi Vigyan Kendra (Farm Science Centres) located in the district is implementing the programme in 121 districts, the Centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA) implementing the programme in 23 districts and the ICAR Institutes involved in the implementing in 7 districts. Eleven Agricultural Technology Application Research Institutes (ATARIs) of ICAR are involved in coordinating the project in their respective zones. NRM interventions included site specific rainwater harvesting structures (RWH) in drought affected areas; recycling of harvested water through supplemental irrigation to alleviate moisture stress during midseason dry spells; improved drainage in flood-prone areas; conservation tillage; artificial groundwater recharge and water saving micro-irrigation methods were demonstrated.

Conclusion

Risks to food systems with ripple effects on income security of the agricultural sector and nutritional security of the population can originate from climatic factors. Though there are many adaptation strategies and technologies available the reach of these technologies to the people is limited. Indian researchers and policy makers should work hand in hand to address these issues and mitigate the negative impacts of climate change to feed the future population.

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How System of Rice Intensification Conserve Resources, Benefits Environment and Resilient to Climate Change

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Abstract

Conventional paddy production is the world's largest single consumer of water and uses 34-43% of the total world's irrigation water or 24-30% of the total world's freshwater withdrawals. Water scarcity constrains agricultural production, particularly for rice, one of the most important global food crops. Adopting a system of rice intensification (SRI) can raise yields and income while using lesser water and other inputs. Additional benefits of SRI are diminished greenhouse gas (GHG) emissions, less runoff water pollution, and greater climate resilience. Changes in crop and water management practices for growing rice offer improvement in food security, could conserve resources, benefits the environment, and be adaptable to climate change. Evidence to support these facts is discussed here in this paper.

Key words: Rice, Growth, Climate change, Greenhouse gas emissions, Flooding rice

Introduction

Increasing water scarcity, rising costs of inputs, growing environmental degradation, and climate change poses severe threats to agricultural production (Nelson *et al*., 2009). Rice is a staple food for billions of people and is the largest consumer of water within the agricultural sector and increasing water shortages threaten its sustainable production to feed human beings. Existing rice production practices rely heavily on high seed rates, mineral fertilizers, chemical biocides, and irrigation water. Conventional paddy production is the world's largest single consumer of water and uses 34-43% of the total world's irrigation water or 24-30% of the total world's freshwater withdrawals. It gives negative impacts on soil health and water quality while increasing production costs and lower returns (Peng *et al*., 2010).

Growth in yields for rice has stagnated since the end of the 20th century (Sheehy *et al*., 2007; Ray *et al*., 2012) and its demand is continuously increasing (GRiSP, 2013). This trend can be altered either by developing high-yielding and well-adapted rice cultivars or by exploiting prevailing agro-ecological potentials including genetic resources suited to varying climate regimes, or both (Xiong *et al*., 2014).

The System of Rice Intensification (SRI), an integrated soil-crop-nutrient-water management methodology developed in Madagascar, increases grain yield with less water consumption (Thakur *et al*., 2011a), and it also has other benefits (Stoop *et al*., 2002; Thakur and Uphoff, 2017). The efficacy of these modifications in rice production management has been demonstrated in China, India, and 60 plus other countries (http://sri.ciifad.cornell.edu/countries/).

In this paper, we will discuss how this method of rice cultivation could conserve resources (seed, water, chemical nutrients/pesticides, and labor) to improve the income of the farmers. Also, facts about its benefit to the environment and climate resilience will be presented.

Resource conservation and income enhancement through SRI

Under SRI management, very young seedlings are transplanted singly, one per hill in a square grid pattern in a wider spacing of 20 x 20 cm or more, depending on the varieties used and the nutritional status of the soil (Thakur *et al*., 2011b). The use of single seedlings and wider spacing reduces plant population per m^2 by 80-90%, thereby, reducing seed requirements and cost by 80-90%.

SRI management practices advocate keeping rice fields moist by adopting or irrigating alternate wetting and drying (AWD) at least during the vegetative stage, which discourages to keep continuous flooding (CF) (Stoop *et al*., 2002). Thakur *et al*. (2011a) reported an increase in grain yield by 48% with an average water saving of 22% in SRI than continuously flooded scientific management practices (SMP). They found that water productivity with AWD-SRI management practices was almost doubled (0.68 g l^{-1}) compared to CF-SMP (0.36 g l^{-1}). Also, under SRI, water productivity increased by 73%, from 3.3 to 5.7 kg ha-mm^{-1}. The highest SMP grain yield and water productivity were with the 1-DAD (days after the disappearance of ponded water) treatment (4.35 t ha^{-1} and 3.73 kg ha-mm^{-1}), while in SRI grain yield and water productivity was the greatest at 3-DAD (6.35 t ha^{-1} and 6.47 kg ha-mm^{-1}) (Thakur *et al*., 2014).

A meta-analysis of published evaluations from 8 countries revealed that SRI methods raised total water productivity (including rainfall) by 52%, with 78% greater productivity of irrigation water. SRI management gave higher crop yield with, on average, 35% less irrigation water (Jagannath *et al*., 2013). Physiologically, SRI phenotypes have been found to synthesize twice as much carbohydrate in their leaves per unit of water taken up by the roots (Thakur *et al*., 2010). With water constraints for agriculture becoming more severe, water-efficient phenotypes with greater water productivity will become ever more important. SRI experience shows that this is possible to achieve with existing genotypes. Water saving and greater water productivity with SRI practices have been confirmed by studies in countries as varied as Afghanistan (Thomas and Ramzi, 2011), China (Zheng *et al*., 2013), India (Satyanarayana *et al*., 2007; Thakur *et al*., 2011a), Indonesia (Sato and Uphoff, 2007), Iraq (Hameed *et al*., 2011), Kenya (Ndiiri *et al*., 2013), and Sri Lanka (Namara *et al*., 2008).

Researchers from China found that rice yields with hybrid varieties were as much as 2.5 t ha^{-1} higher when planting fewer plants (less seed), switching from flooding to AWD (less water), and providing half of the N soil amendments in organic form rather than 100% as chemical fertilizer (Lin *et al*., 2009).

In Asia, where 90% of the world's rice is produced, rice cultivation is already relatively labor-intensive. While some studies of SRI labor requirements have shown it to require more labor, e.g., in Bangladesh (Latif *et al*., 2009), most evaluations have found SRI to be labor-neutral, e.g., in Cambodia (Anthofer, 2004) and Indonesia (Sato and Uphoff, 2007), or labor-saving in China (Li *et al*., 2005) and India (Sinha and Talati, 2007). For the adoption of SRI under labor-shortage conditions, mechanization for land leveling, weeding, and transplanting should be adopted.

An evaluation of rainfed SRI experience in West Bengal reported an average of 67% increase in net income ha^{-1} compared to farmers' current practices (Sinha and Talati, 2007). A broad evaluation of SRI economics in India conducted across 13 states and 2,334 farmers sampled surveyed found that even partial SRI use increased rice farmers' incomes by 18% (Palanisami *et al*., 2013).

Reduction in global warming potential and water quality benefits

Keeping rice fields unflooded, as well as, reductions in mineral fertilizer and other agrochemical use, also contribute to diminishing net greenhouse gas emissions from rice paddies as seen in studies from India (Rajkishore *et al*., 2013; Jain *et al*., 2014; Gathorne-Hardy *et al*., 2016), Vietnam (Dill *et al*., 2013) and Korea (Choi *et al*., 2014). Jain *et al*. (2014) found that with SRI production management, there was a 62% reduction in CH_4 emission accompanied by a 23% increase in N_2O emission, however, a net reduction of 28% in global warming potential. An evaluation of SRI in India calculated that SRI's 60% average yield increases were accompanied by 40% lower net GHG emissions ha^{-1}, with also 60% less groundwater depletion, and 74% less fossil-energy use kg^{-1} of rice produced (Gathorne-Hardy *et al*., 2016). Pollution in runoff from paddy field water is also diminished (Choi *et al*., 2014).

Climate-resilience through SRI

The more-robust plants, with better roots, and shoot growth, under SRI production management are better able to tolerate water stress (Zheng *et al*., 2013; Thakur *et al*., 2015) and withstand pests/diseases (Pathak *et al*., 2012; Visalakshmi *et al*., 2014). Namara *et al*. (2008) found in Sri Lanka that under drought conditions, SRI plants produced and stored more photosynthates, with 30% more grain-bearing tillers, more grains per panicle, and 38% higher grain yield.

SRI plants were found to better tolerate strong winds and rain with less lodging (Chapagain and Yamaji, 2010), as well as cold stress (Sudhakar and Reddy, 2007). Further, a shorter crop cycle with SRI management (Uzzaman *et al*., 2015) reduces exposure of rice plants to both biotic and abiotic stresses at the end of their season, when maturing and particularly vulnerable to losses. Greater tolerance to climate-related stresses can be attributed to the positive effects that SRI management practices have on more root growth and more abundant and diverse life in the soil, having stronger and greater prolific shoot growth with more grain-bearing tillers.

Conclusion

Altering conventional rice-growing practices of flooding rice paddies, using chemicals and lots of seeds will have both economic and ecological benefits, demonstrated under SRI. SRI production system helps to get higher yields despite changing climatic conditions while lowering production costs and making it more profitable for farmers, using less water, fewer agrochemicals, and greater income. SRI production system also offers additional benefit for the environment and climate-resilience.

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LEAD LECTURE https://doi.org/10.58297/KRHI2562

Study to Estimate Water Savings, Yield and Income Benefits from using SRI Methods in Southern Iraq

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Evaluations of SRI at the Al-Mishkhab rice research station started in 2005. Because Iraq is a water-stressed country, the water-saving aspect of SRI has been most important. A field study in southern Iraq sought to establish what intervals of irrigation with SRI methods would achieve the best returns under the conditions in which rice is grown in our country. Economic and not just agronomic assessments were made under Iraq's water-deficit conditions.

In this study, input and output data were gathered and analyzed for when SRI methods were used under three different irrigation regimes: continuous submergence of the rice crop; irrigation at 3day intervals; and at 7day intervals. The amounts of water used for the different methods were measured by water meter. **Table 1** below indicates the amounts of water used for the three respective methods of irrigation.

Table 1. Amounts of irrigation water used (m^3 ha^{-1}) with SRI practices under different irrigation regimes

Irrigation method	Irrigation water used	Water use as % of continuous submergence
Continuous submergence	79,090	--
3-d intervals	39,485	50%
7-d intervals	22,072	22%

When the irrigation schedule was modified to give SRI-managed rice plots an issue of water only every three days (no continuous submergence), paddy yield was 20% higher with a 50% reduction in the total water issues (**Table 2**). In this way, water productivity was more than doubled (104%).

It was found that the highest water productivity was achieved with 7day intervals of irrigation, important because water is Iraq's scarcest resource. There was some sacrifice of yield with 7day rather than 3day intervals. But the water saving with 7day intervals was 73% compared with continuous submergence of the rice crop, and a saving of 44% compared to 3-day intervals.

Table 2: Average grain yield and water productivity with SRI under different irrigation methods

Irrigation methods	Grain yield (t ha^{-1})	% of CS	Water consumption (m^3 ha^{-1})	% of CS	Water productivity (kg m^{-3})	% of CS
Continuous submergence	5.83	--	79,090	--	73.73	--
3-d intervals	7.02	+20%	39,485	-50%	177.81	+241%
7-d intervals	5.20	-11%	22,072	-72%	235.73	+320%

The amount of water saved with 7day intervals could allow many more farmers in Iraq to cultivate a larger area of land, thereby greatly increasing their and the country's rice production. It would benefit the country and a large number of farmers if the current rice farmers could be compensated for using water more productively even if there is some reduction in their own grain production.

Cultivating a larger area with the water saving from 7day irrigation intervals using SRI methods should raise national rice output by more than enough to compensate current rice farmers for the production forgone by changing to 7day irrigation intervals rather than 3day intervals. There would also be additional value created by using some of the water saved for other social purposes, e.g., for expanding industrial production, after farmers have been compensated for using SRI methods with 7day rather than 3day intervals.

If no such incentive scheme could be established so that rice would be grown with 7day intervals, there would still be great benefit to farmers and the country from moving to SRI production methods with 3day intervals rather than continuing present methods with routine flooding of rice fields.

If an inclusive economic analysis were done, there would be costs and/or cost-savings added to the calculations below in **Table 3**. But this gives a picture of the scale of resources involved.

Table 3: Comparison of the costs and returns when growing rice using SRI methods with alternative irrigation regimes

Irrigation methods	Cost (dollars/ ha^{-1})			
	Cost of production	Value of production	Net economic returns	Change from continuous submergence
Continuous submergence	1,208	3,158	1,950	---
3 day intervals	1,166	3,803	2,637	+35%
7 day intervals	1,116	2,818	1,702	-13%

*Note 1 : Production inputs included: seed, fertilizer, pesticides, electricity, fuel, transport, machinery, field preparation, and repairs.

*Note 2 : Costs of harvesting are not included. They would be somewhat higher for 3day intervals and lower for 7day intervals because of differences in yield.

In any case, the present continuous irrigation of rice fields in Iraq is a waste of irrigation water achieving no significant agronomic or economic benefit. In a water-stressed country like ours, using SRI methods for growing irrigated rice should be a very attractive option for farmers and policy-makers alike.

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Targeted Nitrogen Management to Increase Cereal Production while Reducing Nitrogen Consumption in India

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Abstract

Nitrogen is the most essential nutrient in crop production but a substantial portion of applied N to the cropland is lost into the environment by means of volatilization, leaching, or emissions causing multiple adverse effects on terrestrial and aquatic systems and on human health. Consumption of Fertilizer-N in India, the second largest consumer of N fertilizer in the world, has increased steadily since 1960s and is expected to further increase in the future to produce more food to meet the projected food demand. However, inequality is the core of the problem with some regions applying more N fertilizer than required leading to negative environmental externalities and other regions applying far less N leading to lower yields and soil mining adding to the vicious cycle of food insecurity. A data-based approach to identify areas of N surplus/N deficit, the magnitude of nitrogen-use-efficiency (NUE) and N harvest gaps helps develop location-specific fertilizer management strategies. Here, we developed a global NUE atlas using various sources of data on N input and N output to show the priority areas of N management work to address the issues of over- and under-fertilization. Adopting this data-based approach and using examples from field and national level analyses, we suggest spatially tailored agronomic, economic, and policy strategies of N management to address food, fertilizer, and climate crisis in India.

Keywords: Nitrogen, Rice, Maize, Wheat, Nitrogen-Use-Efficiency, Food Security, India

Introduction

India is the second largest consumer of nitrogen (N) fertilizer in the world after China. With the increasing share of consumption and imports of fertilizer, India has emerged as the dominant player in the world fertilizer market since the late 1970s. Over the last 50 years, N consumption in India has increased by over 800% but the average NUE has not increased since the 1980s. Projections indicate that cereal production will have to increase by about 1-2% per annum, respectively, over the next four decadesto meet the food demand in India. This means that the consumption of N fertilizer in India will continue to grow in the future. At the same time, nutrient-use-efficiency (NUE) in India is one of the lowest in the world (Farnworth *et al.*, 2017) suggesting that opportunities exist to increase crop production while reducing N consumption by improving NUE. This implies that although increased N input has had tremendous positive benefits concerning food security, a significant amount of applied N is lost into the environment, leading to increased production cost, decreased profit from agricultural production, and numerous negative environmental externalities. Fertilizer recommendations in India are based on the response trials conducted to represent wide geography but in reality, India has such a diverse agro-ecological and socio-political environment that such blanket recommendation leads to over-fertilization in some fields and under-fertilization in others, even within an agro--ecological zone. Given the situation, we need to find ways to eliminate over-fertilization in some places and soil mining in others to meet food security and environmental goals. For this, we need a data-based approach to identify areas of fertilizer surplus and fertilizer deficit in order to develop location-specific fertilizer management strategies. Using various sources of data on N input and N output, we developed a high-resolution gridded database of NUE and N surplus showing the priority areas of work to address the issue of over- and under-fertilization and recommend differentiated approaches (technological, market and policy instruments) across over- and under-fertilized agricultural landscapes.

Using crop N input and output data and information potential N harvest, we classified rice, maize and wheat areas based on NUE, N surplus/deficit, and N harvest gap (Fig. 1). For this, we considered all source of N inputs into the production areas i.e. synthetic N input inputs (Lu and Tian, 2017), manure N (Zhang *et al*., 2017) residue N (IPCC, 2019) atmospheric N-deposition (Eyring *et al*., 2013), N mineralization (IPCC, 2019). We used harvested crop area and crop yield from Spatial Production Allocation Model (SPAM) and their corresponding N content (Feliciano *et al*., 2017) to calculate N output. For each crop, the yield gap was calculated as the difference between SPAM and potential yield obtained from the FAO Global Agro-Ecological Zones (GAEZ) v4 data portal (https://gaez.fao.org/). N surplus or deficit was determined as the difference between N input and output, NUE as ratio of N output to N input and N harvest gap as the difference between potential N removal (i.e. potential yield x N content) and actual N removal (SPAM yield x N content). We suggest spatially targeted N management strategies based N status-quo in maize, rice, and wheat fields across India.

Results

Our data-based analysis shows that maize field in the transact of the Indo-Gangetic Plains (IGP) and Northeastern India has high N surplus, low NUE and high removal gap (**Figure 1**). Low removal gap in western arid area and eastern tip is mainly driven by lower potential yield. In wheat field, central river basin and eastern coast of India experience high N surplus, low NUE and low to high N harvest gap while western semi-arid region experiences medium NUE and low removal gap. Western most semi-arid region of India is characterized with N deficit, medium NUE and low N removal gap because of low input and low productive area. Most of the rice growing areas in India has high N surplus, low NUE and low (central river basin

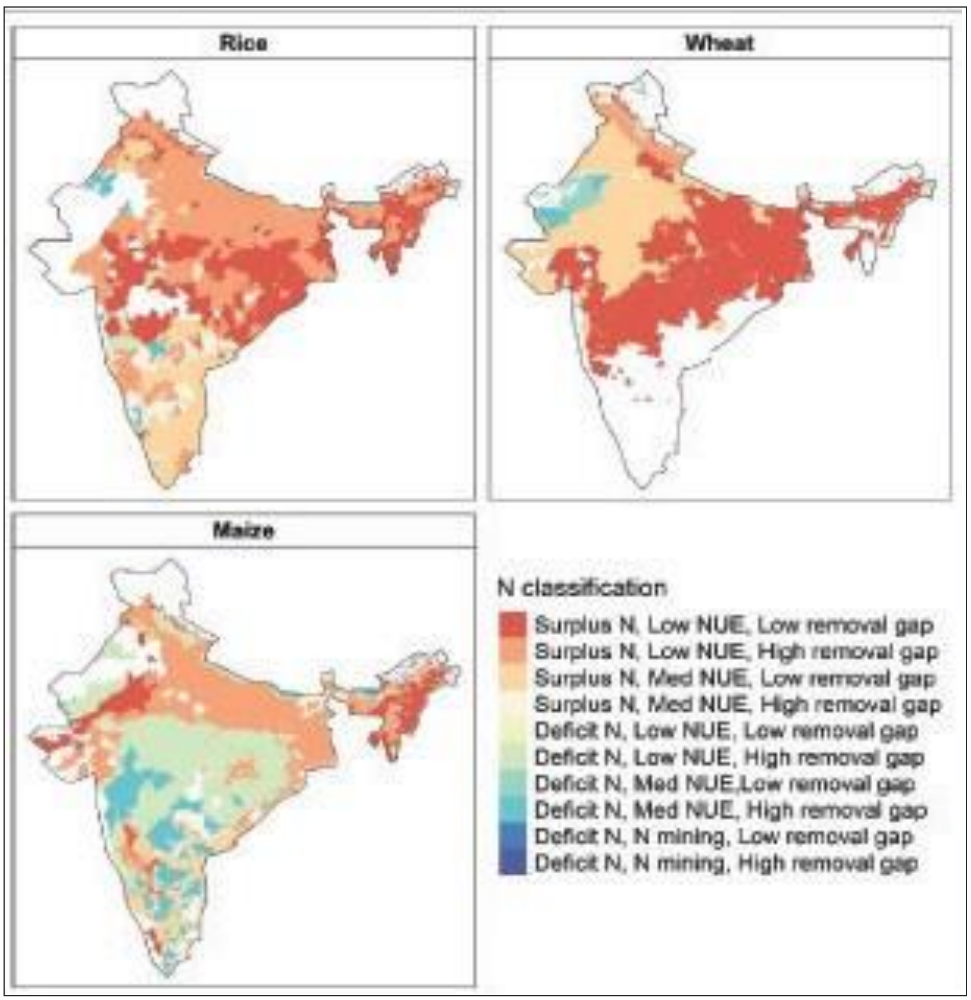

Figure 1: Rice, Wheat, and Maize production area in India classified based on N surplus/deficit, nitrogen-use-efficiency and N removal gap.

and eastern region) to high (transact of IGP) N removal gaps except in southern region where rice fields show medium NUE and low N removal gap. Low N removal gaps in central river basin and eastern region of India is mainly due to low production potential in this region.

Based on these analyses, we identified areas with excessive N use i.e. pollution hotspots and emerging pollution hotspots, areas with inadequate N use i.e. N mining hotspots and emerging production hotspots and areas with minimum N use concern i.e. minor or non-hotspots and improvements in such hotspots. Inspired by the apparent success of Green Revolution and due to availability of subsidized N fertilizer, farmers applied N fertilizer in quantities in excess of the crop's requirement leading to persistent or worsening potential N surplus across the countries. In such areas, efforts should be placed in increasing NUE to secure yield gains while minimizing fertilizer consumption through systematic implementation of best fertilizer management practices. A number of technologies (e.g. 4R nutrient stewardship, precision agriculture, fertigation etc), tools (e.g. Leaf color chart, GreenSeeker etc) and decision support systems (e.g., Agvisely, GreenSat, Nutrient Expert, Crop manager etc) have been developed to help farmers implement integrated soil fertility management based on crop requirement thereby increasing NUE and minimizing N surplus. Federal and state governments should focus their efforts on contextualizing and scaling such tools, techniques and DSS through digital extension, citizen science, ICT, decision support systems and partnership. Increasing NUE by diversifying cropping systems could also help increasing food production while reducing fertilizer N consumption in such areas. Areas characterized by N mining and emerging production hotspots require increasing N supply through increased access to fertilizer and increasing farmers' awareness on field-level optimization through organic (e.g. use of farm-yard-manure, producing compost, growing/integrating legumes etc) and inorganic fertilization. Promoting integrated organic and inorganic N management is a 'no regrets' fertilizer-N management strategy. While government should continue research on cutting-edge nature-based solutions for managing nitrogen, carbon and greenhouse gas simultaneously for net zero farming (e.g. BNF, BNI, ISFM), emphasis should also be given to repurposing fertilizer subsidy and connect farmers with carbon market as well as private sectors for responsible sourcing.

Conclusion

While India is second largest consumer of fertilizer N in the world, N fertilizer use in India is going to further increase in future necessitated by increased food demand. Opportunities exist to increase NUE to increase food production yet reducing fertilizer N consumption but differentiated responses are needed based on the status-quo of N surplus/deficit, NUE and N harvest gap. Based on the trajectory of N status across rice, wheat and maize areas in India, we suggest relevant N management strategies to address food security, climate change and number of other sustainable development goals.

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Organic Farming, Nutritional Security and Environment Sustainability

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Introduction

Organic farming has expanded rapidly in recent years and is seen as a sustainable alternative to chemical-based agricultural systems (Avery, 2007). Nutrient management in organic farming systems is often based on soil fertility building via nitrogen (N) fixation and nutrient recycling of organic materials, such as farmyard manure and crop residues, with limited inputs from permitted fertilizers (Gosling and Shepherd, 2005). Although organic farming has been criticized for relying on the build-up of soil phosphorus (P) and potassium (K) by past fertilization before converting to organic, its acceptance and popularity are growing mostly due to environmental and health related concerns (Galantini and Rosell, 2006). The fact that the use of organic fertilizers improves soil structure, nutrient exchange, and maintains soil health has raised interests in organic farming. The increasing scarcity of water is a major threat to rice production in many countries (Bouman *et al.,* 2009). Several approaches like alternate wetting and drying, raised beds, ground cover production system, aerobic rice systems (Prasad 2011) and System of Rice Intensification (SRI) are advocated to save water (Bruderie *et al.,* 2009). Therefore, with such background, field experiments were conducted to explore possible outcomes of sustainable production of organic basmati rice in rice-based cropping system in terms of productivity, water use-efficiency and methane emission reduction.

Methodology

Researches on organic farming under different aspect of management practices are being going on at G.B. Pant University of Agriculture and Technology, Pantnagar, India etc. under the Network Project on Organic Farming funded by ICAR. Since 2004-05 to explore possible outcomes of sustainable production of organic basmati rice in terms of productivity and water use efficiency the experimental soil was silty loam, medium in organic carbon (0.65%), available N (238 kg/ha), P (16.7 kg/ha), K (156 kg/ha) and high in available sulphur (29.3 kg/ha). Five management practices *viz.,* Green manure + FYM, FYM + Vermicompost, SRI with FYM, DSR+Soybean and Chemical in strip plot design. *Sesbania* was incorporated as green manure prior to basmati rice only. A similar experiment treatment also showed that the FYM+VC and GM+FYM were best to increase the antioxidant activity such as SOD, CAT, APX, GPOX, GR, TPC and TFC in the leaves.

Results

Among nutrient sources, use of DSR + Soybean recorded higher dry matter production, crop growth rate as well as grain yield and system productivity of basmati rice as compared to other sources and chemical fertilizers. Among the different basmati rice crop establishment, system productivity in terms of basmati rice grain equivalent was observed higher in System of Rice Intensification (SRI) as compared to conventional planting with continuous flooding. Irrigation water applied efficiency can also be increased by adopting system of rice intensification and direct seeded rice establishment systems. Highest irrigation water use efficiency in direct seeded rice (DSR) was due to decreased number of irrigations as compared to conventional transplanting and SRI. Organic control and chemical control recorded least irrigation water use efficiency due to continuous flooding which are being adopted by the farmers. FYM+VC and GM+FYM were best to increase the antioxidant activity such as SOD, CAT, APX, GPOX, GR, TPC and TFC in the leaves. Improvement in WHC of soil from initial in organic treatments receiving green manure and vermicompost was observed after one decade of continuous organic farming which was almost 76 % higher as compared to conventional farming. Bulk density of soil is decreasing under organic basmati rice based cropping system over ten years of continued crop cycles thereby decreasing the energy requirement. There has been a build-up of soil organic matter under organic farming system which is almost doubled after one decade of continuous organic farming as compared to chemical farming.

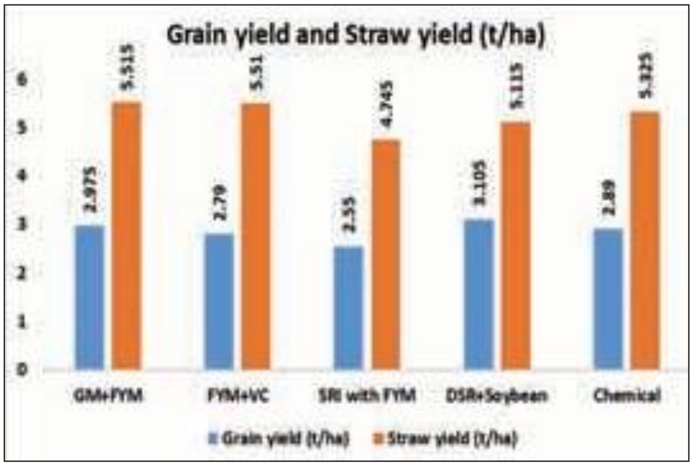

Fig.1: Effect of different Organic, Inorganic and integrated nutrient sources on grain yield and straw yield(t/ha) in Basmati rice.

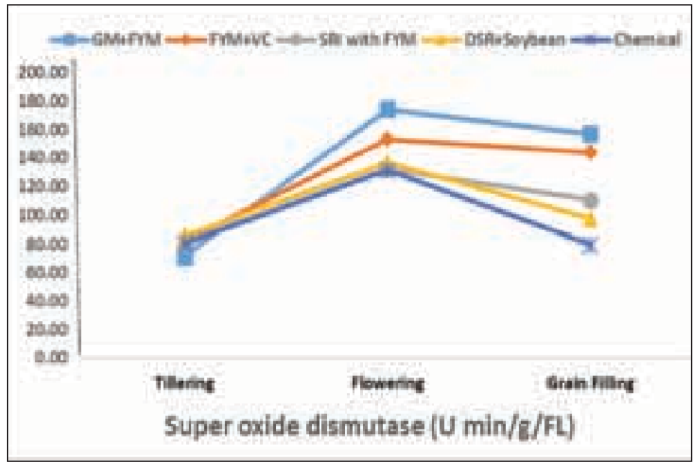

Fig.2: Effect of different Organic, Inorganic and integrated nutrient sources on Super oxide dismutase (U min/g/FL) in Hulled and Milled Basmati rice.

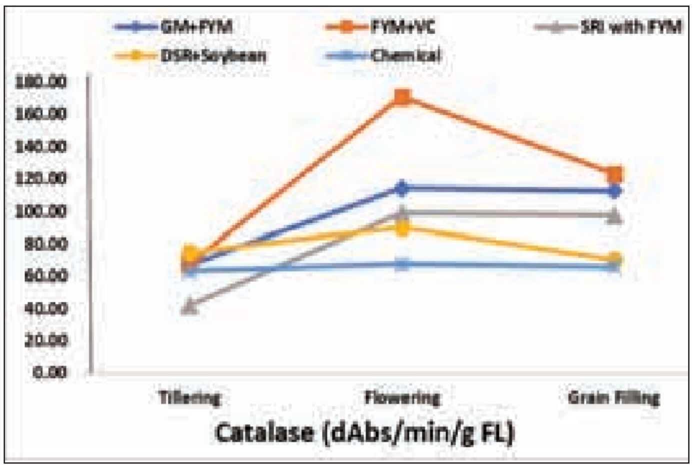

Fig.3 Effect of different Organic, Inorganic and integrated nutrient sources on Catalase (dAbs min/g FL) in Hulled and Milled Basmati rice.

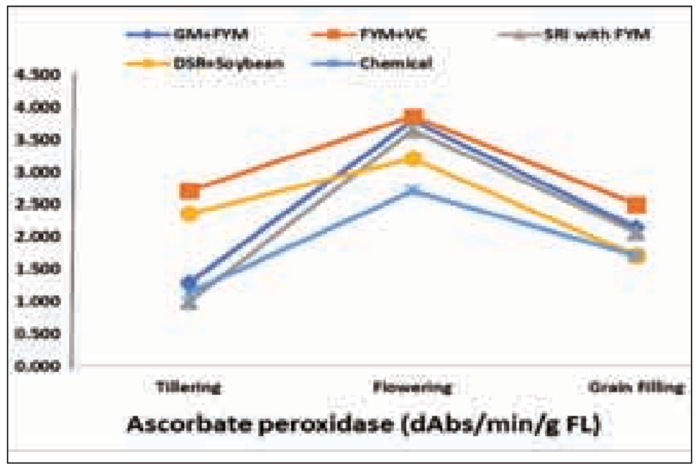

Fig.4 Effect of different Organic, Inorganic and integrated nutrient sources on Ascorbate peroxidase (dAbs min/g FL) in Hulled and Milled Basmati rice.

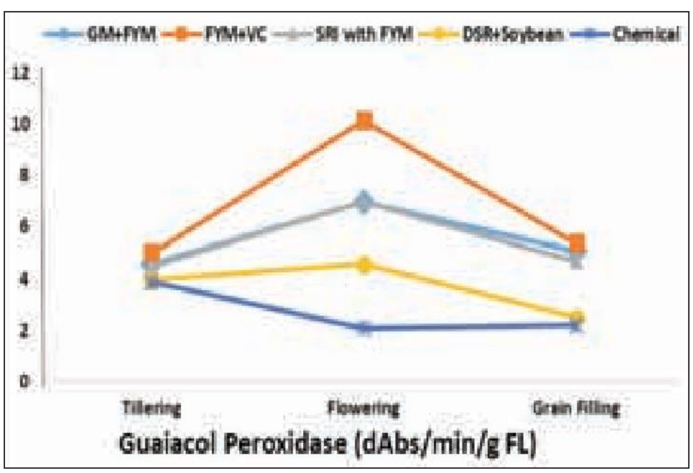

Fig.5 Effect of different Organic, Inorganic and integrated nutrient sources on Guaiacol Peroxidase (dAbs min/g FL) in Hulled and Milled Basmati rice.

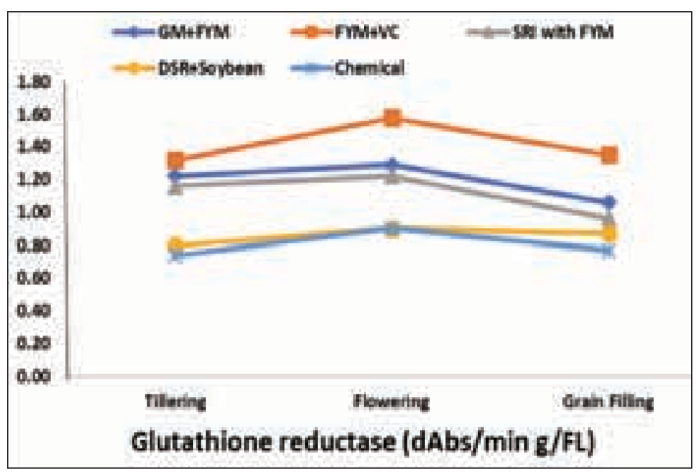

Fig.6 Effect of different Organic, Inorganic and integrated nutrient sources on Glutathione reductase (dAbs min/g FL) in Hulled and Milled Basmati rice.

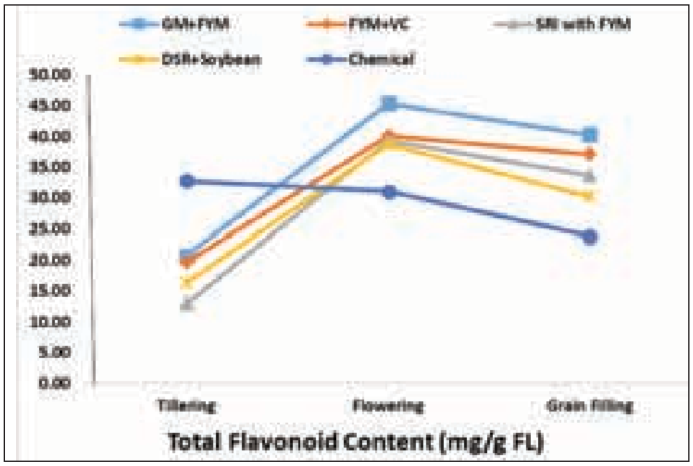

Fig.7 Effect of different Organic, Inorganic and integrated nutrient sources on Total Flavonoid Content (mg/g FL) in Hulled and Milled Basmati rice

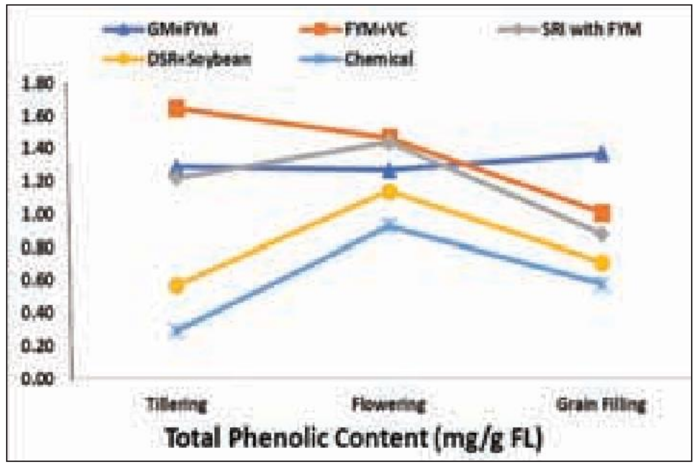

Fig.8 Effect of different Organic, Inorganic and integrated nutrient sources on Total Phenolic Content (mg/g FL) in Hulled and Milled Basmati rice

Conclusion

Build-up of soil organic matter is a key to adaptation in changing climatic scenario through increase in water holding capacity, improve soil ability to store the nutrients, proper aeration, to provide media for soil microorganism & buffering capacity or reduction of soil temperature. Availability of both macro and micro-nutrients enhanced under organic farming system as compared to chemical system. Therefore, crops in organic modes of cultivation can be sustained even under moisture stress situations i.e. rainfed conditions.

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Amelioration Potential of Biomass-Derived Ashes in Agroecosystems

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Abstract

Bioash (mineral residue left after oxidation of different biomass) is physicochemical complex, ultra-alkaline, and potentially hazardous waste, with a huge potential to become value-added products for; i) chemical amelioration of acid and nutrient-deficient soils in agro-/forest-ecosystems, ii) wastewater purification and iii) civil and bio-tech engineering. It was confirmed that finely-powdered bioash structure is the main operational management obstacles for its use in land amelioration; hence, specifically designed forms (e.g. pellets, microspheres, emulsions, granules) are needed to temporarily stabilized the bioash reactive form(s), making them more applicative. In addition, application and relatively low bioash rates (e.g. several tons per ha) can induce significant perturbations in targeted (cultivated crops/forests, removal of pathogens) and adjunct (bacteria, fungi) biota. Overall, bacteria responded more pronouncedly to ash amendment than fungi. However, amendment effects vary depending on the properties of both the ash and the target soil, so these aspects need to be considered closely.

Key words: Bioash, Acid soils, Chemical amelioration, Soil conditioner, Solid waste

Introduction

The reduction in greenhouse gas emission decarbonisation and promoting bio-renewables, especially forest/agro biomass, has resulted in an increased use of biomass-derived energy sources. However, one of important environmental issue arising from such progressive increase in the amount of biomass used for renewable energy generation is an increase in biomass-derived ash (bioash) waste material (Ondrasek *et al*., 2021a). However, bioashes as alkaline and mineral-enriched waste co-products have multi-benefit advantages for reusing as soil conditioners in chemical amelioration of agro-/forest-ecosystems and some other sectors (e.g. civil and bio-tech engineering, construction, waste management) **(Figure 1).**

Figure 1: Bioashes and their potential for reuse to sustain ecosystem services and underpin circular economy

It was confirmed that physicochemical properties of bioash are closely related to their feedstock composition and combustion parameters. For instance, combustion temperatures >400◦C increase the levels of bioash carbonisation and promote the aromatic condensation of degraded aliphatic groups, followed by losses of O_2, H and N atoms during dehydration and decarboxylation processes (Ondrasek *et al*., 2021a). A pH reaction of wood-derived bioashes is generally strongly alkaline (11.8–13.1), mostly due to a high content of alkaline oxides (e.g. in %; CaO >47, SiO_2 >12, K_2O >11, MgO >4; Ondrasek *et al*., 2021a).

In comparison with coal ashes, bioashes usually have lower abundance of S-containing minerals (e.g. arcanite – K_2SO_4), making them highly effective in reclamation of soil acidity, nutrient deficiency, and immobilization of potentially toxic metals and/or metalloids.

Bioash effects on soil pH and nutrients recovery

Numerous studies have been conducted using diverse bioash matrices (e.g. fly ash, bottom ash), revealing positive effects of bioash application on pH and nutrient recovery as well other pedovariables. For instance, controlled experiments confirmed strong basic reaction of wood ash leachates (pH 12-13) (Cabral *et al*., 2008; Freire *et al*., 2015) as a result of hydrolysis, dissolution and weathering of dominantly alkaline oxides, hydroxides, carbonates, bicarbonates, silicates, silanols and other metal salts (Doudart de la Grée *et al*., 2016; Vassilev *et al*., 2013) capable of displacing exchange able H^{+}, Al^{3+} and/or Mn^{2+} from the soil CEC (Maresca *et al*., 2018; Shi *et al*., 2017) or even removing some of them (e.g. Al^{3+}) as precipitates down the soil profile (LI *et al*., 2010). Consequently, bioashes neutralise strongly and rapidly different acidic soils, and increase availability of most macro/micronutrients in soils. Recently was shown that fly bioash addition can strongly rise soil pH_{KCl} (up to 9.1), and the content of most phytonutrients (up to 5.4-fold); however its addition at >1.25% can restrict the maize root and shoot growth, likely due to alkaline stress as indicated by necrotic and chlorotic symptoms at >5.0% rate (Ondrasek *et al*., 2021b). In addition, fly bioash increased total concentration of metals in soil (without exceeding the levels recognized as contamination), whereas phytoextraction of Cd, Zn, Mn, Cu and Mo was significantly suppressed (Cd by almost 12-fold), confirming that fly bioash improved soil-plant metal immobilization, shifting rhizosphere biogeochemistry towards chemisorption reactions (Ondrasek *et al*., 2021b).

Some studies showed that bioashes induce stronger and faster pH recovery as well as higher acid neutralizing capacity (ANC) than other liming materials (e.g. limestone, dolomite) (Cabral *et al*., 2008; Ondrasek *et al*., 2020; Ondrasek *et al*., 2021c). These findings can be explained highly reactive and developed surface and chemically/ mineralogically more complex bioash matrix (vs. dolomite/ lime) and ii) domination of the more reactive hydroxide fraction (in ash) over relatively slowly reactive carbonate fraction (in dolomite/lime).

Additionally, bioash matrices have a huge potential for further improvements to optimize their use as soil conditioners/fertilizers. For instance, (Zhao *et al*., 2019) showed that different bioashes can be qualitatively improved if co-incinerated with sewage sludge, resulting in transfer of relatively poorly available P ($AlPO_4$) to its more readily-available mineral forms [e.g. $Ca_2P_2O_7$, $Ca_5(PO_4)_3Cl$, $Ca_4Mg_5(PO_4)_6$ and $Ca_3(PO_4)_2$] that are highly desirable in fertilizers/soil amendments. The content of other macronutrients such as N (which is lost to the atmosphere in gaseous forms during combustion) can also be boosted in bioash materials. By mixing wood- and peat-derived fly ash with an appropriate proportion of sewage sludge and lime, (Pesonen *et al*., 2016) created fertilizer aggregates with N content increased by more than an order of magnitude (e.g. from 120 to 2690 mg N/kg).

Bioash effects on soil microbiomes

Given that wood ash has been used as a soil amendment for several decades, many studies have investigated its impact on the soil microbial communities that play a key role in nutrient cycling, plant growth and carbon sequestration (Fierer, 2017). Ash amendments were shown to increase microbial activity as measured by soil CO_2 production (Bååth and Arnebrant, 1994, Khanna *et al*., 1994), as well as microbial biomass turnover or growth rate (Lupwayi *et al*., 2009) and nutrient cycling (Perkiömäki and Fritze, 2005; Saarsalmi *et al*., 2012). In addition, ash addition changed soil bacterial abundance (Bååth and Arnebrant, 1994; Bang-Andreasen *et al*., 2017; Vestergård *et al*., 2018). However, some of these effects were recorded only after high application rates or repeated applications of ash (Omil *et al*., 2013; Pennanen, 2001). In addition to stimulating microbial abundance and activity, the application of ash typically altered soil bacterial community structure (Liiri *et al*., 2002; Lupwayi *et al*., 2009; Mahmood *et al*., 2003; Perkiömäki *et al*., 2003) or total microbial community structure (Perkiömäki and Fritze, 2005). For instance, by using 16S rRNA gene amplicon sequencing, (Bang-Andreasen *et al*., 2017) and (Noyce *et al*., 2016) reported shifts in the soil bacterial community composition after wood ash application, with the enrichment of copiotrophic bacterial groups such as *Bacteroidetes* and a decline in oligotrophic phylum such as *Acidobacteria.* In contrast to (Noyce *et al*., 2016) who found no difference in the bacterial community with increasing ash addition from to 5.7 t ha^{-1}, (Bang-Andreasen *et al*. (2017) found more pronounced effects with increasing ash addition rate from 5 t ha^{-1} (the current legislation threshold in Scandinavian countries) to 22 t ha^{-1}. However, detrimental effects on soil bacteria were observed only at an extreme, unrealistic rate of 167 t ha^{-1}, with alkaliphilic genus *Alcalibacterium* and spore-forming bacteria dominating.

In addition, some studies revealed that the fungal communities showed only minimal responses to ash addition compared to bacterial communities (Bang-Andreasen *et al*., 2020; Mahmood *et al*., 2003; Noyce *et al*., 2016). Other studies found that addition of high rates of ash to soil increased fungal abundance (Bååth *et al*., 1995; Bang-Andreasen *et al*., 2020), especially the abundance of fast-growing saprotrophic fungi such as the genera *Mortierella* and *Peziza* as well the order Hypocreales (Bang-Andreasen *et al*., 2020). Compared to free-living fungi, the impact of ash on ectomycorrhizal (EM) and arbuscular mycorrhizal (AM) fungi, which make symbiotic associations with plant roots improving plant nutrient uptake, remains less clear. Several studies reported changes in EM fungal species composition after wood ash applications. Typical acidophilic species such as *Tylospora fibrillosa*, *Piloderma croceum* and *Russula ochroleuca* decreased in relative abundance, whereas that of species from genera *Amphinema* and *Tuber* increased (Kjøller *et al*., 2017; Klavina *et al*., 2016; Mahmood *et al*., 2002; Taylor and Finlay, 2003). In contrast, (Cruz-Paredes *et al*., 2019) did not observe a change in the EM fungal community composition after adding up to 6 t ha^{-1} of wood ash, possibly because the applied doses, which were within the recommended dosage range, were much lower than high doses in other studies, e.g. 50 t ha^{-1} in (Klavina *et al*., 2016). Despite above-mentioned changes in microbial activity and community composition, some studies showed no, or only minor, microbial response to wood ash addition (Aronsson and Ekelund, 2004; Huotari *et al*., 2015). However, given a prolonged impact of ash (e.g. nearly 14 years after application of silico-aluminous/sulfo-calcic fly ash (Leclercq-Dransart *et al*., 2019); or 30-52 years after application of wood bioash (Moilanen *et al*., 2006; Saarsalmi *et al*., 2012), long-term field studies in different pedo-conditions are highly desirable to underpin elucidation of ash-induced changes to soil microbiomes.

Bioash effects on other pedovariables

Bioashes contain a relatively high proportion of Si and its pozzolanic forms and thus can have beneficial effects on physico-mechanical variables in texture-heavy clayey soils. For instance, addition of fly ash (up to 15% w/w) in clay soil significantly reduced the bulk density and improved the soil structure, i.e., porosity, workability, root penetration and water retention (Sahu *et al*., 2017), and modestly improved soil hydraulic conductivity (Chang *et al*., 1977). Application of the S-Ca and Si-Al fly ashes was shown to be effective in lowering soil bulk density in the long term, i.e., even around 14 years after amending the soil (Leclercq-Dransart *et al*., 2019). In highly expansive and plastic or soft soils (e.g. sensitive to variations in water content, showing strong volumetric changes as cracking/shrinkage), use of different ashes stabilized the soil and improved consistency, reduced plasticity index (i.e. free swelling and compressibility), and decreased soil dry density, making it coarser than original soil (Jafer *et al*., 2018; Mir and Sridharan, 2013). For wider practical application and amelioration of hydraulic and mechanical soil properties, the durability and long-term impacts of bioashes under different field-relevant conditions should be validated further.

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Agro-Ecology Specific Strategies for Resilient Rainfed Production Systems

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Abstract

Rainfed agriculture, practiced in diverse agroecologies contributes, immensely to India's food basket. However, rainfed agriculture in India is constrained with many biophysical and socioeconomic challenges, particularly changing climate and rainfall variability. Managing climate risks, enhancing productivity and profitability, further achieving resilience of the rainfed production systems is need of the hour. To address these, agro-ecology specific crop alignment, agro-ecology specific potential crop zoning and diversifying within farm for sustainable intensification and real-time contingency planning implementation are the key strategies.

Keywords: Rainfed production systems, Resilience, Agroecology

Introduction

Rainfed agriculture is practiced in about 50 percent of net cropped area. It contributes 44% of food grains and supports 40% and 75% human and livestock population respectively. At present, 95% of the coarse cereals, 91% pulses, 80% oilseeds, and 53% rice are from rainfed agriculture. Besides this, it supports two thirds of animal population and a large area of horticultural crops. Thus, rainfed agriculture contributes immensely to country's food production and economy. The key challenges in rainfed agriculture are: i). Managing climatic risks, ii) Resource poor operational land resource base, iii). Bridging yield gaps, (iv). Enhancing water productivity, v). Maintaining soil health and productivity and vi). Low and skewed farm mechanization. Some of the Agro-ecology specific strategies for resilient rainfed production systems are briefed below:

Agro-ecology specific crop alignment

a. Climate resilient crops and varieties to cope with delayed onset of monsoon: As a rule, rainfed crops are sown early with the onset of monsoon to realize higher yields. However, any delay in monsoon beyond normal period affects sowing of crops of longer duration or narrow sowing window. The crops with wider sowing windows can still be taken up during the season without major yield loss by using short duration cultivars. Beyond the sowing window, choice of alternate crops or cultivars depends on the farming situation, soil, rainfall and cropping pattern in the location and extent of delay in the onset of monsoon. For example, pulses and oilseeds are preferred over cereals due to less water requirement and hence can be grown under delayed *kharif* sowing. Beyond the sowing window, choice of alternate crops or cultivars depends on the farming situation, soil, rainfall and cropping pattern in the location and extent of delay in the onset of monsoon. (Ravindra Chary et.al.2010; Ravindra Chary et.al. 2013). Under National Innovation in Climate Resilient Agriculture (NICRA), during 2011 to 2022, more than 100 drought tolerant varieties of major rainfed crops were identified by AICRPDA centres for their suitability to cope with delayed onset of monsoon (Ravindra Chary et.al. 2016).

b. Agro-ecology specific risk resilient cropping systems: Crop diversification with intercropping systems enhances resource use efficiency, and overall system productivity and income per unit area to the small holders. Diversifying from the monoculture of traditional staples can have important nutritional benefits for farmers (Ravindra Chary et. al. 2022). Double cropping system aims to make optimum use of land through permitting the production of an extra crop cultivated in winter/*rabi* after *kharif* season. To develop feasible and sustainable double cropping systems, production factors such as length of growing season, cropping sequence, crop compatibility, biological complementarity, and planting time must be considered. Aligning cropping systems *viz.*, monocropping, intercropping and double cropping systems as per rainfall zones and soil types is the key strategy for crop diversification in diverse rainfed agro-ecologies (**Table.1**).

Table1. Potential cropping systems and agricultural drought vulnerability based on rainfall and soil types

Mean annual rainfall (mm)	Major soil order	Growing season (weeks)	Suitable cropping system	Agricultural drought (frequency)
350-650	Alfisols, shallow Vertisols, Aridisols and Entisols	15	Single rainy season	Severe drought (Once in <5 seasons)
350-650	Deep Aridisols and Inceptisols	20	Either rainy or post-rainy season crop	Moderate drought (Once in 5-10 seasons)
350-650	Deep Vertisols	20	Post-rainy season crop	Moderate drought (Once in 5-10 seasons)
650-800	Alfisols, Vertisols, Inceptisols	20-30	Intercropping	Less prone to drought (Once in 10-20 seasons)
800-1100	Deep Vertisols, Alfisols and Entisols	30	Double cropping	Less prone to drought (Once in 10-20 seasons)
>1100	Deep Alfisols, Oxisols etc	30+	Double cropping	Nil to less prone to drought (once in >20 seasons)

Agro-ecology specific Potential Crop zoning

The cropping pattern in a rainfed areas is largely driven by management (accumulated knowledge), monsoon (south-west) and often with market influence. Currently, there is an imbalance between natural resources endowment and cropping patterns in rainfed areas. The recent trend of shift in climate and impact of rainfall variability in a region/agroclimatic-zone in crop growing season impacting productivity, profitability and stability of rainfed crop production systems and also resulting in poor soil quality. This calls for concerted efforts in efficient Agroecology specific Crop Zoning/Crop Colonies/ Crop Alignment matching natural resources, majorly rainfall and soil resources. *Agro-ecology specific potential crop zoning r*efers to the specific regions /areas of crops and cropping sequences which are bio-physically suitable and also have high productivity and high spread. Efficient crop zones have similar geographic setting in terms of soils, landforms, rainfall, temperature, length of growing period, irrigation potentials, suitable for a specific crops and cropping sequences and have the potentiality to respond similarly for similar kind of management practices (Ramamurthy et.al. 2016). The potential crop zoning helps in developing strategies for various potential zones of the base crop and given in **Table 2**.

Table.2. Strategies for potential crop zoning

Potential zone of the base crop	Strategies
Highly Potential Zones	• Technological interventions (soil, water, crop, land, energy based) for higher water productivity, profitability & stability of the base crop • Sustained, quality and adequate quantity seed production of the base crop • Development of cost effective and energy efficient total farm mechanization of the base crop • Development of the value chain, weather indices based insurance etc. of the base crop • Strengthening base crop based traditional rainfed integrated farming systems
Moderately Potential Zones	• Base crop based crop diversification/intensification (intercropping/double cropping) • Strengthening traditional rained farming systems /agroforestry systems
Marginally Potential and Non-Potential Zones	• Replacing base crop/ Crop substitution with alternate crops/cropping systems and agroforestry systems

Diversifying within farm for Sustainable intensification

- Evolving Rainfed Integrating Farming Systems models by strengthening predominant traditional rained farming systems in prioritized rainfed districts that enhance resource use efficiency and livelihoods by providing risk resilience, food and nutritional security, staggered employment and income. Suggested strategies for strengthening traditional rained farming systems are given in **Table 3**.
- Promotion of proven agro-ecology specific alternate land use systems/ agroforestry systems based on land capability in private and public (gomalas, village common/temple lands etc.) for risk resilience and staggered income, biomass production, soil carbon sequestration. Promotion of pasture, silvi-pasture systems, fodder trees, multiple tree based systems in non-arable on large scale, particularly in village common lands. Boundary plantation with perennial tree species for forage, greenleaf manure, mulching and ecosystem services for moderating microclimate at individual farm level.

Table 3. Suggested strategies for strengthening traditional rained farming systems

Rainfall zone (mean annual rainfall)	Strengthening predominant traditional rained farming systems	Agro-ecology specific components along with efficient *in situ* and *ex situ* rainwater management practices
< 500 mm	Livestock-crop based	Small ruminants, nutritious cereals/millets
500-750 mm/	Crop-horticulture-livestock based	Small/large ruminants, predominant rained crops and dryland horticulture
750-1000 mm	Crop-horticulture-livestock-poultry based	Predominant rained crops, dryland horticulture, agri-hortisystems, rainfed vegetable crops, small/large ruminants, improved breeds of poultry
> 1000 mm	Multiple enterprise based on multiple water use	Predominant rained crops, lowland rice with water saving technologies, dryland horticulture, vegetable crops, other high value crops, agri-hortisystems, small/large ruminants, improved breeds of poultry, fish and other income generating enterprises like seed production, apiary, mushroom cultivation etc.

Integrating trees into agricultural landscapes is an approach for sustainable intensification of arable systems and contributes towards enhancing productivity in unit time and area with multifarious benefits, thus enhancing the adaptive capacity of farmers to climate risks. Some of the strategies for development of efficient pasture and or fodder production systems in rainfed areas: Fodder production from arable lands; Integrated fodder production systems; Tank beds- Common Pool Resources for fodder production; Intensive rainfed fodder production systems; Perennial non-conventional fodder production systems; Fodder production systems in homesteads and Fodder production as contingency plan.

Real-Time Contingency Planning Implementation

Real Time Contingency Planning (RTCP) is conceptualized in All India Coordinated Research Project for Dryland Agriculture (AICRPDA) as "any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season" (AICRPDA-NICRA Annual Report, 2013-14) as two pronged approach i) Preparedness and ii) Implementing contingency measures on real-time basis. The RTCP aims first to establish a crop with optimum plant population during the delayed onset of monsoon, to ensure better performance of crops during seasonal drought and extreme events, enhance performance, improve productivity and income and to enhance the adaptive capacity of the small and marginal farmers. The preparedness emphasizes on a combination of tolerant variety/crop/ system, rainwater/soil/crop/nutrient management practices along with timely availability of inputs while real-time basis implementation focus on the crop/soil/moisture /nutrient management measures to cope with delayed onset of monsoon, seasonal drought, floods and other extreme events (AICRPDA -NICRA Annual Report 2013).

Way Forward

i. Delineating Length of growing period (moisture availability period) at sub-district level

ii. Risk assessment in prioritized rainfed districts for crops/varieties alignment and crop diversification with alternate cropping systems and crop intensification in high rainfall zones

iii. Energy efficient and cost effective farm mechanization

iv. Climate resilience in rainfed agriculture can be better addressed through risk and vulnerability assessment at sub-district level; mainstreaming resilient technologies through strong convergence with government schemes and appropriate policy interventions; strong preparedness for weather aberration (based on long term experiences or trends) along with actually responding to the situation and capacity building of primary and secondary stakeholders

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Effects of Alternate Wetting and Drying Water Levels and Planting Methods on Performance of Rice (*Oryza Sativa* L.) and Selected Soil Properties in a Nigerian Sudan Savanna

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Abstract

This study was conducted to determine the effect of changing the depths of water and planting methods on soil properties and rice yields under alternate wetting and drying (AWD) in the Systems of Rice Intensification (SRI). The treatments consisted of four irrigation levels and four planting methods. The irrigation treatments included 4 water drop levels (WDL) in observation well: 6 cm, 10 cm, 14 cm water drop levels below the soil surface and continuous flooding with 5 cm layer of water above soil. Four planting methods included seed drilling, broadcasting, transplanting 12 day-old seedling and transplanting 21 day-old seedlings. Lowland rice (FARO 44) was established in randomized complete block design. Alternate wetting and drying at 6 and 14 cm WDL showed 14.27 % and 11.59 % increase in total porosity respectively, when compared with initial soil total porosity. All plots showed a decrease in bulk density compared with initial soil bulk density. Paddy yield for irrigation treatments ranged between 6.03-9.92 t ha^{-1}, with AWD at 10 cm WDL having highest yield of 9.92 t ha^{-1}, the lowest was observed in the continuously flooded plots (6.03t ha^{-1}). System of rice intensification method of transplanting was observed to yield 10.08 t ha^{-1} of paddy and showed percentage increases in paddy yields by 26.3%, 69.9% and 33.5% over conventional transplanting (21 day seedling), broadcasting and drilling, respectively. This study showed the superiority of using younger seedlings in transplanting and 10cm water drop level in the observation well for increased food security and income.

Keywords: Alternate wetting and drying, planting methods, soil porosity, water drop level, Paddy yield

Introduction

Rice is the most widely consumed staple food for a large part of the world's human population, especially in Asia. It is the agricultural commodity with the third-highest worldwide production (741.5 million tonnes in 2014), after sugarcane (1.9 billion tonnes) and maize (1.0 billion tonnes) (FAOSTAT, 2014). In 2022, world production of paddy rice was 509.99 million MT, led by China (147 million MT) and India (126.5 million MT) with a combined 50% of this total. Other major producers are Bangladesh (35.65 million MT) and Indonesia (34.6 million MT), with Nigeria being the 13th highest rice producer with 5.4 million MT (FAOSTAT 2021; WAP 2022).

Rice is one of the most consumed staples in Nigeria, with consumption per capita of 32 kg. In the past decade, consumption has increased by 4.7%; almost four times the global consumption growth, and reached 6.4 million tonnes in 2017 – accounting for 20% of Africa's consumption. Given the importance of rice as a staple food in Nigeria, boosting its production has been accorded high priority by the government in the past 7 years and significant progress has been recorded.

Rice is produced in Nigeria under both rainfed and irrigated cropping systems and with varieties adapted to different agroecologies across the country. Among the major rice producing states, Kebbi State produces 2.05 million MT in wet season and 1.51 million MT in dry season.

Previously, there was a huge demand – supply gap of around 2 million metric tons of rice annually in Nigeria. Recent policies and peoduction strategies has led to a closing up of this gap. To meet the demand of growing population, intensification of yield from each unit of land cultivated to a crop must be increased. A big challenge in Irrigated lowland rice production is that it consumes more than 50% of total freshwater and irrigated flooded rice requires two or three times more water than other cereal crops, such as wheat and maize (Barker *et al.,* 1998). In addition, rice production is facing increasingly competition with rapid urban and industrial development in terms of freshwater resource (Tuong and Bouman, 2001). The need for “more rice with less water” is crucial for food security and irrigation plays a greater role in meeting the future food needs and is gaining more attention in the recent times (Tuong and Bouman, 2004). One strategy of meeting up this rice demand is through the systems of rice intensification (SRI). The system of rice intensification refers to a set of sustainable cropping strategies that was shown to increase crop yields with less water and reduced greenhouse gases emissions (Uphoff, 2015).

Nigeria is well endowed with water and land resources for irrigation farming; such as the vast irrigation schemes that exists such as the Bakolori Irrigation Scheme in Zamfara State. Utilization of these existing resources can close the demand supply gap of rice in the country. The objective of this research is to test the effect of different planting methods and water application under SRI and conventional practices on rice yields and on selected soil properties.

Materials and methods

Experimental Site and Description

The research work was conducted at in the dry seasons of 2019 at the Bakolori Irrigation Scheme Talata-Mafara, Zamfara State, located on latitude 12° 41. 714’N and longitude 006° 01.079’E in the Sudan Savanna of Nigeria (Fig. 1). According to NiMet (2012), the study area has an elevation of 313 m above sea level and an establishment of rainfall from mid-June, with an error margin of 1 to 6 days, and a cessation at 11th October. The length of growing season is 126 days with an error margin of 2 to 11days. Seasonal rainfall is 615 mm with an error margin of 22 to 94 mm. The average annual temperature is 27.9°C.

Treatments and Experimental Design

The treatments consisted of four irrigation treatments and four planting methods. The irrigation treatments included four water drop levels (WDL) in observation tube-well: 6 cm, 10 cm, 14 cm water drop levels below the soil surface and continuous flooding with 5 cm layer of water above the soil surface. The four planting methods included direct seed drilling, direct seed broadcasting, System of Rice Intensification (SRI) method of transplanting 12 days old seedlings after sowing and Conventional method of transplanting 21 days old seedling. This comprised of 16 treatments combination laid out in a randomized complete block design in a split plot arrangement. The main plots consisted of irrigation treatments while planting methods was assigned to the sub-plots. The plots were prepared in a plot size of 2.5 m x 2.5 m (6.25 m^2), with a bund spacing of 0.5 m between sub-plots and 1 m between main plots.

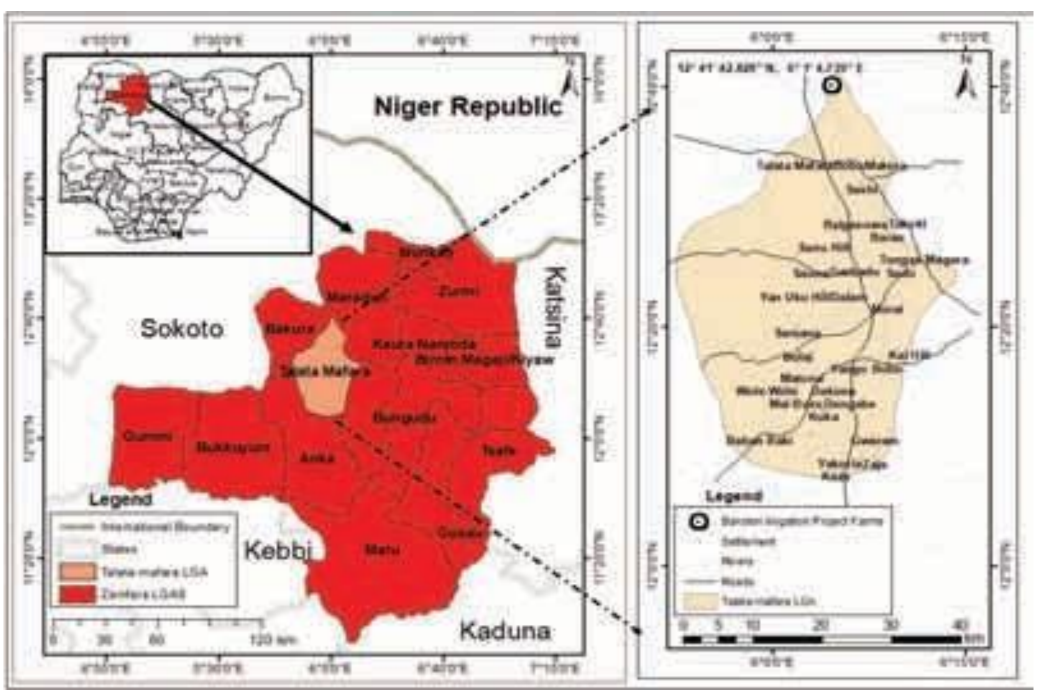

Fig. 1: Map of the study Area in Zamfara State, Nigeria

Soil Sampling

Soil samples were randomly collected from the field both before and after land preparation. At land preparation stage, disturbed soil samples were collected at 0-15 cm and 15-30 cm depths using auger for routine analysis of soil. A composite sample was formed from each depth. After harvest, disturbed soil samples were also collected from each experimental plot to determine effect of the treatments on chemical properties of the soil. Post-harvest, undisturbed bulk samples were taken at 13 points in a W-shaped pattern at 4 depths (0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm) to determine selected soil physical properties viz. total porosity and bulk density.

Results and Discussion

Effects of Irrigation Treatments and Planting Methods on Soil Bulk Density and Total Porosity

The mean bulk density for plots under the various irrigation treatments ranged between 1.43-1.49 Mg m^{-3} **(Table 1),** with AWD treatment plot where re-irrigation was done at 10 cm water drop level recording the highest (1.49 Mg m^{-3}). This showed a 4.48 % decrease in bulk density when compared with initial soil bulk density and was significantly different from bulk density at 6 cm, 14 cm and continuous flooding treatments. The relatively higher bulk density in plots where re-irrigation was at a 10 cm water drop level might be due to a higher stand planting density, which suggests a direct effect of planting density on soil compaction (Duan *et al*., 2019). It could also be attributed to the increased activities of aerobic soil organisms which led to the collapse of small soil aggregates. Collapsed soil aggregates are deposited in spaces within the soil groupings, which causes the formation of semi-compressed layers and increased soil bulk density (Abdul and Sinan, 2008; Al-Wazan, 2009).

Plots where rice was established by broadcasting and conventional method of transplanting recorded the highest mean bulk density (1.46 Mg m^{-3}), which showed a 6.41 % decrease in bulk density when compared with initial soil bulk density. This was statistically similar with bulk densities for plots established by drilling and SRI the method of transplanting. The interaction effect of the irrigation regime and planting method on bulk density was significant ($p<0.05$).

Table 1: Effect of Irrigation Treatments and Planting Methods on Bulk Density and Total Porosity

Treatments	Bulk Density (Mg m^{-3})	Total Porosity (%)
Irrigation Treatments (IT)		
6 cm AWD WDL	1.43c	42.10a
10 cm AWD WDL	1.49a	40.73b
14 cm AWD WDL	1.43c	41.11a
Flooding	1.46b	41.06ab
SE±	0.008	0.353
Planting Methods (PM)		
Broadcasting	1.46	41.46
Drilling	1.45	41.68
SRI	1.44	41.51
Conventional TP	1.46	41.22
SE±	0.008	0.353
IT*PM	*	NS

Means followed by the same letters within a treatment column are not significant at 5% level of probability. Ns: not significant; *: significant at 0.05 level; **: significant at 0.01 level. AWD: alternate wetting and drying; WDL: water drop level; SE: standard error

Broadcasting method combined with continuous flooding had similar effect on bulk density, as combination of conventional transplanting method and re-irrigation at 6 cm water drop level under AWD did.

Mean total porosity for irrigation treatments was observed to range between 40.73-42.10 %, with AWD at 6 and 14 cm WDL having the highest total porosity (42.10 and 41.11 % respectively). Both were statistically at par, but significantly different from total porosity when AWD was applied at 10 cm WDL. Alternate wetting and drying at 6 and 14 cm WDL showed 14.27 % and 11.59 %

increase in total porosity respectively, when compared with initial soil total porosity. Increased total porosity in AWD might be due to increased activities of plant roots and soil organisms when AWD was applied at both 6 and 14 cm WDL.

With respect to the planting methods, mean total porosity of plots ranged from 41.22 to 41.68 %, with plots established by drilling method and those transplanted using SRI practices giving the highest values of 41.68

and 41.51 % respectively) values; but statistically at par with the porosity of plots established by broadcasting and conventional method of transplanting. Drilling and SRI method of transplanting were observed to show 13.14 % and 12.68 % increase in total porosity respectively, when compared with initial soil total porosity. This might be due to increased tillering in drilling and SRI, which increased plant population and root activities. There was no significant difference observed in total porosity when irrigation regimes interacted with planting methods.

Effects of Irrigation Treatments and Planting Methods on Paddy Yield and Some of the Yield Components

Table 2 presents the effects of irrigation treatments and planting methods on rice yield and some yield components. Mean number of tillers in irrigation treatments ranged from 39 to 48.

Table 2: Effect of Irrigation Treatments and Planting Methods on Paddy Yield Parameters

Treatments	Number of Tillers/hill	Number of Productive Tillers/hill	Straw yield (t/ha)	Paddy yield (t/ha)	Total biomass (t/ha)
Irrigation Treatments (IT)					
6 cm AWD WDL	39.34c	38.35c	27.10b	6.95c	34.05c
10 cm AWD WDL	48.43a	47.17a	30.73a	9.92a	40.65a
14 cm AWD WDL	45.03b	43.58b	28.35ab	8.64b	36.99b
Flooding	40.98c	40.15c	24.60c	6.03d	30.63d
SE±	0.648	0.648	0.871	0.197	0.971
Planting Methods (PM)					
Broadcasting	34.36d	33.28d	24.73b	5.93c	30.66c
Drilling	40.90c	39.54c	26.51b	7.55b	34.06b
SRI	52.50a	51.30a	29.58a	10.08a	39.66a
Conventional TP	46.03b	45.13b	29.95a	7.98b	37.93a
SE±	0.648	0.648	0.871	0.197	0.971
Interactions					
IT*PM	***	***	**	**	**

Means followed by the same letters within a treatment column are not significant at 5% level of probability. NS: not significant; *: significant at 0.05 level; **: significant at 0.01 level; ***: significant at 0.001 level. AWD: alternate wetting and drying; WDL: water drop level; SE: standard error.

with AWD at 10 cm WDL giving the highest mean of 48.43; which was attributed to better vegetative growth observed when AWD was applied at 10 cm WDL. Alternate wetting and drying at 10 cm WDL showed percentage increase in number of tillers by 23.1%, 7.5% and 18.1% over AWD at 6 cm WDL, 14 cm WDL and continuous flooding respectively. Mean number of tillers in planting method treatments were observed to range from 34.36 to 52.50, with SRI and conventional transplanting having highest mean of 52.50 and 46.03 respectively.

Plots established by system of rice intensification were observed to show a percentage increase in number of tillers by 14%, 28.3% and 52.7% over conventional transplanting, drilling and broadcasting respectively. Wider spacing in SRI method of transplanting, improved the crops' effective utilization of available resources such as space, nutrient area for the root system, better root spread, more light interception etc resulting in an enhanced tiller production (Thavapraprakash *et al.,* 2008; Singh *et al.*, 2015). Interaction between irrigation treatments and planting methods for number of tillers at harvest was observed to be significant (P<0.001). Alternate wetting and drying at 10 cm WDL water drop level combined with SRI method of transplanting was observed to have highest number of tillers from the interaction figure (not shown).

Paddy yield for irrigation treatments ranged from 6.03-9.92 t/ha, with AWD at 10 cm WDL having highest yield of 9.92 t/ha, which statistically differ from yield at 6 cm and 14 cm AWD WDL; as well as continuous flooding. This may be because wetting and drying process at this depth provides a suitable soil-plant relationship that allows plant roots better access to water, nutrient adsorption and air; when compared to continuous flooding and other irrigation depths (Lhendup, 2008). Paddy yield was observed to range from 5.93-10.08 t/ha for planting method treatments, with SRI method of transplanting yielding the highest value of 10.08 t/ha, which was significantly different from means of conventional transplanting, drilling and broadcasting. System of rice intensification method of transplanting was observed to have percentage increase in paddy yield by 26.3%, 69.9% and 33.5% over conventional transplanting, broadcasting and drilling respectively.

Perhaps this could be due to efficient utilization of externally applied nutrients in SRI and more foraging area of root volume in SRI plots as shown in several studies. Alternate wetting and drying at 10 cm WDL combined with system of rice intensification method of transplanting was observed to have highest paddy yield, which was significantly different from all treatment combinations (**Figure 2**).

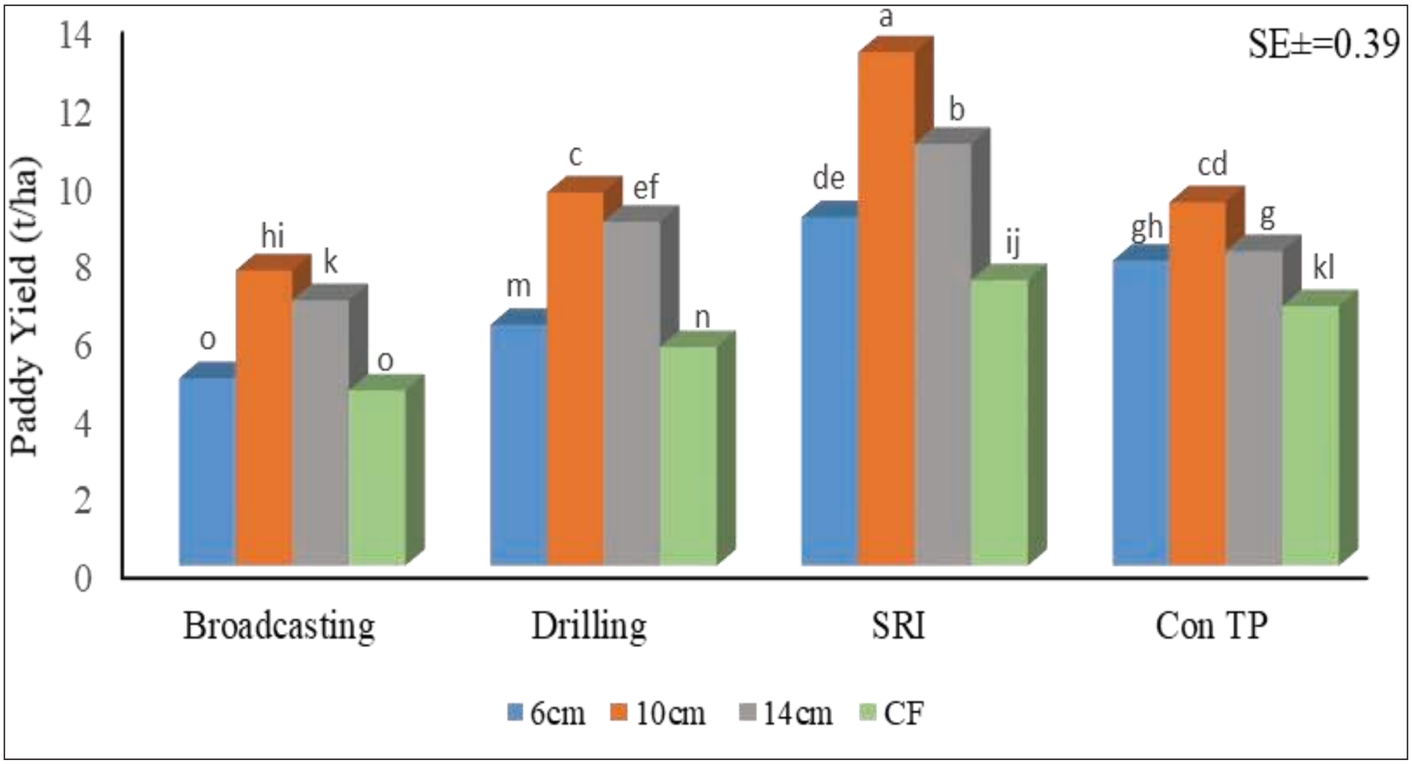

Figure 2: Interaction of Irrigation Treatment and Planting Methods on Paddy Yield

Conclusion

Alternate wetting and drying at 10 cm WDL recorded highest soil bulk density of 1.49 Mg m^{-3} which showed a 4.48 % decrease in soil bulk density when compared with initial soil bulk density. Alternate wetting and drying at 10 cm WDL combined with system of rice intensification method of transplanting was observed to have highest number of tillers which translated to higher paddy yields than all treatment combinations. This is consistent with previous findings that show the superiority of SRI methods of rice production over conventional methods.

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Theme IV

Agro-Industries/Mechanization for Scaling up SCI

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Trend in Sustainable Mechanization of Indian Agriculture

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Abstract

Agriculture is one of the most important sectors of the Indian economy contributing 18.5% of national income, about 15% of total exports and supporting two-thirds of the work force. At the same time, biotic and abiotic stresses, degrading and depleting land and water resources and climate change are major challenges for sustainable agricultural production and productivity. The small and marginal land holdings (less than 2.0 ha) account for more than 86% of land holdings. The labour availability in agriculture is expected to go down to 26% of total workforce by 2047. Mechanizing small and non-contiguous group of small farms is against 'economies of scale' for individual ownership of farm machinery. With no possibility of increase in net cultivated area and diminishing farm labour availability, intensive agriculture with higher input use efficiency is essential for the growth of Indian agriculture in near future.

Farm power and agricultural machinery are essential inputs for sustainable agricultural production and productivity to feed India's burgeoning population. The intensification of crop production must be sustainable with low environmental footprint. A holistic, value-chain approach is necessary for agricultural mechanization, going beyond green production through precision agriculture and digital agriculture. Precision agriculture for region specific crop planning, controlled precision application of inputs (seeds, fertilisers, chemicals, water, etc), multi-functional farm equipment to conserve energy and to reduce turnaround time, application of drones in agriculture, application of sensors, micro-processor and computer in agriculture are some of the futuristic technologies that need more attention for sustainable agriculture in India. There is a need to simplify these technologies and make them cost-efficient for maximum adoption at the farmers' level.

Keywords: Sustainable agriculture, Mechanization, Precision Agriculture

Indian population is expected to reach 1.6 billion by 2047. At the same time, biotic and abiotic stresses, degrading and depleting land and water resources and climate change are major challenges for sustainable agricultural production and productivity. Over the years, Indian farming system has not given an expected remuneration to farmers besides its remarkable growth in food-grain production and processing sectors. However, agriculture remains a principal means of livelihood for over 58% of the rural households and 86% of small and marginal land holdings (Mehta *et al*., 2019). In addition, as per World Bank estimates, half of the Indian population will be urban by the year 2050. It is estimated that the percentage of agricultural workers to total work force will reduce from 54.6% in 2011 to 25.7% in 2050. This highlights the need to enhance farm power availability and farm mechanisation level in the country (Mehta *et al.*, 2014; NITI, 2018).

Agricultural mechanization is an important symbol of agricultural modernization. The agricultural equipment is the carrier of agricultural modernization and thus an important tool used to promote agricultural mechanization. The level of economic development has a positive impact on the mechanization level. The levels of farm mechanization in USA, Russia, Brazil, China and India have been reported as 95, 80, 75, 60 and 47%, respectively. However, the level of mechanization is inversely proportional to contribution of agriculture in the countries GDPs (World Bank Indicators, 2013; Mehta *et al*., 2019). Therefore, there is a need for further promotion of farm mechanisation.

Presently, the farm machinery in India are being primarily used for production of field crops like cereals, pulses and oilseeds crops. The agricultural mechanization is at an early stage in India and growing at 7.5% per annum in spite of challenges of small land holdings, cropping pattern, market prices of crops and government policies and legislations. The ignorance of these challenges will exaggerate the redundant labour force, low return against inputs for yield and ultimately decrease the enthusiasm of farmers in agriculture. Due to lower probability of increase in net cultivated area and scarcity of agriculture labour in the near future, Indian agriculture may require energy intensive agriculture with higher input use efficiency, better soil health management practices and value addition to produce in production catchments.

The agricultural scenario has changed during all these years, and farmers now fully understand the value of time which is scarce and inputs which are ever costlier. So, it is a challenge not only to cover the farm area in shorter time but also to use all inputs (seeds, fertilizers, chemicals, water, energy etc.) precisely and efficiently. There was a need to sustain Green Revolution through time, energy and input saving equipment which were efficient, covered larger area per day, improved productivity per unit area and per unit costly inputs (seed, fertilizer, water, energy) and gave the farmers sufficient time for preparation for next crop. Further, the previous generation of farmers is giving way to new generation which is more educated, looks beyond his village and conscious of doing operations smartly on time and with less drudgery. Thus, today's challenges in farming cannot be met by yesterday's technologies and machinery.

Modern engineering interventions in agriculture are the need of the hour to reduce cost of cultivation, to improve input use efficiencies, to provide right timing and right sizing of the mechanical inputs, to provide better control over the pre and post-harvest operations, to reduce post-harvest losses, to harness energy through clean sources, to prevent burden on environment and animate power sources, and to make agricultural operations safer, more comfortable and gender neutral. In modern agriculture, farm mechanization has become imperative to growth and sustenance as it facilitates the judicious utilization of agricultural inputs. The use of available farm power with efficient farm implements has resulted in increased farm productivity.

Time has come to think of newer designs of agricultural machinery which are of higher capacity, more efficient, perhaps remote/drone controlled, automated robot operated, operator/user friendly especially for women who are taking up agriculture in larger number due to several factors like migration of male folks to cities causing real problem of farm successors.

Within Indian ecosystem, labour-intensive farm activities are automated, stakeholders (farmers, labours, manufactures, etc.) and decision makers across the value chain are more connected with one another, and information and data, physical products, service and touch point experiences will be united as one integrated solution that solve users/stakeholders needs. It will enable the agricultural machinery manufacturing industries for sustainable production in country.

Present Indian agriculture is highly labour intensive whereas smart agriculture is all about machines and technologies. The themes of precision agriculture (PA), digital agriculture (DA) and artificial intelligence (AI) in agriculture can be applied across disciplines and may bring a paradigm shift in how we see farming today. There are four recurring themes for sustainable smart agricultural mechanization in India.

1. Farm power and agricultural machinery are essential inputs if sustainable agricultural production and productivity are to be increased and managed to feed India's burgeoning population.
2. The intensification of crop production must be sustainable. Its environmental footprint (carbon and energy) must be as low as possible, and in any case lower than the rate of natural renewal.
3. Top-down solutions are rarely efficacious. All stakeholders need to be considered from the outset and the private sector must lead the development process on the field.
4. A holistic, value-chain approach is necessary for agricultural mechanization, going beyond green production through precision agriculture and digital agriculture.

If agricultural mechanization efforts are to succeed in India, there is an urgent need for all stake holders like farmers, manufacturers, supporters, planners or decision makers, to understand and contribute to sustainable agricultural mechanization efforts across the entire farming system. The agricultural machinery manufacturing sector in India requires incentives for the manufacturing of equipment for sustainable mechanized agricultural practices.

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Lotus Foods' Experience Developing Value Chains for SRI Rice

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Abstract

Since 2008, Lotus Foods, a US-based importer of heirloom and pigmented rice produced on family farms, has been sourcing marketable surpluses of rice grown by farmers using System of Rice Intensification (SRI) practices. It presently sources SRI-grown rice in Cambodia, India, Indonesia, and Thailand. Lotus Foods'commitment is based on the recognition that SRI is a more efficient, environmentally responsible, and equitable way to grow rice, especially for smallholder producers. In the countries where it sources rice, it works with long-term business partners who aggregate the rice and process it for shipment, handling also certifications and quality control. In the US, Lotus Foods has the job of ensuring final quality, packaging, marketing, sales and distribution. While the company has increased the amount of SRI rice it imports over the past 10 years, it had expected to be importing a lot more. This is due to challenges on both the supply and demand side. This includes supply chain partners' initial lack of experience in processing, business skills, and export, as well as access to credit and modern equipment. The price of Lotus Foods' SRI rice in the marketplace is thus at the upper range due to premiums paid for organic and fair-trade certifications and supply chain inefficiencies. Nonetheless, pro-active outreach to educate American consumers and the food industry about the benefits of SRI has resonated with both and generated growing support for the company's pioneering efforts to help "change how rice is grown around the world."

Key words: Lotus Foods, SRI, Rice, Value Chains, Marketing

Introduction

In 2008, Lotus Foods, a small US-based rice importer specializing in heirloom and pigmented rice grown on family farms, committed to sourcing rice from SRI farmers. We began with one container apiece (about 18 metric tons) in 2009, from Cambodia, Indonesia and Madagascar, having identified, with assistance from the Cornell International Institute for Food, Agriculture and Development (CIIFAD), organizations representing SRI farmers producing marketable surpluses. The company's goals were to: 1) raise awareness of the benefits of SRI practices for people and planet and thus drive change in how rice is grown to be more socially and environmentally responsible; 2) create market incentives and rewards for farmers to adopt SRI; and 3) educate consumers so they could use their purchases to "be part of the solution" to make rice production more sustainable and equitable.

Methods

About Lotus Foods

Established in 1995, Lotus Foods pioneered varieties of heirloom pigmented rice to the US. It is best known for its black rice from China, trademarked Forbidden Rice®. The company's founding mission was to preserve rice biodiversity, ensure fair prices for family farmers, and promote sustainable agriculture. Headquartered in California, the company has 17 full-time employees, is a certified B Corporation, and co-founder owned and led. It is present in all channels: natural, grocery, e-commerce, foodservice and club. This includes retail stores across North America such as Albertsons and Whole Foods Market. And in club and e-commerce Costco and Amazon, respectively. Lotus Foods is aamong a core group of brands in the natural foods space respected for innovation, ethics, and championing of small-scale farmers and sustainability.

In the past eight years the company has moved increasingly into value-added products like rice-based noodles due to consumers seeking more nutrient dense, convenience foods. The company maintains close association with SRI-Rice at Cornell University to connect with SRI-related research and the global SRI community. It achieves this through direct communication and by retaining on its team a part-time SRI Liaison. It has also on occasion paid for the attendance of SRI scholars at international conferences and for production of videos highlighting the role of women in rice production.

Strategy

To create and expand markets for SRI rice required: 1) importing a supply of high-quality rice from in-country partners sourcing the SRI rice from farmers; and 2) sales and marketing in the US. In-country supply partners handle all the on-site responsibilities including processing, quality control, and bulk packing. Lotus Foods receives the containers in Oakland, California, and has the job of ensuring final quality, packaging, marketing, sales and distribution.

In marketing SRI rice, pro-active education and outreach have been critical and a linchpin of our approach. SRI and the rice varietals first launched in 2009 were unknown in the US. This required a brand refresh to explain SRI on retail packaging and the Lotus Foods website, and educating all levels in the industry from brokers, distributors, and stores to consumers. This has been done with banners, sales materials and promotions, and handouts at four major annual trade shows, in-store product demonstrations, presentations at various conferences, interviews, panel discussions, videos, magazine articles, and award nominations. Since SRI represents such a complex set of issues, to make the concept more accessible to consumers, Lotus Foods has marketed it as More Crop Per Drop®. In 2010, when the company was conducting its brand refresh, the state of California was suffering from a multi-year drought, so concern about water featured highest in consumer surveys.

Making the Case for SRI

Telling the SRI story has not been easy, as it requires that an audience know some fundamentals about rice cultivation before it can appreciate the benefits. Key elements of making the case for SRI have included:

- Rice is the major recipient of irrigation water, and current practices contribute to global warming, soil degradation, and biodiversity loss. There are many places where paddy can no longer be grown due to water scarcity.
- Less than 10% of rice is internationally traded. Most of the world's rice is produced on small family farms. Roughly one fifth of the world's population depends on rice farming. The majority struggle to make a living. Many are already becoming climate refugees. We urgently need inclusive solutions.
- Rice is quite literally grown on the backs of women. They work perpetually in bent positions in stagnant water exposed to diseases. Hotter temperatures will increase the stress on their bodies. Their health has a direct impact on farm productivity.

We then provide a visual comparison of conventional and SRI practices, pointing out why we're so committed to SRI:

- SRI is a climate-smart, agroecological methodology for increasing the productivity of rice and other crops by changing the management of plants, soil, water and nutrients.
- SRI is a lot more efficient in use of seeds (80-90% fewer seedlings to plant), water (25-50% less), and women's labor. A simple weeder allows women to weed in an upright position, and they no longer have to work in flooded conditions. One of the many benefits of SRI is the larger root systems that enable plants to withstand storms. Lodging can wipe out an entire season of food. With less cost, inputs and time compared to conventional practices, farmers can increase their yields and incomes.

Results

The company presently imports about 1100 metric tons of SRI-sourced rice from Cambodia, India, Indonesia and Thailand. The rice is certified organic and fair trade. In 2020 our basmati rice from India achieved the highest industry standard, Regenerative Organic Certification. This represents an opportunity for SRI to gain validation as a regenerative practice. Based on over 10 years of buying and selling SRI rice we have the following observations.

What Is Working: At the **farm level,** SRI is an effective methodology for mitigating climate change and promoting farmer resilience. Smallholder farmers can afford it. They can produce surpluses with most varieties, qualify for organic, biodynamic, fair trade and even regenerative standards, and scale quickly if needed and with the necessary training. At the **company level,** Lotus Foods and its supply partners are committed. We have sustained long-term relationships and continue to explore how to improve efficiencies and overcome challenges with our in-country supply partners. There is evident interest from socially responsible lending institutions in getting more involved. **Consumers and retailers** are extremely enthusiastic and supportive of SRI benefits for people and planet, greater rice biodiversity and connection to farmers.

Challenges and Obstacles: There are two major constraints to scaling SRI in North American markets. The first is related to high pricing. This is due to numerous constraints. These include the time and resources required to overcome supply chain partners' lack of experience in processing, business skills, and export. This affects quality control**,** which must be present in every aspect from seed purification to post-harvest and processing, including milling, cleaning, colour sorting, metal detection, lab analysis, packaging for organic standards, storage, transport and shipping. Related to this is outdated or poor-quality equipment, inadequate knowledge about equipment and maintenance thereof as well as, inadequate funds or credit to maintain or purchase better equipment. Access to capital for partners to secure inventory to scale and to cover the cost of certifications is also a limitation. The cost of certifications themselves add further to the ultimate price that consumers are charged.

The second problem is demand. Rice is not part of traditional food culture in North America. Rice can take time to cook, and many Americans aren't comfortable cooking rice. There is a strong desire for convenience products like noodles. Rice is still perceived as a cheap carbohydrate. Once all the costs of bringing SRI rice to market are tallied, the price for a bag of Lotus Foods rice in the supermarket (currently about $6.50 for .4 kg retail bag and $9 for .85 kg retail bag) exceeds what most consumers can afford, and the company's margin is minimal. American consumers have yet to embrace other pigmented rice besides the company's most popular black Forbidden Rice®.

Discussion

The company has achieved mixed success due to challenges of working with under-resourced supply partners and the costs of certifications, which make our rice less competitive in mainstream grocery. Nonetheless, the company has gained recognition in the natural products industry for the benefits of SRI, especially around its positive impact on water conservation, mitigating climate change and on women's well-being. From 2009 to 2021, we estimate that on the farms from which we sourced SRI rice, 5 billion gallons less water were used on paddies, and 44,000 tons of CO_2 equivalent were not emitted. Our organic and fair-trade premiums have impacted some 5000 household members and contributed to community enhancements through fair trade social development premiums. In Cambodia, for example, these have included installing wells, bridges, ponds, building a community centre and investing in a community-owned mill.

In recent years, Lotus Foods has been hampered in its operations and ability to grow due to tariffs on Chinese goods imposed under the Trump administration, the 900-fold increase in freight costs after the COVID pandemic, and now rising inflation. By the end of 2022, we will have paid some $9 million in tariffs. These are funds that could have been applied to address many of the challenges to scaling SRI we have been encountering.

What this also highlights is that the value chain from farmers' fields to American tables is a long one. Since the goal is to scale SRI to mitigate climate change, address food security, and improve farmer resilience, SRI advocates should focus on developing domestic markets to reduce the distance from producer to consumer--promoting also traditional varietals-- making the rice affordable while ensuring fair prices for producers.

Another important opportunity for farmers is the growing market for convenience and value-added foods like noodles that use rice flour in particular. This will require identification of appropriate varieties, compatibility with manufacturing processing, capacity building and investing in new kinds of training and equipment.

Conclusions

Since no large company was initially interested in the small volumes of surplus rice SRI farmers were producing or willing to work with partners who had no experience in export, Lotus Foods has filled an important void. By linking SRI farmers to markets it is having a meaningful impact on farm households and climate mitigation. But we would like to see SRI scale in both international and domestic markets. A key challenge is lowering prices at the store shelf while maintaining premium pricing for farmers.

An overarching goal would be more policy support for agroecological farming in general, with incentives and reward systems, including carbon credits and crop insurance, for producers who deliver key climate mitigation and ecosystem services. Other strategies might include: 1) Ensuring affordability and accessibility of organic fertilizers and tools for farmers, especially women-friendly tools; 2) Improving water delivery and water capture and storage to provide safety nets during times of both flood and drought, and provide more stability for farmers and buyers; 3)

Improving efficiency and quality in all steps from farms to when companies like Lotus Foods take delivery is critical, which means in-country partners need to have access to low-interest credit for equipment and capital investments and technical assistance and capacity building in milling, packaging, quality control, staffing and accounting;

4) Funding to spur local innovation to improve farmer ownership of the value chain, and commercialize value-added innovations and technologies, would contribute to more robust rural economies.

Help is also needed to bring consumers closer to farmers and make the case for SRI so that they appreciate the benefits for climate, women, communities. This includes research on the health properties of traditional rice. Affordable technology to measure on-farm GHG emissions and reward farmers with carbon credits is a goal gaining global momentum. In November 2021, at COP26 U.S. President Biden was joined by 100 governments in his Global Methane Pledge to reduce the world's methane emissions 30% from 2020 levels by 2030. This includes facilitating private investment in climate-smart development. Given SRI's impact on diminishing methane emissions, opportunities like this should be investigated and leveraged. With individuals like Bill Gates starting to invest in the decarbonisation of rice, and many countries facing serious food shortages, it would seem that a major public-private sector partnership to scale SRI could deliver on many of the UN's Sustainable Development Goals simultaneously, including reducing hunger, minimizing methane emissions and promoting farmer and rural resilience. All while also conserving our planet's freshwater. Finally, UN organizations and government procurement programs should stand behind their values and procure SRI rice grown by smallholders.

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ICAR CIAE-SBI Mechanization Package for Sustainable Sugarcane Initiative (SSI) through Bud Chip/ Single Bud Propagation

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Abstract

Sustainable Sugarcane Initiative (SSI) is a method of sugarcane production which uses less seeds, less water and optimum utilization of fertilizers and land to achieve more yields. Sugarcane bud chip planting/ Sugarcane Single bud planting is the latest technique of sugarcane planting, wherein the bud along with a portion of the nodal region is chipped off and planted in portray with Farm Yard Manure (FYM), soil and sand. This technology is going to be in great demand for successful SSI method of sugarcane cultivation. Package of equipment for Bid chip/ single bud planting of sugarcane was developed by ICAR Central Institute of Agricultural Engineering- Regional Centre, Coimbatore, Tamil Nadu, India in collaboration with ICAR Sugarcane Breeding Institute, Coimbatore, Tamil Nadu, India. The package of equipment consists of equipment for removal or scooping of bud chip from sugarcane, equipment for single bud cutting, equipment for portray filling for sugarcane bud chips, Protocol for Storage and transportation of sugarcane bud chips, mechanization package for effective fungicidal treatment for sugarcane bud chips, mechanized Planting of sugarcane bud chip settlings grown in portrays and Elevated Hybridization Runways (EHR) Facility. The equipment can be adopted in total or selected equipment/protocol can be used based on the mechanization requirement for Sustainable Sugarcane Initiative (SSI). On an average, there is a savings of about Rs 15000 per ha if the developed mechanization package is used. Apart from this, there will be savings of about 90 percent of the cane material, which can be used for sugar/jaggery industry. Cost economic analysis revealed significant saving in cost and labour over traditional planting of Sustainable Sugarcane Initiative (SSI). The biometric parameters viz., diameter of the cane, cane height, single cane weight, juice content and yield of sugarcane settlings raised using Mechanization package were on par with the manually planted sugarcane settlings. Similarly, the juice quality of sugarcane from planted settling in terms of brix, CCS, sucrose and purity using mechanization package was on par with sugarcane from manual method at the time of harvest.

Key words: Sugarcane, Sustainable Sugarcane initiative, Bud chipping, Single Bud cutting, Low pressure Treatment, Mechanized planting, Elevated Hybridization Runways

Introduction

The conventional method of planting of sugarcane, using stalk cuttings (setts), is gradually becoming uneconomical as the cost of "Seed Cane" used for replanting accounts for about 20 per cent of the total cost of production. In the conventional system prevailing in India, about 10 tonnes seed cane / ha (nearly 10% of total produce) is used as planting material.

Of late, there has been a lot of emphasis on Sustainable Sugarcane Agriculture. Sustainable Sugarcane Initiative (SSI) now recommended in many states, aims at reducing the use of seed, water besides optimizing the use of fertilizers and land to achieve higher yields. SSI is an alternative to the conventional seed, water and space - intensive sugarcane cultivation. Use of single bud grown in protrays is the single major intervention for successful SSI.

This large quantity of planting material poses a great problem in pretreatment, transport, handling and storage of seed cane and can undergo rapid deterioration thus reducing the viability of the buds and subsequently their sprouting. In view of this, the scope for adoption of bud chip technology for large scale of propagation of sugarcane was realized and is becoming increasingly popular. Production of bud chips, effective treatment of budchips, raising of bud chip nurseries, transplanting of bud chip plants etc manually needs considerable time and resources and are serious deterrents in the popularization of the bud chip technology. The mechanization package for sugarcane bud chip planting been developed by Central Institute of Agricultural Engineering-Regional centre, Coimbatore, Tamil Nadu in collaboration with Sugarcane Breeding Institute, Coimbatore, Tamil Nadu. For effective large scale propagation of sugarcane bud chip technology, there was an urgent need for mechanization.

Methods

The following equipment / technology have been used. The conventional method of planting of sugarcane, using stalk cuttings (setts), is gradually becoming uneconomical as the cost of "Seed Cane" used for replanting accounts for about 20 per cent of the total cost of production. In the conventional system prevailing in India, about 10 tonnes seed cane / ha (nearly 10% of total produce) is used as planting material.

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Results

The following equipment / technology have been developed, evaluated, popularized in collaboration with the agricultural machinery manufacturers.

a. Removal or scooping of bud chip from sugarcane: Three models of sugarcane bud chipping viz., pedal operated, pneumatic and motorized models
b. Equipment for single bud cutting
c. Equipment for portray filling for sugarcane bud chips
d. Protocol for Storage and transportation of sugarcane bud chips
e. Mechanization package for effective fungicidal treatment for sugarcane bud chips
f. Mechanized Planting of sugarcane bud chip settlings grown in protrays
g. Elevated Hybridization Runways (EHR) Facility

On an average, there is a savings of about Rs 15000 per ha if the developed mechanization package is used. Apart from this, there will be savings of about 90 percent of the cane material, which can be used for sugar/jaggery industry. The indirect benefit of development of industries involved in fabrication of agricultural equipment is going to add to the overall impact seen from the production, productivity and profitability by adopting the sugarcane bud chip technology.

The package of equipment has become popular and widely accepted by various sugarcane mills, farmers and entrepreneurs. Four patents have been filed by the team. Based on the success of the package of equipment technology developed by the interdisciplinary team for propogation of sugarcane bud chip technology, the technology is being adopted for sugarcane single bud, which is also fast catching up.

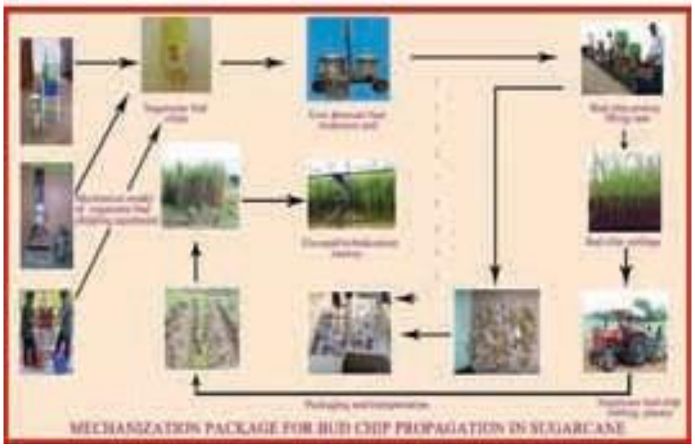

Figure 1: Mechanization package for Bud chip propagation in Sugarcane for SSI

Figure 2: Mechanization package for single bud propagation in Sugarcane for SSI

Conclusions

Sustainable Sugarcane Initiative (SSI) is a technology which is being adopted by large farming community in India which uses less seeds, less water and optimum use of input resources with higher economic returns. Use of sugarcane bud chip/ Single bud technology is a revolutionary step towards successful adoption of SSI. To mechanize various operations, package of equipment has been developed, evaluated and commercialized. The cost economic studies revealed that this equipment were more economic in operation, leading to significant saving in cost and time. This equipment is a boon to entrepreneurs who are involved in large scale production of the sugarcane bud chip nursery with an aim to undertake the Sustainable Sugarcane initiative programme in Indian Scenario.

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Application of Renewable Energy in Indian agriculture

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Abstract

Energy plays a key role in agricultural production, post-production, rural domestic and livestock raising sectors, both directly as different forms of energy and fuel inputs for various purposes like operation of machinery, equipment, lighting, etc., and indirectly, for seed, fertilizers and chemicals production used in rural activities. India needs a secure, affordable and sustainable energy system to power effective economic growth well supported with renewable energy sources. Engineering interventions for effective (functionally, energetically and economically) systems is utmost needed for rural India. There is need for a revolution in mechanized agriculture, so that new energy efficient systems and machines can be recommended and introduced for small and marginal farmers. There is need to enhance the power availability and optimize the energy input to the rural sector to obtain the better income to agro-rural producers, traders and industrialists.

Energy interventions are needed to use the locally available energy sources curtailing the use of fossil energies. The major targets in Indian perspective are the use of available and developed renewable and conventional energy sources & gadgets in rural society and agro-industry using all kinds of available biomass resources including solar electricity, heating and pumping at decentralised mode. We need to employ recent advanced technologies like plasma technology, nano-technology, IoT, artificial intelligence and robotics for effective generation of energy and valued products from rural local renewable resources. Research on solar energy use for production agriculture is challenging due to fluctuating need of torque depending on the agricultural field conditions. The use of batteries for storing and releasing power is another concern for long term use of solar photovoltaic (SPV) gadgets. Bio-CNG has emerged as an option for ex-situ management of crop residue. Thermo-chemical and bio-chemical conversion based electrical power routes are available and there is a need to promote these with better incentives. Energy efficient functionally improved mechanical systems to be introduced in the Indian farms need to be evolved.

Key words: Renewable energy, Thermo & Bio chemical conversion, energy efficiency, nanotechnology, solar electricity & pumping,

Introduction

Farm power availability and energy input has significant positive impact on the agricultural productivities. There is need to precisely regulate the inputs like, water, labour, seed, fertilizer, machines, prime movers and agricultural land to enhance the yield. Energy optima can impart the yield maxima. But in present scenario, the use of inputs is not optimal which is leading to higher cost of production and energy input. Further, India needs to enhance the income to the farmers, which can be achieved by properly managing all the input resources to reduce the cost and to use the optimum energy input. Economic growth, urbanisation, rising incomes, Agricultural and Industrial activity are the drivers for increased energy consumption in India. The sectoral energy consumption by industry is 42.7% followed by Domestic (24%), Agriculture (17.7%), and Commercial (8%), Traction and railway (1.5%) and others (6.1%). The farm power availability is nearly 2.08 kW/ha which is to be increased by 4.0 kW/ha by 2025 to increase the productivity. Renewable energy is having important role for augmentation of grid power, to provide energy access, to reduce the consumption of fossil fuels and to support Indian economy to pursue its low carbon development path. India has a target to increase the share of renewable based installed electric capacity to 40% by 2030. India is also encouraging the establishment of a solar based economy across the globe. With France partnership, India promoted the establishment of the

International Solar Alliance (ISA) in 2015. In 2018, ISA was transformed into a treaty-based organisation having head-quarter in India.

In India agriculture provides livelihood to two-thirds of the total working population. The contribution of agriculture to Gross Domestic Product (GDP) is 15%. Indian agro-positive climatic conditions make India as one of the top producers of cereals, pulses, fruits, vegetables, milk, meat and fish. In India, due to Green Revolution in the 1960s, there was an increase of 45% in per capita food production till now. Tremendous growth in Indian agriculture in the last 75 years due to various efforts and initiatives has improved food security and raise agricultural output. But this has not resulted in the income enhancement of farm households. About 20 % of rural households primarily engaged in agriculture have income less than the poverty lines. To increase the farmer's income, the Government of India tried a strategy in 2018 - Doubling Farmers' Income. The strategy aimed to double the income by 2022 with yearly growth rate of 10.4%. About one fifth of the total electricity consumed in the country, is used for agriculture practices, mostly for irrigation. As the climatic conditions are erratic and irrigation is dependent on monsoon, the dependence on groundwater has increased. Presently 90% of country's groundwater is consumed for irrigation. For this, the farmers are using 12 million electricity connections and 9 million diesel pumps sets to take out the groundwater for irrigation use. Solar energy can play a significant role in addressing this critical issue. Ministry of New and Renewable Energy (MNRE) has launched PM KUSUM (Kisan Urja Suraksha Evam Utthaan Mahaabhiyan) scheme to support farmers for; (a) Setting-up of 10 GW of decentralized ground mounted grid-connected renewable power plants upto 2 Mega Watt (MW) capacity, (b)Installation of 1.75 Million stand-alone solar agriculture pumps, and (c) Solarisation of 1 Million grid-connected agriculture pumps. Solar pumps are a reliable power source for irrigation with almost negligible cost to run in the long term. Their uses also cut down the diesel cost, and reduce the pollution caused due to burning fuels. The decreasing cost of solar modules has made solar pumps a viable solution for farmers. Solar pumping holds great potential to save 4 billion litres of diesel yearly and 5% of total greenhouse gas emissions. Besides, using grid-connected pumps, cultivators can sell surplus power back to the grid, creating a good income to them.

Another approach to the farmers is the raw material needed in biofuels production - Biomass. National Policy on Biofuels, 2018 and Biomass based cogeneration plants, mentions to produce biodiesel and ethanol utilising sugarcane and its by-products, surplus rice, maize, damaged food grains and non-edible seeds. This is a straight forward opportunity for farmers to increase their income using un-utilised organic waste. Further, this will also reduce the emissions to an extent, as burning of agricultural residue will be reduced.

Energy availability and supply in agriculture is imperative to ensure agriculture sustainability. The changes in farm power and usage of energy resources in Indian agricultural over time have taken place in different magnitudes, accordingly influencing the energy productivity & profitability. The dynamic nature of energy demand and consumption scenario in the agriculture mostly depends on the primary sources of energy such as diesel, petrol and electricity. The dependency on such conventional sources energy not only brings burden on the foreign reserves but also creates huge environments hazards. Hence, India needs a secure, affordable and sustainable mechanised energy system to power effective economic growth. This can be achieved by developing the methodologies, technologies for precise use of renewable energy sources for better energy and grain productivity management.

Renewable Energy Sources

These energy sources are inexhaustible and are renewed by nature itself. Solar, wind, tidal, geo-thermal, hydro and biomass are examples of non-conventional energy sources.

Solar energy: Solar energy is the basic energy source available in abundance and provides food, feed and fiber through photosynthesis. The surface of the earth receives about 1014 kW/m^2/day from sun in the form of solar energy which is approximately five orders of magnitude greater than that currently being consumed from all resources. Solar energy can be used for heat and electricity generation. When converted to thermal (or heat) energy, solar energy can be used to heat water (for use in homes, buildings, or swimming pools), heat spaces (inside homes, greenhouses, and other buildings) and heat fluids (to high temperatures to operate a turbine to generate electricity). Solar energy can be converted to electricity through Photovoltaic (PV devices) or "solar cells" and concentrating Solar Power Plants.

Wind energy: Wind is simply air in motion. It is caused by the uneven heating of the Earth's surface by the sun. Because the Earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates. The main advantages of wind energy are that wind is renewable and free of cost, pollution free and can be installed in remote locations. Electrical energy can be generated from wind by converting its kinetic energy. Wind can be used to run a wind mill which in turn drives a generator to produce electricity. Wind mills are classified into horizontal axis and vertical axis wind machines. Horizontal axis machines have to be orientated towards the direction from which the wind is flowing, thus requiring a mechanism for yaw, whereas vertical axis machines are omnidirectional meaning they can operate independent of the direction of flow the wind.

***Tidal energy*:** The periodic rise and fall of water level of sea, which is carried by the action of the sun and moon on water of the earth is called "tide". A barrage is a barrier constructed across the sea to create a basin for storing water. During high tide, water will flow from sea to tidal basin through turbine, thus producing electricity. During low tide, water will flow from tidal basin to sea through turbine again producing electricity.

Geothermal energy: Geothermal power plants derive energy from the heat of the earth's interior. There are five general categories of geothermal sources namely hydrothermal convective systems (vapour dominated or dry steam fields, liquid dominated or wet steam fields and hot water fields), geo-pressure resources, petro-thermal or hot dry rocks, magma resources and volcanoes. The main advantages of geothermal energy include cheaper cost and can be used as space heating for buildings, industrial process heat and are inexhaustible in nature. They have lower overall power production efficiency (about 15%) and require large areas for its exploitation.

Ocean thermal energy: Ocean thermal energy conversion systems (OTEC) use the temperature difference of the seawater at different depths to generate electricity. It utilizes the temperature difference that exists between the surface waters heated by the sun and the colder deep (up to 1000 m) waters to run a heat engine. Such a small temperature difference makes energy extraction difficult and expensive. Hence, typically OTEC systems have an overall efficiency of only 1 to 3%.

Hydroelectricity: Hydroelectricity is the term referring to electricity generated by hydropower; the production of electrical power through the use of the gravitational force of falling or flowing water. It is the most widely used form of renewable energy.

Biomass energy: Biomass is organic material and contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. Biomass is a renewable energy source because we can always grow more trees and crops, and waste products in the form of plant mass will always exist. Some examples of biomass fuels are wood, crops, manure, and some forms of garbage. When burned, the chemical energy in biomass is released as heat, which in turn can be used directly for thermal applications or for conversion to electricity using suitable conversion systems. Indian agriculture sector is largely deficient in energy and power supply in both quantitative and qualitative terms, whereas, agriculture is itself an effective source of energy generation using bio and thermo-chemical processes of biomass. In India, biomass of agriculture origin in the form of surplus straw and stalks is available abundantly. The total annual production of different types of biomass in the country is around 1000 million tonnes derived mainly from agriculture & forestry. The effective use of this locally available biomass for energy conversion is the best strategy to cope up with energy requirement in Indian Agriculture & Rural Sector. This would enable the agriculture sector to self-reliance in energy for production and processing of agro products. In relation to agricultural sector, the biomass energy is very important not only for energy generation but also for purposeful utilization of agro-biomass effectively for value addition and income generation to farmers coupled with saving of the environment.

Biomass availability and its supply chain

Biomass energy is essentially solar energy captured by green plants in photosynthesis and then stored chemically, usually as carbohydrate, and hydrocarbon, etc. It is probably oldest source of energy after the sun. The resource includes several terrestrial and aquatic plant species, various agricultural, forestry and industrial residues, process waste, sewage and animal wastes. Some grasses (e.g., miscanthus, elephant grass) and plants like jatropha are now grown as energy crops. The forest residue like leaves and other herbaceous plant are also a source of biomass Concern over depletion of fossil fuel, studies has suggested that biomass-derived energy will provide a greater share of the overall energy. The characteristics and properties of each source are different hence the utilization of biomass in from of energy is diversified. The use of biomass a source of energy is very attractive, since it can be a zero net CO_2 energy source, and therefore does not contribute to increased greenhouse gas emission.

Biomass is potentially an infinitely renewable resource. Biomass contributes over a third of primary energy in India. Biomass fuels are predominantly used in rural households for cooking and water heating, as well as by traditional and artisan industries. Biomass delivers most energy for the domestic use (rural - 90% and urban - 40%) in India. Surveys were carried out by different agencies over period of time to estimate the biomass availability, utilization and surplus however the estimates found to be very variable. The quantity of recoverable biomass from cropland, grassland, forest, roadsides, and agro-forestry and estimated total available crop residues in India ranges 500-600 Mt/year and surplus as 90-130 Mt/year. The residues of most of the cereal crops and 50% of pulses are used for fodder. Coconut shell, stalks of rapeseed and mustard, pigeon pea and jute & Mesta, and sun flower are used as domestic fuel. A major residue goes to more competitive use as cattle feed, animal feed, packing material, heating and cooking fuel. Among all the crops, rice was found to contribute highest crop residue. MNRE [Ministry of New and Renewable Energy] made an effort to bring out a Nationwide Biomass Atlas for different sources of biomass with a development of web enable data base on biomass based on GIS and Remote sensing techniques. The ratios of various residues were recorded to estimate the total state wise and crop wise biomass production.

Biomass supply chain

Biomass technologies aimed at transformation of different types of non-food biomass into valuable chemicals and energy are recognized as one of the effective ways to decrease fossil fuel usage. The availability of this biomass is diverse in nature and hence additional cost and technologies are required in collection, transport and storage. The low bulk density is limiting factor during handling of biomass. Locational constraints reflect the physical difficulties of harvesting, collecting and transporting biomass from the point of production to the place where it will be burned. The gathering and transport of biomass is influenced by the terrain and the distance over which the biomass is transported, and also by the availability of biomass in a determined area. **Figure 1** shows the elements and machines needed for biomass supply chain for Ex-situ biomass management.

Figure1: Process and mechanical systems for biomass supply chain

Rivers, steep slopes, areas of marshland and so on, all act as barriers to access. The different means of collection of biomass are includes Chopper and Rakes Balers, Straw combines etc. Two types of balers, viz., high capacity round balers and low capacity square balers are normally used in India. However, most common balers are square because of their low cost. The normal sizes of bale are 0.36 m x 0.46 m and 1.25 m for square and round bale respectively. The average field capacity and field efficiency of conventional field baler are 1-1.2 ha/h and 70-75% respectively. The baling could increase the bulk density of straw to about 110-140 kg/m and makes its handling and storage much easier. To collect the straw tractor operated chopper is being used to cut the straw because the baler cannot collect straw standing especially in combine harvested field. A rake is used to gather the crop into a swath that not only helps to facilitate drying, but windrows the crop so that it can be picked up by the baler. Straw output is almost 2 times more in with raking condition than that of without raking. The field capacity of the baler is almost doubled and energy required per ton of baling is almost half in case of baling with raking.

Long-term storage of biomass fuels is necessary to avoid a time gap between production and utilization. Considering the fact that biomass fuels generally have a relatively low energy density, the design of the storage facilities is quite important in order to keep fuel costs low. Short-term storage with an automatic discharge system is needed for feeding the fuel to the conversion plant. The most common way of storing biomass is to pile it. When applying this method several aspects have to be taken into account. First, some general points have to be considered when long-term storage of straw in a pile is performed. Biological and biochemical degradation as well as, in some cases, chemical oxidation processes result in heat development, which can cause deterioration and self-ignition in certain cases. Second, dry-matter losses, changes in moisture content, and health risks (growth of fungi and bacteria) should be taken into consideration.

In order to strengthen the Indian agriculture and to enhance the farmer's income, the biomass supply chain management is utmost needed so that the market value of agro-residues can be enhanced which will ultimately lead to increased economic gain to farmers and also sustainable rural energy security.

Briquetting

Briquetting is high level densification process which uses two main high pressure technologies namely ram or piston press and screw extrusion machines. Briquettes can be produced with a density of 1000-1300 kg/m^3 from loose biomass of bulk density 80-120 kg/m3. Transportation, storability and use of loose biomass are enhanced by briquetting. In fact, the briquetting process includes collection of biomass, storage, drying, particle size reduction and homogenization, mixing of binding agent, pressing, cooling and storage. Briquetting process could be either binderless (no external binders are added) or with binder (such as molasses, clay, soil, sodium bentonite, bitumen etc.). The agro-residues were dried before grinding in the hammer mill coupled with blower and cyclone separator. The optimum moisture content of the biomass may be 8-12% for grinding and briquetting purpose. In binderless process, the hemicellulosic and cellulosic bonding collapse due to the high temperature (170-200 °C) and very high pressure (1.2-1.4 x 108 N/m^2) and lignin is fluidized dispersing evenly throughout the granular mass. The energy density of fuel is increased in both the cases. Binder can be used during briquetting. Small plunger type or screw type manually operated machine can be used to produce the briquettes from biomass char. Char produced is normally mixed with cattle dung or soil in the ratio of 10: 1 by weight. Adequate amount of water is added to the mixture to obtain the moisture content in the range of 30-35%. The density of char produced through pyrolysis of biomass is quite low (300-600 kg/m^3). A tractor operated briquetting machine developed at CIAE, Bhopal is shown in **Figure 2**.

Figure 2. Briquetting (With binder) machine

Bio-chemical conversion

Biomass can be used through two methods which are bio-chemical conversion and thermochemical conversion, for wet and dry biomass, respectively. The biogas generation is most promising and used method for wet biomass especially for cattle waste. Bio-methanation is a process of conversion by which organic material is microbiologically converted to biogas under anaerobic conditions. Animal dung is a major substrate used for biogas production. Along with cow dung, lignocellulosic material in the form of crop residues from agricultural field, kitchen waste, agro-industrial wastes can also be used for biogas production. Biogas comprises of 50 - 70% methane, 28 - 48% carbon dioxide and 1 - 2% H_2S, N_2, H_2, CO. The digested mass contains about 1.5 - 2%, 1.0% and 1.0% nitrogen, phosphorous and potash, respectively, depending upon the feed material used. The entire biogas production process (anaerobic digestion) may be considered as a three-stage process namely hydrolysis, acidification and methanogenesis. A biogas plant consists of digester, gas holder/ gas storage space, influent inlet, outlet, slurry mixing tank, gas outlet pipe and stirrer, etc. The optimum pH range for methane production is between 7.0 - 7.4. Total solids content of in-fluent between 8-12% is suitable for smooth operation of biogas plants. Satisfactory gas production can be achieved in the range of carbon to nitrogen ratio of 20:1 to 30:1. Biogas technology has been implemented since the 1970 through many programs. On the basis of construction, the rural household digesters are classified as floating drum and fixed dome plants.

Floating drum biogas plants: This type of plant consists of a well-shaped digester, movable cylindrical gas holder, mixing tank, inlet and outlet. Collected cattle dung is mixed into the mixing tank with equal quantity of water and fed into the digester through inlet. It remains there for certain specified period of time and digested mass comes out through the outlet. With the increase in gas production, gas holder rises up and with the use it moves down. Small family type biogas plants have also been started in rural areas, which can produce 1 to 10 cubic meters of biogas per day.

Fixed Dome Biogas Plant: In case of fixed dome biogas plants there is no separate gas holder and gas holding space is constructed as an integral part of the digester. It is entirely a masonry structure and both digester and gas holder form an underground combined unit. The volume of dome is generally kept 60% of plant capacity. When the gas is formed, it rises upwards and gets collected in the dome, by pushing the slurry into inlet and outlet chambers. The gas is liberated at variable pressure from 0-90 cm of water column. The volume of gas stored in the dome at any time is equal to total volume of slurry displaced in inlet and outlet chambers. Besides, there are some flexible dome biogas plants in which external storage like balloons are used for gas storage. For industrial biogas production, vertical column type biogas plants are used with stirrer system, temperature control system to increase biogas production.

Crop residue-based bio-methanation: Crop residue-based bio methanation gives integrated approach of ex situ management as well as conservation agriculture.

This process involves collection of crop residue from farm, transportation of material to the biogas plant, pre-treatments of the crop residue, one stage, two stage digestion or co-digestion. Utilization of lignocellulosic material like crop residue requires pre-treatment for loosening the bond between the complex fiber structures of the material. Biogas production efficiency varies based on the pre-treatment type. Combination of two or more pre-treatments can produce higher amount of biogas. There are various pre-treatments chemical, microbial, thermal, mechanical treatments etc. These treatments have different effect on the increase of surface area of substrate, solubilization of hemicellulose, solubilization of lignin and alteration of lignin structure etc. **Figure 3** shows sold state digestion concept used for paddy straw biomethanation using co-digestion of paddy straw and cow dung.

The produced biogas can be further utilized for thermal or power generation purpose and the digested slurry can be used in farm as a fertilizer. Biogas is commonly used as domestic cooking fuel in rural areas and to a limited extent, it is used for illumination (lighting using mantle lamps.). On industrial scale, biogas is being used for steam generation, shaft power applications and power generation. SI engines can run completely on biogas. The use of biogas in SI engines requires modification in air inlet manifold for entry of gas and of air cleaner pipe for provision of a metering device to throttle combustion air. Test results indicate that SI engines develop 85% of maximum brake power on biogas and the ignition timing should be advanced to 25° BTDC to get the best results. The brake thermal efficiency of engine is slightly higher on biogas and the specific gas consumption is 0.9 m^3/kWh.

Bio CNG (Compressed Bio Methane) is produced in the bio-digestion process. The earlier standard IS 16087:2013

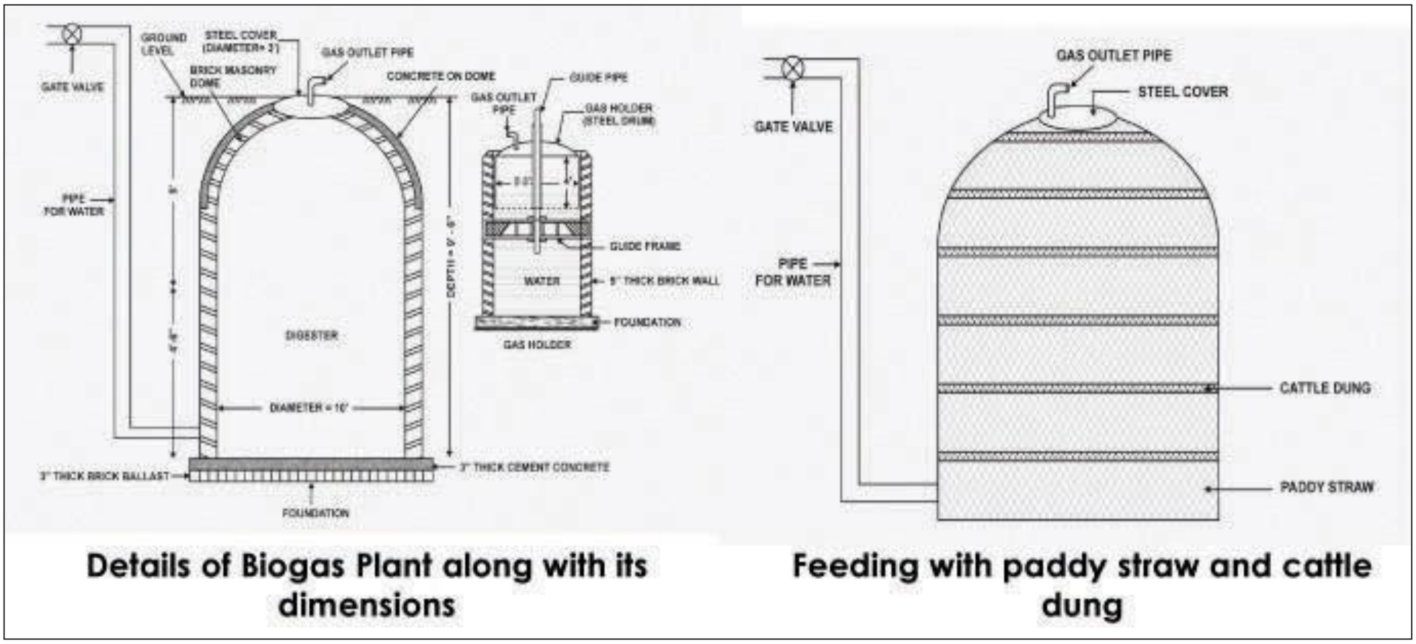

Figure 3: Paddy straw based biogas plants (PAU, Ludhiana)

was replaced by IS 16087:2016 to incorporate significant changes in specifications to bring Bio CNG at par with fossil CNG used in vehicle applications. Compressed Bio Methane is derived from cow dung as well as crop residue-based biogas. Generated biogas passes through scrubbing process where CO_2 and other non-combustible gases are removed and pure methane of more than 95% concentration is achieved and then compressed in to the cylinder.

Composting

Composting is controlled decomposition and natural breakdown process of organic residues by micro-organisms. Organic materials such as residues and by products from crops, food and industrial processing, enhance their suitability for application to the soil as a fertilizing resource, after having undergone composting. Composting has been practiced in rural areas for centuries. Physical, chemical, and biological nature of substrate determines the progress of composting process by given microorganisms. Quantity and the balance of nutrients, as well as degree of availability of nutrients to various microorganisms are essential. Composting may be divided into two categories by its nature of the decomposition, breakdown process and oxygen use. Compost could be produced either aerobically (with oxygen) or an-aerobically (without oxygen). Aerobic composting is the most efficient form of decomposition and produces finished compost in the shortest time. In anaerobic composting, decomposition occurs where oxygen (O2) is absent or in limited supply. Anaerobic micro-organisms dominate and develop intermediate compounds including methane, organic acids, hydrogen sulphide and other substances. The different parameters affecting composting process are carbon and nitrogen ratio, surface area of substrate, aeration, moisture, temperature and pH. Carbon and nitrogen are the two fundamental elements in composting, and their ratio (C:N) is significant. Bacteria and fungi in compost digest or “oxidize” carbon as an energy source and ingest nitrogen for protein synthesis. Carbon can be considered the “food” and nitrogen the digestive enzymes. Surface Area of substrate allows the microorganisms to digest more material, grow more quickly, and generate more heat for decomposition. Insects and earthworms also break down materials into smaller particles that bacteria and fungi can digest. The decomposition occurring in the compost pile takes up all the available oxygen. Micro-organisms can only use organic molecules if they are dissolved in water, so the compost pile should have a moisture content of 40-60 percent. If the moisture content falls below 40 percent, the microbial activity slows down or becomes dormant. Microbes generate heat as they decompose organic material. A compost pile with temperatures between 32 and 60°C is composting efficiently. Temperatures higher than 60°C inhibit the activity of many of the most important and active organisms in the pile. Some microorganisms like cool temperatures and continue the decomposition process, though at a slower pace. The most advantageous pH range for most of the biological reaction is between 5.5 and 8.0. During the process of decomposition, the pH increases and at the lower pH, fungi facilitate the decomposition. Bacteria dominate at 6.5 to 7.5 pH and ammonia gas may be generated, which may cause adverse odor, microbial population decline resulting into poor quality of compost.

Thermo-Chemical Conversion of Biomass

The processes of converting biomass into liquid, gaseous or solid fuel using oxidation, partial oxidation and anaerobic oxidation are known as thermo-chemical conversion processes.

Combustion: Combustion is the process of complete oxidation of the fuel. The fuel may be solid, liquid or gas. Theoretically, carbon and hydrogen in the fuel are oxidized to generate the heat and the products of combustion are carbon dioxide and water. Complete oxidation of biomass by burning to produce heat is called combustion. The rate of heat release is very rapid in combustion.

Gasification: Gasification is partial oxidation of biomass. Biomass gasification is the process in which solid biomass is converted by a series of thermo chemical reaction to a combustible gas called producer gas, liquids (tar and oils) and solids (char and ash). The supply of oxygen is reduced to do the gasification of biomass. Nearly 1 kg of biomass can produce about producer gas volume of 2.5 m^3 at standard temperature and pressure. During gasification, about 1.5 m^3 of air is needed. For complete combustion of wood, the requirement of air is about 4.5 m^3. Therefore, for gasification about 33 per cent of theoretical stoichiometric ratio for wood biomass is needed. The average energy conversion efficiency of wood gasifiers is about 60–70 per cent. The reactions are carried out in the reactor which is called gasifier. The combustible gas comprises mainly of carbon monoxide (18-22%); hydrogen (15-20%); methane (1-5%); carbon dioxide (8-12%) and nitrogen (45-55%). The calorific value of producer gas is 4.2-5.0 MJ/Nm^3 whereas the conversion efficiency is 80%. About 10 to 30 % energy of the solid fuel is lost in the conversion process. Producer gas can be generated from charcoal, coke, wood, peat or from agricultural residues such as corn cobs, groundnut shells, rice husks, soybean stalk, saw dust, bagasse, cashew shells, etc. In addition, char and tars are also produced. Sulphur compounds and nitrogen along with tar vapour, water vapour, dust and mineral vapour may also be present which are pollutants and can be corrosive. Tar content may be 1-180 g/Nm^3 in the producer gas and varies depending on of fuel, the oxidizing agent, reactor type. This concentration has to be lowered to only 50-500 mg/Nm^3 depending on the application or, even brought to practically zero for integrated gas power generation system and fuel cells.

Gasifier systems: The gasifiers can be used to generate the producer gas for use in thermal and shaft power applications. Thermal applications mean the producer gas is being burnt to generate the heat at utility point. Shaft power applications mean that producer gas is being used to generate the power from engine. The engines can be used for electricity generation, water pumping, running gas vehicles, and operating some machines taking power from flywheel, etc. A gasifier system consists of (a) a gasifier, and (b) a gas cleaning and cooling unit. For thermal applications, a suitable burner is needed to burn the gas to generate the heat. Gasifier system is to be integrated with an engine generator set for electricity generation. The gasifiers are usually classified on the basis of direction of fuel and air or gas flow in the reactor as Up draft, Down draft, Cross draft and Fluidized bed. A natural draft gasifier developed at CIAE, Bhopal having thermal capacity of 100 kW is shown in **Figure 4**.

Figure 4. CIAE 100 kW natural draft gasifier

Pyrolysis of Biomass

Pyrolysis is defined as destructive distillation of organic material heated to more than 200°C in the absence of air or oxygen. In practice, a restricted quantity of air is allowed for partial combustion to achieve the temperatures required for pyrolysis. During pyrolysis solid char, liquid tar, organic liquids, and combustible gases are produced. Carbonization of wood at temperature above 280°C liberates energy (exothermic process). The process of breakdown continues until only the carbonized residue, called charcoal, remains in the pyrolyser. The process stops and the temperature reach a maximum of about 400°C. This charcoal contains a lot of volatile matter. Further heating increases the carbon content by driving off and decomposing the tars. The rate of temperature change, temperature of pyrolysis, chemical composition of the biomass and residence period are the important factors which determine the nature and relative proportion of various products of pyrolysis. Slow heating rates and low temperature favor the formation of char, whereas rapid heating promotes the formation of liquids. Control of air in the process is required to ensure that the wood / biomass do not burn away to ash but is decomposed chemically to form charcoal. In the traditional method of charring, some of the biomass is burnt to generate the heat required for maintaining the process temperature of pyrolysis. In this method all products of pyrolysis, except char, are lost to the atmosphere. In the advanced methods, the reactor is externally heated in a controlled manner. The pyrolysis gases produced during the process are normally used as fuel for heating the reactor. The charring conditions best suited are temperatures of 150°C for 6 h for rice husk and 200 - 250°C for 2.0 - 2.5 h for maize / sorghum stalk. Lignin content of biomass is important and lower lignin content results in lower char recovery. The temperature of piloted and spontaneous ignition of wood is typically about 350°C, and approximately 600°C, respectively.

Charring Equipment: Biomass pyrolysing system is for three different levels of application, i.e. domestic unit, community level unit and commercial unit. Based on material used for fabrication, three different types of kilns are used for charcoal production. The oldest method of charcoal production has been earthen mounds and pits. Properly constructed and operated brick kilns give high quality charcoal with fairly high yield. The size of kilns may be decided depending upon the requirements. Large size kilns are used for commercial operation while the small kilns may be made for domestic / community use. The performance of the brick kiln was found between 25-60% depending upon the type of biomass and the operating variables. Portable and stationary metallic kilns are also available. The portable kilns are useful for producing charcoal for domestic uses whereas the stationary metallic kiln are used for community and commercial charcoal production. The char produced using pyrolysis can also be used as biochar. The biochar term is used for char when it is used for soil amendment and for carbon sequestration. CIAE has developed several pyrolysis systems for different applications. Annular core biochar production system developed by CIAE is shown in **Figure 5**.

Figure 5. Annual core biochar production system developed by CIAE, Bhopal

(Cost: 1.6 lakhs for 100 lit capacity and 10 kW system; License fee: 1.25 lakh; Recovery 30-38 %; room temperature to 700 °C; Dominant convective two side Radial heating of biomaterial bed for uniformity)

Activation of char: The char produced through thermochemical conversion process, is often activated, or modified using different activation methods such as physical, chemical and impregnation method to improve its effectiveness. The type of raw feedstock, its compositions, pyrolysis process conditions and activation parameters have significant influences on the properties of resultant activated biochar. Activation of char increases the surface area of the raw biochar to many folds. The activation process is mainly done to improve the surface area, pore volume, and porosity of the biochar for a specified application. Physical and chemical activation are the most widely used techniques for the preparation of activated char. In the physical activation process, the raw material is subjected to pyrolysis at higher temperature and then activated using steam or CO_2. The physical activation is also called dry activation method. Whereas in chemical activation, i.e., wet oxidation, char or precursors are impregnated by chemical activating agents and then heated at high temperature under inert atmosphere. Chemical activation can be either in the form of acid activation or alkali activation mode, which induces acid functional groups, oxygenated functional group, and removes impurities. Chemical activation is preferred over physical activation method due to its low process time and activation temperature.

Thermal degradation at lower temperature in absence of air is called torrefaction which is process to generate the bio-coal or torrefied biomaterial from crop residues to impart the hydrophobicity, brittleness and other beneficial storage properties in the material. Torrefaction is lower segmental treatment in pyrolysis zone for biomass. One torrefaction unit having biomass capacity of 200 kg per batch developed by CIAE is shown in **Figure 6**.

Figure 6: Electrically controlled torrefaction system developed by CIAE, Bhopal

Compared with traditional activated carbon, activated biochar appears to be new potential cost-effective and environmentally-friendly carbon materials with great application prospect in many fields such as water pollution treatments, CO_2 capture and energy storage. Activated char is efficient, cost effective and environmentally friendly material. It has distinctive features over raw biochar such as large surface area and increased adsorption capacity. At present, crop residues based activated biochar are gaining worldwide popularity due to its wide application in waste water treatment, supercapacitors and in fuel cell technology.

Due to rapid industrialization, industry waste water becoming a dominant source of water contamination. There is an urgent need to find out the alternative, environmentally friendly, and cost-effective material to remove the pollutants, heavy metals. Activated char is considered as a green remediation material for removal of heavy metals, inorganic contaminants due to its higher adsorption capacity. Use of activated biochar in supercapacitor as an electrode material can be justified with the cost associated for the use of commercial activated carbon, carbon nanotube, and graphene. As compared to these materials activated char-based electrode material shows higher surface area, porous structure, high electrical conductivity, which is requirement for ideal electrode material. Supercapacitor as an energy storage device is superior over conventional capacitor owing to its high-power density, higher chemical stability, quick charge and discharge ability and its long-life cycle. The activated char has been used as a material for direct carbon fuel cell for conversion of carbonaceous material into electricity.

Other important aspects pertaining to renewable energy utilization in Indian agriculture

The Drone based mapping for agricultural fields is needed to find the real time generation, uses, availability of agro-biomass area-wise, crop-wise and season vise. IoT based artificial e-system need to be established at national level using national e-portal which can receive wide range of problem and suggest solutions with respect to agro-mass utilization for enhancing the income of farmers. Our efforts to develop technologies for site-specific application is need to be intensified. Energy systems should be designed using the 95^{th} percentile of biomass availability data which demand a national wide pertinent survey, assessment and measurements. The whole value chains of energy mechanization covering farmers, KVKs, researchers, engineers, small and medium manufacturers, and traders, is to be established in different states. There is need to evolve a complete system which can take needed systems to farmers with minimized cost and time.

Water scarcity problems in irrigated agriculture also need the solar pumping intervention at massive scale. By switching over from traditional surface irrigation to improved and efficient irrigation techniques, powered by solar energy, such as sprinkler and drip irrigation to produce more crops per drop of water, is giving multi facet advantages and benefits. It is therefore, development of quality solar based micro-irrigation products, systems and their applications through use of sensors and other advanced techniques such as drones and IoT. Decentralized solar pumping system is a concept of using more water to agricultural fields with minimum energy load on itself. For that, the solar coupled micro irrigation systems are best suited. Agro-voltaic is also being promoted in Gujarat state to produce the crop and energy from same field. This technology also tries to tap the rain water falling on the solar panels and this collected water can be channelized for irrigating the crop being grown there itself.

Conclusions

Renewable sources of energy (RES) are major contributors to provide energy security by reducing dependence on fast depleting fossil fuels with a positive environmental impact. Solar, wind, geo-thermal, bio-mass energy can fulfill around 33% of India's energy needs and 75% of the rural energy needs. According to the Central Electricity Authority of India, about 50% of the country's power supply will be generated by renewable energy sources by 2030. The nation needs effective use of renewable sources for enhanced energy use efficiency.

The major targets should be to use of available and developed renewable and conventional energy sources & gadgets for rural productive activities and agro-industry using existing local renewables covering solar electricity, heating and pumping. Research on solar energy use for production agriculture needs fluctuating torque demand depending on the agricultural field conditions. The use of batteries for storing and releasing power is another concern for long term use of solar photovoltaic (SPV) gadgets. The battery operated systems including vehicle are facing few threats like, replacement cost of battery, safe disposal of discarded batteries and its components, quick and safe charging, solar based prompt charging, etc.

Compressed clean biogas and Bio-CNG have also emerged as an option for ex-situ management of crop residue. Biomass based power generation has already in place in several state. They need to be promoted by giving adequate incentives as they are supporting the green electricity generation. However, the cost of electricity generation for each unit in biomass based power generation is high in comparison to that obtained in new solar electricity generation technology. Thermo-chemical and bio-chemical conversion based electrical power routes are available and there is a need to promote these with better incentives.

The development of energy efficient machinery, use of nano-lubricant for fuel saving in different agricultural systems, energy management in agriculture, energy optimization with yield maximization, input cost reduction with maximized yield, energy cost optimization, biomass utilization for energy and value addition, development of process and protocol for second and third generation biofuels, crop residues management, bio-hydrogen generation, bio-ethanol and butanol production, bio-crude generation and its downstream processing, etc., are prime theme areas for renewable energy research and applications in near future.

Energy efficient and cost effective mechanization systems for rural activities covering crop production, post-harvest, rural domestic operations and livestock raising are to be provided with energy supply security. We need to focus to introduce and implement the recent advanced technologies like plasma technology, nano-technology, IoT, artificial intelligence and robotics for enhanced effectiveness of processes for generation of energy and valued products using rural local renewable resources.

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Spread of Drip Irrigation and Fertigation in India and its Role in Enhancing Water Productivity of Rice Crop

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Abstract

Micro irrigation is found to be the only alternative to sustain irrigated crops in a scenario of impending shortage of fresh water the country is facing. Farmers in India have successfully adopted MI taking the country to number one position in MI coverage (16.6 million ha) in the world. Continuing with the adoption process, even rice crop is successfully grown with drip irrigation. Data on yield, water consumption and water productivity of basmati rice grown in selected farmers' field with drip irrigation in Haryana is reported here. Rice yield improved by 10-18%, water consumption reduced by 51% and water productivity enhanced by 63%. The drip system could also be adapted to the rotation crop in the rice-wheat cropping system.

Key words: Drip irrigation, fertigation, rice, water productivity.

Introduction

Agriculture in India is climate restricted; 48% of the geographical area of the country receiving less than 1000 mm rain and the rest 1000-2500 mm. The difficulty is that the rainfall is occurring in 3-4 months' duration making it imperative for rainwater storage and irrigation. But the available water for irrigation is not enough to cover the net cultivated area. Only 42 % of cultivated area is presently irrigated. Irrigation cover cannot be increased as the available 1143 BCM water would be insufficient. By 2050 our water need (both irrigation and total need) would cross the availability level. This is a grim situation. It is made more so by the need for increasing food production. To achieve the increased food production of 494 million t by 2050, our net irrigated area should increase from 62 million ha to 146 million ha. This cannot happen as water is limited. Production cannot be increased by increasing in area alone; area will increase only by 2 million ha during 2010-2050. So we are into a very difficult situation.

Micro irrigation in India

The only way out is to identify water conserving irrigation methods. Incidentally, the technology of micro irrigation serves better in this scenario. It offers a way of irrigating more land with less water (water security); more yield with less water (food security) and more food production with less energy use (energy security).

Today, micro irrigation technology has become very popular in India and been adopted in large areas in several states of the country. This stage has come about over a period of past 30 years. The role of private manufacturers, government policies and level of farmer awareness and the assistance of media etc. have helped to arrive at the present situation.

The coverage of micro irrigation (MI) is 16.6 million ha (drip + sprinkler) in India (Table 1) (2022 March end, PMKSY, GoI). The awareness level however has grown tremendously. The spread of technology has however, been restricted to states like, Andhra Pradesh, Gujarat, Karnataka, Rajasthan, Tamil Nadu, and Madhya Pradesh, the so called TOP 7 of India (Table 1). The government subsidising the system cost first began in Maharashtra (at State level), and later spread to other states. Top 7 states' administration implemented the Central (Federal) government subsidy schemes with more ardour and commitment. Some of these states also toped up the subsidy amounts from their own resources. Few of these states like Andhra Pradesh (APMIP), Gujarat (GGRC) and Tamilnadu (TanHODA) have created special purpose administrative entities for extension and administration of MI provision in their states. These special purpose bodies and horticulture and/or agriculture departments in other states took over the effective administration of the introduction, spread and farmer level utility of MI systems in collaboration with the large MI suppliers who opted to work with the governments in these states. Farmers and other users of the MI systems are getting trained in the farm on the operation and effective use of the MI components. Most of these training and capacity building is initiated and jointly done by private supplier companies working hand in hand with the public extension bodies. Thus a silent revolution has been occurring in the remote farming villages of not only the in the TOP 7 but other states also. In the years to come, this era of rapid reach of MI in Indian farms would probably be designated as Golden Era of irrigated crop production. Among the TOP 7 states Andhra Pradesh, Karnataka, Maharashtra, Tamilnadu and Gujarat have covered more than 30% of their respective net irrigated area with MI.

Introduction of drip, both surface and sub- surface, to closely planted row crops (like sugarcane, cotton, cereals, pulses and oil seeds and flower crops and vegetables) in addition to tree crops has really caused a revolution in MI reach. Even States with sufficient water resources are adopting micro irrigation which is a good sign.

The idea of rain water harvesting, and farm pond concept would have to be taken with high priority to bring in the presently rain fed areas also under micro irrigation. According to the latest data from Min. Agri. GoI. (2021) Andhra Pradesh (1,68,613) Maharashtra (1,23,399) and Tamil nadu (57,114) followed by Rajasthan (30,482) are the leading states with most micro- level water harvesting/ storage structures. The micro storage structure in combination with micro irrigation offers possible sustainable means of increasing the irrigation cover. It is a heartening trend that this combo is getting acceptance. This strategy also leads to convert more rainfed land into irrigation.

Table 1 Current status of reach of micro irrigation in Indian States

Micro irrigation coverage in different states in India as on June 2022**						
TOP 7	**STATES**	**Drip (ha)**	**Sprinkler (ha)**	**Total Micro Irrigation (ha)**	**Share of Drip**	**Share of Sprinkler**
1	Andhra Pradesh	1716673	626915	2343588	0.73	0.27
2	Gujarat	1135403	999476	2134879	0.53	0.47
3	Karnataka	953297.7	1762250.14	2715547.9	0.35	0.65
4	Maharashtra	1572242	691906.41	2264148.1	0.69	0.31
5	Rajasthan	385044	1840484	2225528	0.17	0.83
6	Tamil Nadu	963714.8	448785.91	1412500.7	0.68	0.32
7	Madhya Pradesh	476572.3	334840.18	811412.48	0.59	0.41
	Sub total	7202946	6704657.64	13907604	0.52	0.48
North zone						
8	Haryana	47662.79	652795.84	700458.63	0.07	0.93
9	Himachal Pradesh	5160	4130	9290	0.56	0.44
10	Jammu & Kashmir	24	70.1	94.1	0.26	0.74
11	Punjab	36640.81	15359.19	52000	0.70	0.30
12	Uttar Pradesh	58837	270300	329137	0.18	0.82
13	Uttrakhand	18161.64	12644	30805.64	0.59	0.41
	Sub total	166486.2	955299.13	1121785.4	0.15	0.85
East zone						
14	Bihar	21370.62	113635.1	135005.72	0.16	0.84
15	Chhattisgarh	39257.6	368440.2	407697.8	0.10	0.90
16	Jharkhand	41159.45	17969.61	59129.06	0.70	0.30
17	Odisha	37495.02	166114.11	203609.13	0.18	0.82

Micro irrigation coverage in different states in India as on June 2022**						
TOP 7	**STATES**	**Drip (ha)**	**Sprinkler (ha)**	**Total Micro Irrigation (ha)**	**Share of Drip**	**Share of Sprinkler**
	Sub total	139282.7	666159.02	805441.71	0.17	0.83
West Bengal, Assam and North East						
18	Arunachal Pradesh	2841	781	3622	0.78	0.22
19	Assam	3767.8	10302	14069.8	0.27	0.73
20	Manipur	288	2924	3212	0.09	0.91
21	Meghalaya	308	307	615	0.50	0.50
22	Mizoram	3428.43	1428	4856.43	0.71	0.29
23	Nagaland	4895	6072	10967	0.45	0.55
24	Sikkim	6383	5617	12000	0.53	0.47
25	Tripura	2304	3204	5508	0.42	0.58
26	West Bengal	10649.11	109073.64	119722.75	0.09	0.91
	Sub total	34864.34	139708.64	174572.98	0.20	0.80
27	Goa	1186	1129	2315	0.51	0.49
28	Kerala	23274.89	8438.17	31713.06	0.73	0.27
29	Telangana	355825.2	140389.2	496214.4	0.72	0.28
30	Others	15169	30636	45805	0.33	0.67
	Sub total	395455.1	180592.37	576047.46	0.69	0.31
INDIA TOTAL		**7939035**	**8646416.8**	**16585452**	**0.48**	**0.52**

** Data sources: Compiled using the data reported in the following sources

1. Department of Agriculture, Cooperation & Farmers Welfare
   Pocket Book of Agricultural Statistics 2018- 19 (data up to 2019 March)
2. PMKSY, Ministry of Agriculture and Framers' Welfare Report June 2021
   (Data from 2019-2021)
3. Personal communication (2021 March to 2022 June) from PMSKY

Micro irrigation for rice and rice based cropping systems

India is the world's second largest producer of Rice. It is cultivated over an area of 44.2 million ha, which is about 50 % of the total irrigated agriculture area of the country (Anon, 2016). Short duration rice cultivation in rainy season (Kharif) is common in almost all States, however its cultivation is more concentrated in Northern States of Haryana and Punjab besides Eastern states and the Southern Peninsula.

Traditionally, low land rice or wet rice is cultivated in puddled soil as semi-aquatic crop. Under the low land system, water is consumed as much as 2295 mm/ha and 3000- 5000 liters utilized by the crop to produce one kg of grain [Dawe, 2005]. The water productivity is as low as 0.15 kg/m3 [Ghosh et al 2010]. The excessive use of irrigation water for rice production is a major socioeconomic, environmental and health concern for the region [Soman, 2012]. Several rice exporters' work in Haryana, for example, buying paddy from small holder farmers. The water footprint of these exports is extremely high and uncomfortable to afford.

Rice is also cultivated as dry land crop under rain-fed conditions in about 28 % area, by ploughing and harrowing the field dry and by direct sowing of the seeds. Such aerobic rice system, specially evolved rice varieties are cultivated as in Upland system with irrigation. The seeds sown directly (DSR) and the soil moisture maintained to field capacity throughout the period of crop growth. Compared with traditional low land rice system, water inputs in aerobic rice system were less, 470-650 mm) (Soman, 2012, Soman et al 2018).

Rice-Wheat system is a pre dominant cropping system of India. Haryana has Rice-Wheat cropping system as irrigated and rain-fed crops. Farmers still use the conventional practices of irrigation and method of cultivation of rice so that the water table in Haryana is declining at a rate of 30-50 cm per year. The water table in 1970 was around 5 meter which has become 38-40 meter at present because of decline. The water productivity of rice is said to be 400 g/m3. Keeping this in mind the Water Productivity Project, WAPRO has been launched in Haryana, in 2018 by the active contribution and participation and co-funding of the Swiss Agency for Development and Cooperation (SDC), Helvettas, and Jain Irrigation Systems Ltd., and Partners in Prosperity, an NGO. The data which form the basis of this paper is collected from this on farm project by Jain Irrigation scientists.

All the farmers have been irrigating the land through ground water extraction from bore wells. The farmers are using huge volumes of water for getting a good yield. Rice based cropping system is the predominant cropping system in the four districts. The average productivity of Coarse Rice is about 4-5 t/ha and for Basmati is around 2.5-3 t/ha. The average rainfall in Haryana during the monsoon is low (in sufficient for a full season rice crop). More than 75% of irrigation water has been ground water. A pre-project survey indicated that in spite of declining water table farmers are pumping water for irrigation without any restriction.

At Jain Irrigation, we have come up with a solution in 2007-2008. Irrigating rice crop with drip-fertigation technology reduces water consumption and methane emission besides increasing rice productivity. Soman, 2012 and Soman *et al.,* 2018 reported that aerobic rice hybrid ADT-45 and genotypes 27-P31,27-P63, PHB-71, ARIZE-6129, and ARIZE-6444 using drip irrigation with poly/paddy husk mulch, produced yields 4.5t-8.19 t/ha, harvested early by 8-10 days,17.7 to 25.2 % more yield than the conventional flooded cultivation system and in 27-P31, the maximum water productivity was 0.713 kg grain/m3 water. Anusha and Nagaraju 2015 compared rice genotypes under drip irrigation with conventional puddled and transplanted system and observed that across genotypes drip irrigated rice recorded significantly higher yield 7934 kg/ha, 19% higher than that of conventional flood system (6659 kg/ha), resulted in 58% water saving. Water productivity was highest under drip (11.80 Kg/ha mm) as compared to puddled and transplanted rice 4.17 kg/ha mm.

We continued our interventions with drip-fertigation in the Basmati growers' belt in Southern Haryana. This paper describes on-farm results of the work done in Haryana in farmers' fields as part of the project WAPRO. Under this project SDC funded a part cost of drip systems supplied to the farmers and Jain Irrigation, the technology provider, besides implementing the project and providing agronomy support to the farmers also provided part finance for the drip systems. The project farmers are all Basmati growers from Kaithal, Kurukshetra and Ambala districts of Haryana. Jain team has identified some 19 farmers in these districts who agreed to take up drip irrigated rice cultivation. The farms could be installed with drip during the planting season, *Kharif* 2019.

Data on yield, rain fall, irrigation water, fertilizer use, and yield of these fields were monitored. Detailed data on yield components (yield, tiller number per hill, gran per panicle and grain weight) were also recorded. In this paper, however we stress on yield and water productivity only.

We had already standardized package of practices (POP) for drip irrigated rice cultivation after 12 years of experimental and demonstration trials in many parts of India in farmers' fields. (Soman et al 2018). Generally, the package consists of the following steps.

Table 2. Irrigation schedule for Drip method for rice in Kurukshetra, Haryana $

Period	Pan Evaporation mm/day	Water requirement of rice l/ac/day
June 15- June 30	5.3	1960
July 1- July 15	5.0	11890
July 16- July 31	4.3	12105
Aug 1 -Aug 15	4.7	17547
Aug 15 - Aug 31	4.5	16684
Sept 1 - Sept 15	4.7	14540
Sept 16 - Sept 30	4.4	13724
Oct 1- Oct 15	5.3	13118

Table 3. Fertigation schedule for rice adopted in the farmers' fields.

Recommended fertilizer 60:24:16 kg/acre NPK. Basal dose of 50 kg/acre NPK (12:32:16) applied direct to soil at planting. Balance fertilizer is fertigated as per the schedule given below.

Growth Stage	Days after Sowing	Duration	Schedule
Vegetative	20-59 DAP	39 days	2.1 kg UREA per day or 14.7 kg /week
			1 kg MKP per week for 5 weeks
			2.5 kg MgSO4 per week for 4 weeks
			2 kg Zn EDTA per week for 5 weeks
Reproductive	60-89 DAP	29	5.1 kg UREA per week for 4 weeks
			1 kg MOP per week for 4 weeks
			1 kg Zn EDTA per week for 3 weeks (Last dose only 0.5 kg)
Grain Maturity	90-115 DAP	25	3 kg MOP per week for 3 weeks. (last dose only 1 kg)

Irrigation and fertigation were done as per schedules prepared for the rotation crop (wheat) after rice. Most of the farmers followed the Rice with a Wheat crop in the Rabi season on the drip system. Jain agronomist followed and monitored the rotation crops. The farmers were trained on the irrigation and fertigation schedules for the rotation crops.

Results and Discussion

Rice Yield

Under conventional flood yield ranged from 2.75 to 7.5 t/ha across different rice varieties; and under drip irrigation it ranged from 2.5 to 8.1 t/ha., The varietal difference in yield is very dominant and is expressed both under flood and drip methods of irrigation. The overall shift in yield because of drip irrigation hovered around 10-18%. Overall, transplanted rice yielded more both in flood and drip. Drip out-yielded in both DSR and TPR.

Irrigation water consumption of rice

Average irrigation water consumption in flooded fields is 6324.5 m^3/ac/season and in drip fields 3084 m^3/ac; Drip method releases an average 3240.5 m^3 water/ac for other uses (**Figure 1**). Average water consumption under TPR was more; TPR flood uses 6850 m^3/season and TPR drip

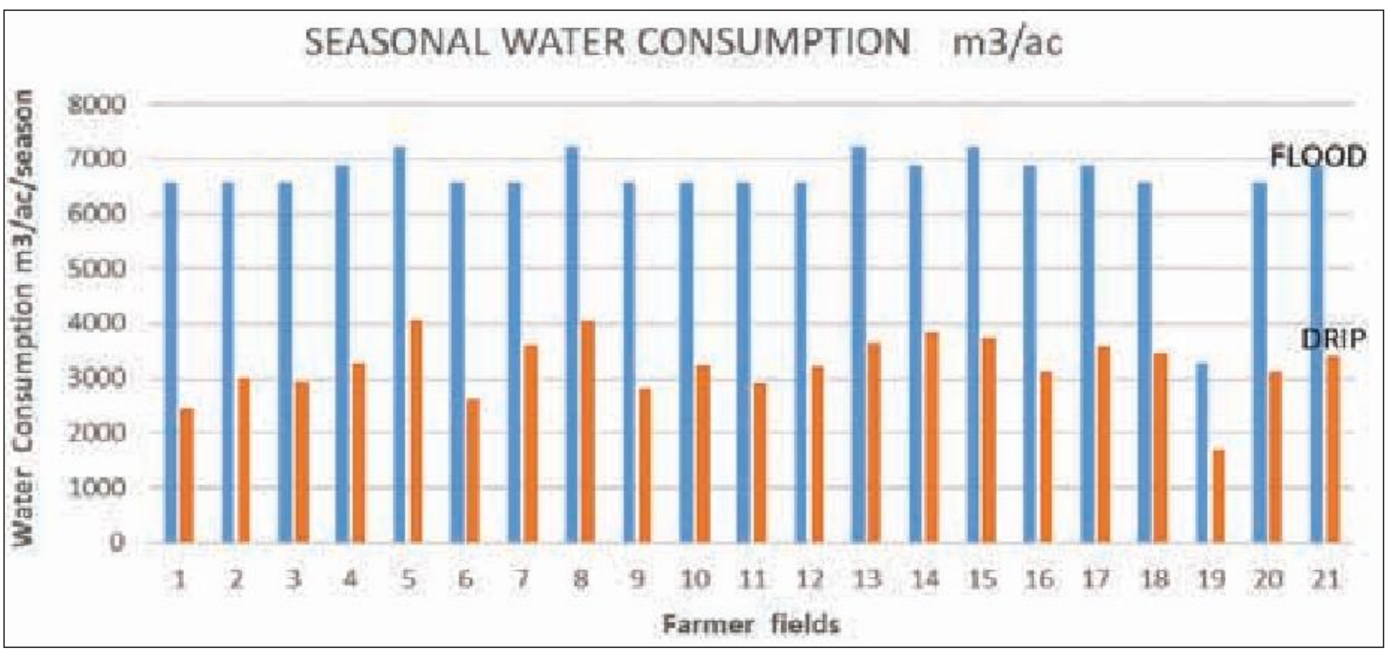

Figure 1: Irrigation water consumption in flood and drip methods of irrigation

Source: (Soman et al 2021)

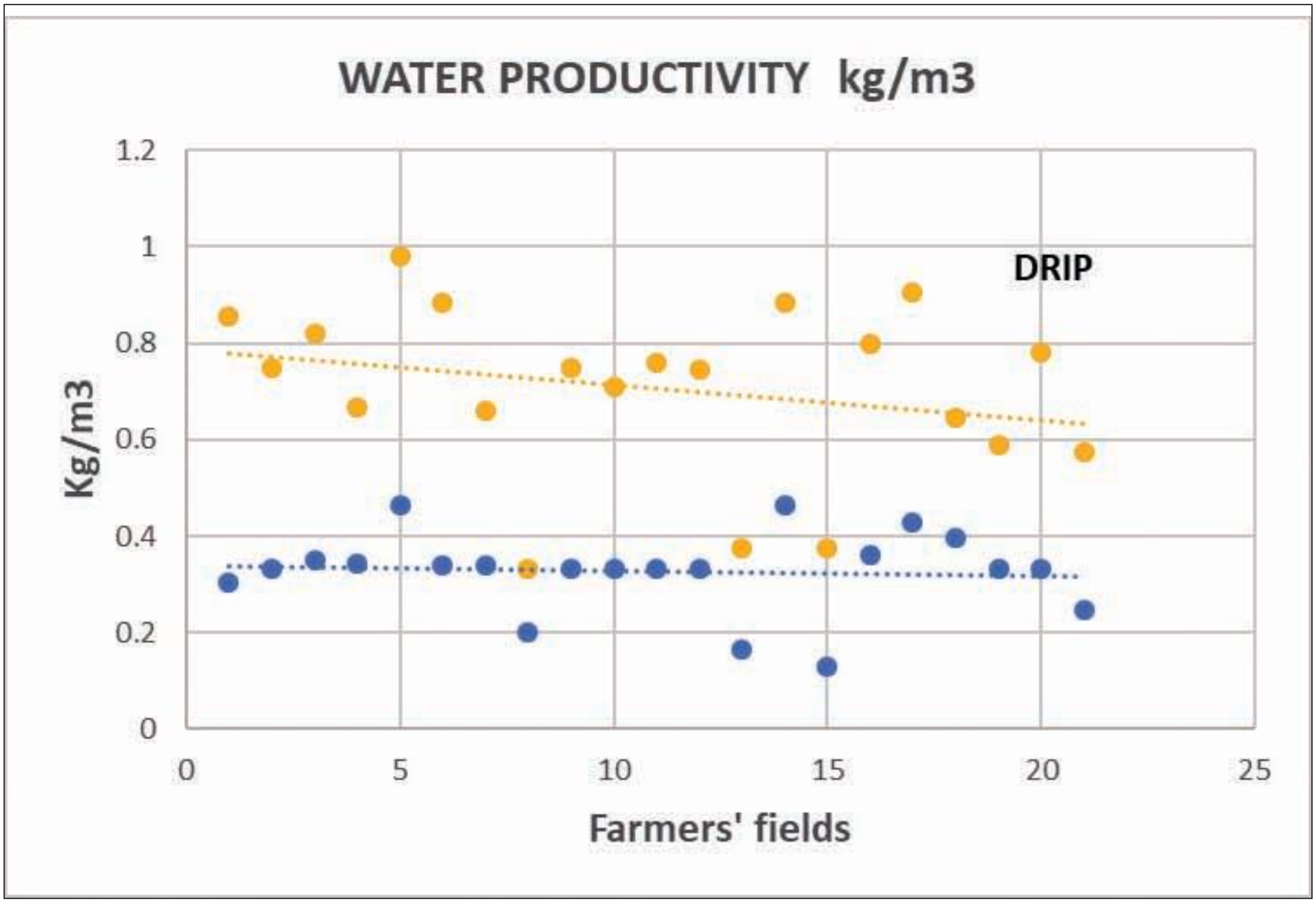

Figure 2: Irrigation water productivity in flood and drip methods of irrigation

Source: (Soman et al 2021)

uses 3434 m^3, and under DSR Flood the water consumption is 6384 m^3 and DSR drip it is 2969 m^3. The savings in water in drip-irrigated rice fields and increased water productivity and grain yields under aerobic rice systems have been already reported by Soman *et al.,* 2018a, and 2018b) and Anusha and Nagaraj 2015.

Irrigation Water productivity (IWP) of rice

The water productivity (based on irrigation water only) was always superior in drip irrigated rice –trending around 0.8 kg paddy grain/m3 as against 0.3 kg/m^3 in flood-irrigated fields (**Figure 2**). Irrigation water productivity (IWP) even of a single variety of rice can't be a constant figure in different locations and under various crop management methods and crop seasons. IWP is also not just dependent on water consumption alone, as other inputs affect productivity. Even in our own work (Soman *et al.*, 2018) the irrigation water productivity obtained in flood and drip irrigated situations differed in absolute values from those obtained in this study. But a comparison of IWP in flood and drip methods of irrigation is relevant for similar crop management situations in the same season.

Rotation crop of wheat planted after the rice harvest.

Under conventional flood, yield of wheat ranged from 3.75 to 5.75 t/ha across different fields; and under drip irrigation it ranged from 4.5 to 6.38 t/ha. The difference in yield expressed both under flood and drip methods of irrigation is not due to the crop variety used, because most of the farmers planted same variety of wheat. Drip irrigation always resulted in higher yield; an overall mean of 13.6% hike in yield of wheat was recorded because of drip irrigation.

Average irrigation water consumption by wheat in flooded fields is 1570 m3/ha/season and in drip fields 1411 m3/ha; unlike in the case of rice, farmers in this district of Haryana, do not keep standing water in wheat fields, hence the flood method of irrigation consumes relatively lower volumes of irrigation water. Drip method reduces the consumption further by 10%.

Conclusion

The summary of the benefits obtained from drip irrigating rice is given below (**Table 4**). Irrigation water consumption is reduced by 51% compared to flood irrigation. There is a slight (3%) difference in water consumption by DSR and TPR methods of planting. Because of heavy rains at the early season the water required for puddling operations were mostly satisfied by rainfall hence the difference between irrigation water consumption by DSR and TPR is very low. Irrigation water productivity improved by more than 100% when drip irrigated.

Table 4. Summary of the benefits from drip irrigating Basmati rice in Haryana in farmers' fields.

Factor	Flood m^3/ac	Drip m^3/ac	Saving m^3/ac	% Saving
Average irrigation water consumption (AVG)	6324.5	3084	3240.5	51%
Transplanted rice	6850	3434	3416	50%
Direct seeding	6384	2969	3415	53%
Water productivity (kg/m^3 water)	0.300	0.800	0.500	63%

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Smart Farming for Smart Future of Agriculture

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Abstract

The domestication of animals and plant cultivation through the adoption of systematic farming practices, as well as the green revolution brought on by the invention of chemical fertilizers and the introduction of hybrid varieties a few decades ago, are just a few of the revolutions that have occurred in agriculture. Now it is the phase of agriculture revolution 4.0 triggered by the exponentially increased use of ICT in agriculture. The smart farming with the help of ICT technologies could bring out possible solution to the challenges faced in agriculture sector that includes lack of resources, climate change etc. The objective of the present investigation was to compare the yield and nutrient requirement (NPK) for cultivating sweet potato (*Ipomoea batatas*) unDer smart farming and farmer's practice as a field trial in a farmer's plot at Nedumangad block of Thiruvananthapuram district. Under smart farming practice, the agro advisory for cultivating the crop was given through SMS to the farmers in every ten days' interval. The advisory was generated based on the field's real-time weather parameters, crop stage, and initial soil analysis. Results revealed that smart farming plots recorded higher yields with lower nutrient application. This technology can be replicated in any crop including rice.

Key words: Smart farming, ICT, IOT, Crop simulation model

Introduction

Agriculture is as old as the history of mankind. Development of human beings is closely knit with agriculture and it played a very significant role in the development of other sectors of economy also. Over the years we aquired a lot of knowledge by doing, seeing and experiencing many things in farming and allied sectors. Current agricultural practices are framed on the sound knowledge we acquired over these years across different agro climatic conditions in different parts of the world. According to the United Nations' Food and Agriculture Organization (FAO, 2016), food production must increase by 60% in order to feed the increasing population. The challenge is further aggravated by the shrinking land area suitable for cropping, shortage of water and above all the big menace of climate change. Under these conditions, the strategy to increase food production should give focus on producing more from lower resource base, ensuring the quality of the produce and faster movement of the produce to the market.

Artificial Intelligence (AI), the technology which is booming very high in the present world is sufficiently capable to take up these challenges in a smart way. Smart farming (SF), the technology where the potentials of AI is integrated with mechanization, sensors and many other areas of information and communication technologies (ICT) is all set to revolutionalize food sector by another green revolution (Adamides *et al*., 2020).

Smart farming is the precision farming done with the help of modern information and communication technologies (ICT) (Shaikh *et al.,* 2022). It is based on the incorporation of ICT into machinery, equipment, and sensors in agricultural production systems. Data plays a very important role in modern agriculture. Large volume of data needs to be collected from the field as well as from other sources. Data on weather, soil, pest and diseases, marketing, production, processing, livestock, fisheries etc are to be collected for taking timely and proper decisions. These data are very important, and the nature and volume of data varies with the sectors and context. Collection and analysis of this data with the help of ICT technologies is the basis of Smart farming. Sustainable use of natural resources for increasing production and at the same time protecting the environment are the major objectives of smart farming (Saiz-Rubio, V. and Rovira-Más, F., 2020).

Use of smart devices and sensors for data collection is one of the major factors of its success. The data collected are processed immediately. After processing, the system takes a decision on what action to be performed. If the action decided is to switch on the fertigation device, the message may be sent to the mobile of the farmer or automatically switch on the device. The whole process from data collection to action happens automatically. This way resource utilization become more efficient and the production increases. The components of smart farming are:

1. IoT devices
2. Software for mapping and data analysis
3. Sensors
4. Internet and
5. Machinery for various activities like production and processing

Devices under the category Internet of Things (IoT) is the most important component as far as smart farming is concerned. (Mohamed *et al.,*2021). Many of the smart farming devices include at least one or the other of the other four components. Components of IoT devices are connected through internet. The sensors collect data and through internet and it goes for processing. After processing of the data, the device takes decision about the action to be performed. The decision may be to do fertigation, spray pesticide using drones, send messages to farmers etc (Islam *et al.,* 2021). These actions will be performed through actuators or through any other means. IoT devices play a very important role in implementing AI for precision farming by which farming reaches new heights (Bacco *et al*., 2019).

Materials and Methods

Smart Farming is a development that emphasizes the use of information and communication technology in the cyber-physical farm management cycle. New technologies such as the Internet of Things and Cloud Computing are the main driving force behind this concept (Sundmaeker *et al.,* 2016).

Field trial was conducted on Nedumangad block of Trivandrum district to compare the yield and nutrient requirement for raising sweet potato crop under farmers practice and smart farming.

Five farmers' plots were selected from the block, initial soil analysis was conducted and sweet potato was planted in 2 cents. One cent crop was raised according to smart farming and the remaining one cent was raised according to farmers practice.

Farmers were given agro advisory in every ten days' interval. The advisory mainly was generated based on the real time weather condition of the field, stage of the crop (represented by crop simulation model) and initial soil analysis (ie the nutrient available in the soil). The farmer's fields were managed using e Crop interface. Final crop yield and total nutrients applied was recorded.

eCrop

This is an important technology developed by ICAR-CTCRI for smart farming. Biological crop produce food through photosynthesis using solar radiation and CO_2 in the presence of sunlight and water. The food produced will be stored in its storage organs after utilizing a portion of it for performing its life processes like respiration, growth etc. The food stored in its storage organs are used by human beings and animals as their food. In contrast to biological crop, its electronic version i.e eCrop computes the quantity of food produced and stored in its storage organs by its biological counterpart. The biological processes involved in the food production are simulated in the eCrop with the help of mathematical formulae. This is a weather proof electronic device which works directly in the field. Sensors in the device are used for collecting data on weather and soil parameters. The data collected by the sensors are sent to the control unit for processing from where it is sent to the cloud. Sensors are positioned on the exterior of the box. This system simulates crop growth real-time, in response to weather and soil parameter data collected from the field and generates agro advisory and send it to the farmer's mobile as SMS. As the part of the experiment, the devices were installed in Krishi bhavans of the corresponding panchayats where the trial plots are located. The weather parameters of the individual farmers' plots were calculated using the mathematical equation that represent the variation of weather parameters with change in latitude, longitude and altitude which is incorporated in the algorithm of the eCrop interface.

Crop simulation model

SPOTCOMS simulation model is used for representing the physiology of the sweet potato and simulating the growth in the system (Mithra, 2018).

eCrop Interface

e Crop web interface is the platform which facilitates the management of farming. There are different types of users based on the rights assigned to manage eCrop. They are:

a. Admin

b. Device Owner and

c. Farmer

Management of Farm using eCrop

Step 1: *Device Owner* adds new farmers for the e-Crop device coming under his purview. Then set up a new simulation for these farmers for their scenarios of crops, soils, varieties, devices etc which were already added by the *Admin*.

Step 2: Creation of *SimulationID*

When a new simulation is setup for the crop, variety, location, date of planting, eCrop device, cultivated area and farmer, a unique *SimulationID* is created, which can be used later for executing the simulation in a single step.

For each *Farmer*, unique *simulationID* is created first. The parameters required for generating this ID are:

1. Crop
2. Crop area
3. Variety
4. Date of Planting
5. Duration
6. Location (Latitude, Longitude and Altitude uniquely identifies the location)
7. Initial values of N,P,K and water in the soil.
8. Soil type
9. e-Crop Id
10. Farmer Id
11. Field Id

Step 3: Input management

In this section the user can add the information regarding the water, N,P and K which were available in soil at the time of planting as well as that added during planting and at later stages.

Step 4: Results of Simulation

Every ten days the crop growth is simulated using the web interface/mobile app using this *simulationID*. The advisory generated from the simulation is sent to the mobile of the farmer as well as to other mobile numbers included while creating the *simulationID*. The advisory contains the information on:

- Date of planting
- Cultivated area
- Normal Yield Predicted
- Variety of Crop
- Potential Yield Achievable as on date
- Water, Nitrogen, Phosphorous, Potassium required

Results of execution of simulation, reach the farmer's mobile through SMS. Fig 1 shows the view of SMS (Crop advisory generated by eCrop) on 10th June 2022. This SMS consist of the detailed data about the field. It includes date of planting, variety, location of field including latitude & longitude, cultivated area, potential yield achieved as on date in Tones. The advisory part of the SMS includes water and fertilizer requirements. It specifies the water requirement (Litres) for that day, next one week and for remaining crop duration in one dose. The fertilizer advisory includes the required amount (kg) of Nitrogen, Phosphorous and Potassium to be applied on that day, next one week and for the remaining total crop duration in one dose.

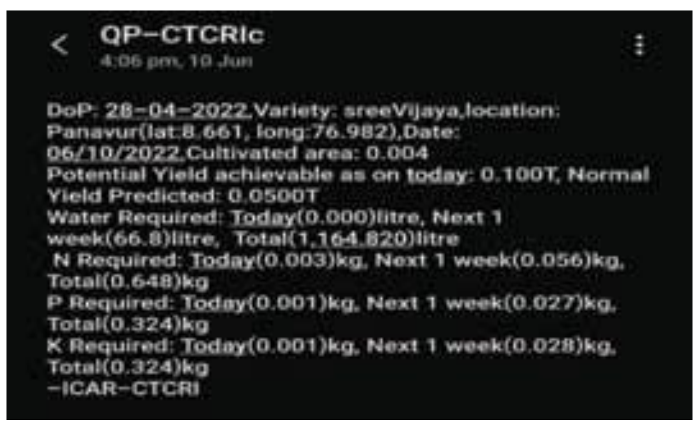

Figure 1: SMS received on farmers' mobile

Planting material and fertilizers

Sweet potato variety Sree bhadra was used in the study. Vine cuttings were planted according to standard recommendation of ICAR-CTCRI. Fertilizers used were Urea, Single super phosphate (SSP) and Murate of potash (MOP).

Results and Discussion

As the part of the experiment, sweet potato was planted in farmers plot in 2 cents. One cent was under farmers practice and the other was under smart farming. The crop was harvested and the observations recorded include final tuber yield and total nutrients applied for farmers plot and experimental plot separately. The result is illustrated in **Table 1**.

Table 1. Yield and applied nutrients under smart farming and farmers practice for sweet potato

Sl. No	Farmer	Panchayat	Yield (kg)		Nutrients applied					
			Smart farming	Farmers practice	Smart farming			Farmers practice		
					N	P	K	N	P	K
1	Farmer 1	Vembayam	30	15.6	0.154	0.091	0.1291	0.37	0.12	0.36
2	Farmer 2	Aruvikkara	9.657	3.475	0.115	0.098	0.135	0.2	0.1	0.2
3	Farmer 3	Aruvikkara	12.29	5.905	0.113	0.095	0.131	0.3	0.15	0.3
4	Farmer 4	Panavoor	35.7	15.32	0.101	0.068	0.139	0.25	0.12	0.25
5	Farmer 5	Thankaraj	18.5	10.25	0.134	0.07	0.166	0.2	0.1	0.2

The result shows that farmer 1 recorded 30 kg/cent under smart farming practice compared to 15.6 kg/cent under farmers practice. Farmer 2 recorded 9.675 kg/cent under smart farming practice compared to 3.475 kg/cent under farmers practice. Farmer 3 recorded 12.29 kg/cent under smart farming practice compared to 5.905 kg/cent under farmers practice. Farmer 4 recorded 35.7 kg/cent under smart farming practice compared to 15.32 kg/cent under farmers practice. Under smart farming practice NPK nutrients applied was found to be lower compared to farmers practice. Farmer 5 recorded 18.5 kg/cent under smart farming practice compared to 10.25 kg/cent under farmers practice. Under smart farming practice NPK nutrients applied was found to be lower compared to farmers practice.

From the results of the field trial in farmers plot it is clear that higher crop yield was obtained for sweet potato under the smart farming practice. Similar findings in improving the yield and profitability in the farms using IoT based precision agriculture was also suggested by (Padmapriya *et al.*, 2022). Based on the study conducted using *An Automated IoT based Fertilizer Intimation System* (Lavanya, G *et al.,* 2019) concluded that a low cost, accurate and intelligent IoT system that intimates the farmer about the fertilizer to be used at right time automatically through SMS in agricultural fields has significantly contributed in boosting the yield. (Rajeshkumar *et al.,* 2019) also concluded that farmers were benefitted with increased production by adopting smart crop field monitoring and automation irrigation system using IoT and thus relying on the real time information about the land and the crops.

Synthetic nitrogen fertilizers have been the most important factor contributing to direct N_2O emissions into the atmosphere as a consequence of their biodegradation by soil microorganisms (Chai *et al.,* 2019). In addition, only 50–60% of synthetic nitrogen fertilizers added to soil is usually taken up by crops the remaining gets leached out into water bodies (surface or groundwater) due to their high dissolution properties (Craswell, 2021).

Phosphorus availability to plants after chemical fertilization can vary depending on the type of fertilizer used and, even under the best conditions, only about 25% of applied P is taken up by plants during the first cropping season (van de Wiel *et al.,* 2016). Depending on the pH and moisture of soil, P can precipitate (at high pH due to the presence of calcium and magnesium and at low pH due to an iron and aluminum presence) (Chauhan *et al.,* 2021) or can be immobilized in soil (Bindraban *et al.,* 2020). The use of P fertilizers also leads to eutrophication (when P runs off to surface waters) (Du Preez *et al.,* 2020). Potassium has several beneficial roles in plant physiological and metabolic processes, including resistance to biotic and abiotic stresses and absorption and utilization of N and P by crops (Li *et al.,* 2019). On the other hand, potassium he highly soluble and gets leached off easily.

The application of nutrients mainly NPK fertilizers in the form of Urea, SSP, MOP was carried out in several split doses based on requirement of the crop under smart farming practice this can reduce the loss of fertilizers from soil. In contrast conventional farming methods fertilizers are applied in higher doses.

Conclusions

Smart farming involving AI and IoT in agriculture has developed applications and tools which help farmers in accurate and controlled farming by providing them with proper guidance about nutrition management, water management, crop rotation, timely harvesting, type of crop to be grown, optimum planting, pest attacks. From the present study regarding the field trial in farmers' plot, it has been concluded that, the sweet potato production/ yield has significantly improved in smart farming practice over the conventional farming method. It is clear from this that smart farming in agriculture helps farmers automate their farming and shifts to precise cultivation for higher crop yield and better quality while using fewer resources. The major challenge for smart farming is developing sensors that are required for extracting the spatial and resolution data, which cannot be measured as they vary significantly and hence pose difficulties in measuring them. Therefore, AI, IoT, and robotics in agriculture are expected to solve several challenges and enable higher quality and productivity. However, there is a need for a technology that integrates and applies these technologies to all aspects of farm management.

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Spatial Products for Crop Monitoring and Sustainable Agriculture

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Abstract

The spatial cropland products are of great importance in water and food security assessments, especially in India, which is home to nearly 1.4 billion people and 160 million hectares of net cropland area. In India, croplands account for about 90% of all human water use. Cropland extent, cropping intensity, crop watering methods and crop types are important factors that have a bearing on the quantity, quality and location of production. Currently, cropland products are produced using mainly coarse-resolution (250-1000 m) remote sensing data., our study was aimed at producing three distinct spatial products at 30m and 250m resolution that would be useful and needed to address food and water security challenges. The first of these, Product 1, was to assess irrigated *versus* rainfed croplands in India using Landsat 30 m data in GEE platform. The second, Product 2, was to map major crop types using MODIS 250 m data. The third, Product 3, to map cropping intensity (single, double and triple cropping) using MODIS 250 m data. For the *kharif* season (the main cropping season in India, Jun-Oct), 9 major crops (5 irrigated crops: rice, soybean, maize, sugarcane, cotton; and 5 rainfed crops: pulses, rice, sorghum, millet, groundnut) were mapped. For the *rabi* season (post rainy season, Nov-Feb), 5 major crops (3 irrigated crops: rice, wheat, maize; and 2 rainfed crops: chickpea, pulses) were mapped. The irrigated versus rainfed 30 m product showed an overall accuracy of 79.8% with the irrigated cropland class providing a producer's accuracy of 79% and the rainfed cropland class 74%. The overall accuracy demonstrated by the cropping intensity product was 85.3% with producer's accuracies of 88%, 85% and 67% for single, double, and triple cropping respectively. Crop types were mapped to accuracy levels ranging from 72% to 97%. A comparison of the crop type area statistics with national statistics explained 63-98% variability. The study highlights production of multiple cropland products to support food security studies using multiple satellite sensor big-data, and RF machine learning algorithm that were coded, processed, and computed.

Key words: Dry agriculture; Spectral bank; crop signatures; geospatial tools

Methodology

Our study was aimed at three remote-sensing products that capture important cropland characteristics (**Figure 1**)

1. Irrigated and rainfed cropland area;
2. Crop type.
3. Cropping intensity (the number of times a crop is grown on the same plot of land in a year);

Methods for product 1: Mapping irrigated and rainfed cropland using RF Machine Learning algorithm

In making Product 1 to delineate irrigated croplands from rainfed croplands with Landsat 30m and ground data, we adopted the RF machine learning algorithm and computing was performed on the GEE cloud platform, which is equipped with hitherto unheard-of petabyte-scale big data analytics. The RF machine learning algorithm is a pixel-based supervised classifier. The method involves the following steps:

- Reference training data collection.
- Knowledge base creation
- Running machine learning algorithms

Method for Product 2: Crop type mapping using quantitative spectral matching technique

MODIS 250 m data was used to classify and identify crop types using quantitative spectral matching techniques (SMTs). The SMTs involved developing ideal spectral signatures (ISSs), classifying images and obtaining class spectral signatures (CSSs), and matching class spectra with ideal spectra to identify and label crop type classes (Thenkabail *et al.,* 2007) (**Figure 2**). Methodological steps involve the following steps:

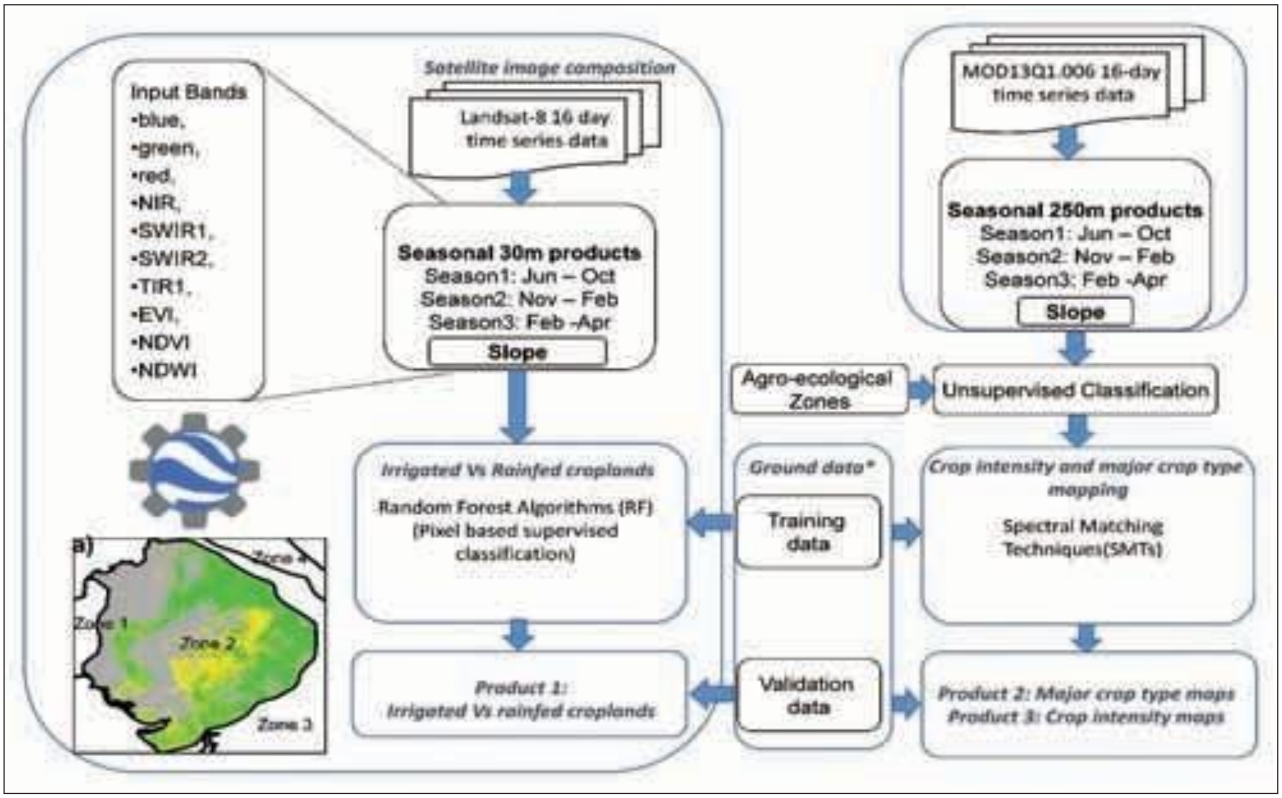

Figure 1: Methodology used for mapping three cropland products

Product 1: Irrigated croplands *versus* rainfed croplands using Landsat 8 data at 30 meters resolution in GEE interface. **Products 2 and 3:** Cropping intensity and crop type using MODIS 250 meters data

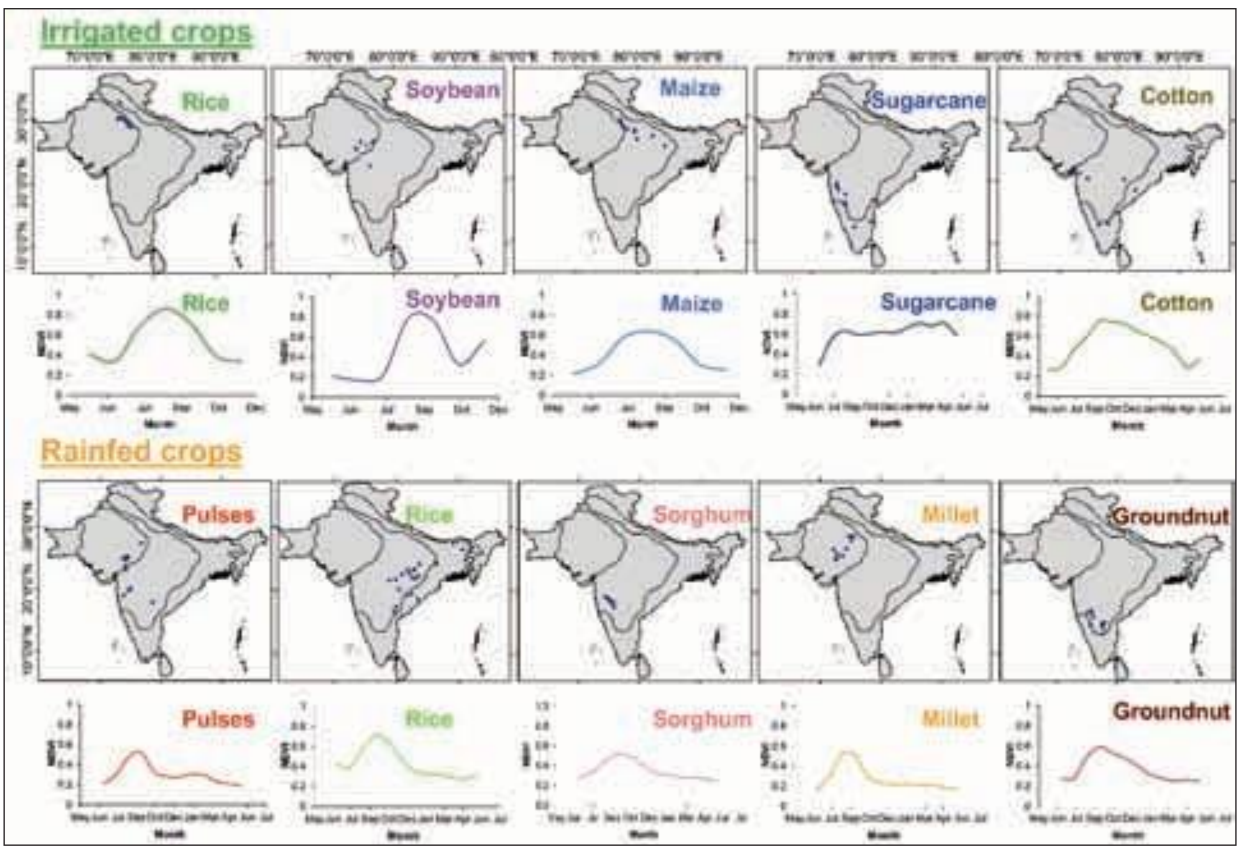

Figure 2: Spectral signatures of major crops obtained using MODIS NDVI time-series data

- Generation of Ideal spectral signatures
- Class spectra generation
- Matching of class spectra on the basis of ideal spectra to group classes using SMTs. (**Figure 3**)

Method for Product 3: Cropping intensity map

Cropping intensity was mapped with the help of a spectral signatures that involves time-series NDVI profiles (**Figure 4**).

Cropping intensity was identified by analysing the peaks of the temporal NDVI profiles of the classes that obtained during the unsupervised classification.

Results

Irrigated vs. Rainfed Cropland

The spatial distribution map of irrigated and rainfed croplands of South Asia derived using Landsat 30 m data is shown in Figure 5. There is a total of 160 million hectares of croplands in India (**Figure 5**) of which 55% is irrigated and 45% is rainfed. While most of the irrigated croplands is located below the Himalayan mountain ranges dominated by the Ganges and the Indus river basins as well as by the major river basins throughout India. These river basins provide irrigated water through reservoirs created by major, medium, and small dams, run of the river diversions through barrages, and riverine water through flows throughout the years either due to runoff from rainfall or from snowmelt from Himalayan Rivers.

Major sources of water for irrigation also comes from ground water (wells on deep acquirers and shallow acquirers), and tanks or small reservoirs along the low order streams. Rainfed crops are found in some concentration in Rajasthan and Odisha states of India and in parts of southern and northeastern India.

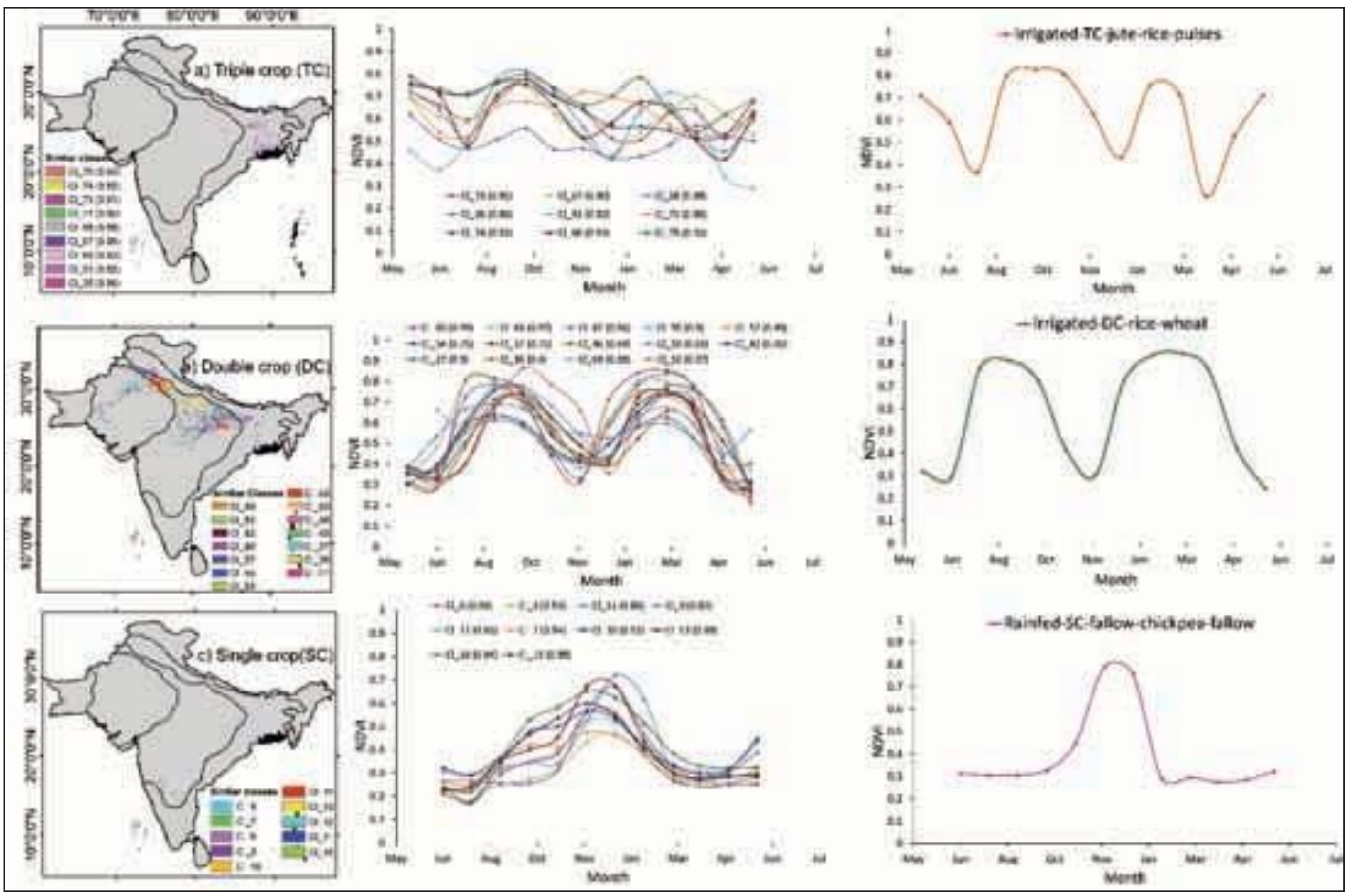

Figure 3: Spectral matching techniques (SMTs) to match class spectra with ideal spectra extracted from MODIS 250 m time series data.

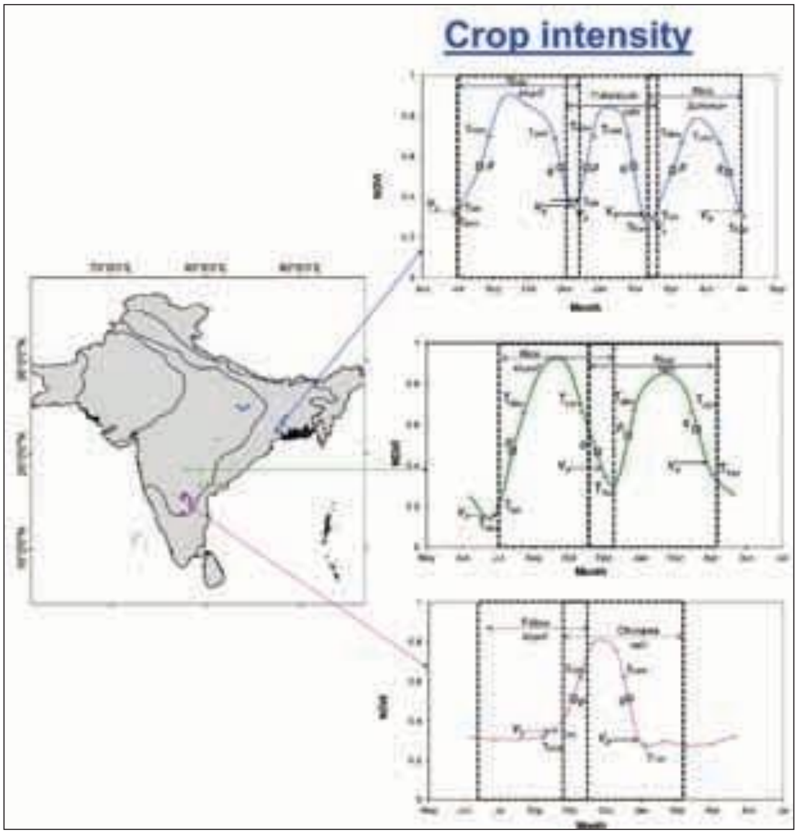

Figure 4: Spectral signatures obtained using MODIS derived NDVI time series data showing crop intensity. Temporal NDVI profile and transition dates for three crop seasons are shown. Each peak indicates a crop season.

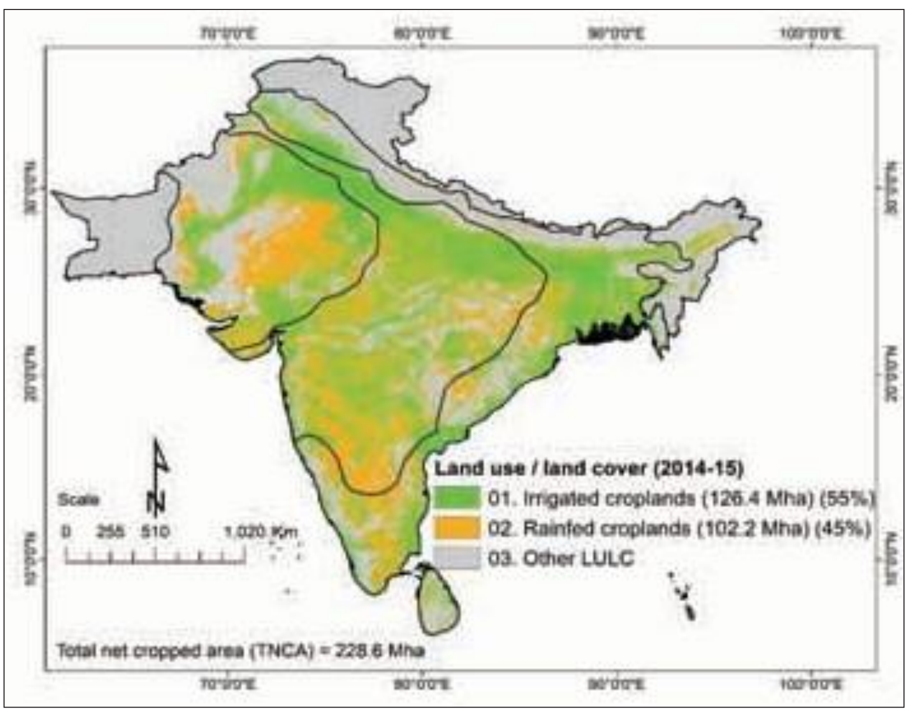

Figure 5: The Landsat derived irrigated versus rainfed cropland map of India (2014-15). The map was made using 30 m time-series data from Landsat 8 on the GEE platform.

Crop type\dominance

The spatial extent of the five irrigated crops (rice, soybean, maize, sugarcane and cotton) and five rainfed crops (pulses, rice, millet, sorghum and groundnut) were depicted in **Figure 6**. This distribution shows crop dominance in various regions of India. In the monsoon (rainy) season, most of the irrigated rice areas (Figure 6A) are concentrated in the northern part of India and along the rivers, amounting to almost 16% of the total cropped area. Irrigated soybean (Figure 6B) is seen mostly in Madhya Pradesh state of India, occupying about 6% of the total cropped area. Irrigated maize (Figure 6C) is found across India, accounting for about 8% of the total cropped area. Irrigated sugarcane (Figure 6D) with 2% of the cropped area is mostly located in north India whereas most of the irrigated cotton (Figure 6E), with 11% of total cropped area, is found in the southern part of India. In the dry areas, most of the crops sown during the monsoon season are dependent on rainfall: pulses (Figure 6F) grown on rainfed cropland are concentrated in the western part of India with almost 13% of the total cropped area; and rainfed rice (Figure 6G) is found in the eastern part of India with almost 11% of the total cropped area. Sorghum (Figure 6H) and Millet (Figure 6I) take a significant share (about 11%) of the rainfed area in India whereas rainfed groundnut area (Figure 14J) is located in the southern part of India with almost 3% of the total cropped area.

As most of the cropland in India has double intensity, crops are grown in winter and summer seasons (Figure 7), with crops like rice (Figure 7A), wheat (Figure 7B), and maize (Figure 7C) being cultivated with the help of irrigation facilities. The share of irrigated rice is about 7% of the total cropped area while irrigated maize takes almost 3%. The largest share of the total cropland area is taken by wheat, nearly 19%, mostly in north India. There are a few rainfed crops like chickpea (Figure 7D) and pulses (Figure 7E) that are sown in the winter and summer seasons, relying on the residual moisture in the field as well as atmospheric moisture, with almost 6% of the total cropped area.

Crop intensity

Crop intensity in India mainly depends upon water availability, either from rainfall or from irrigation, during the cropping seasons. Irrigated croplands allow double or triple cropping annually (in a 12-month period) whereas rainfed croplands are almost always limited to single crops due to rainfall events such as the South-West Monsoon (June-September) or North East Monsoon (October-December).

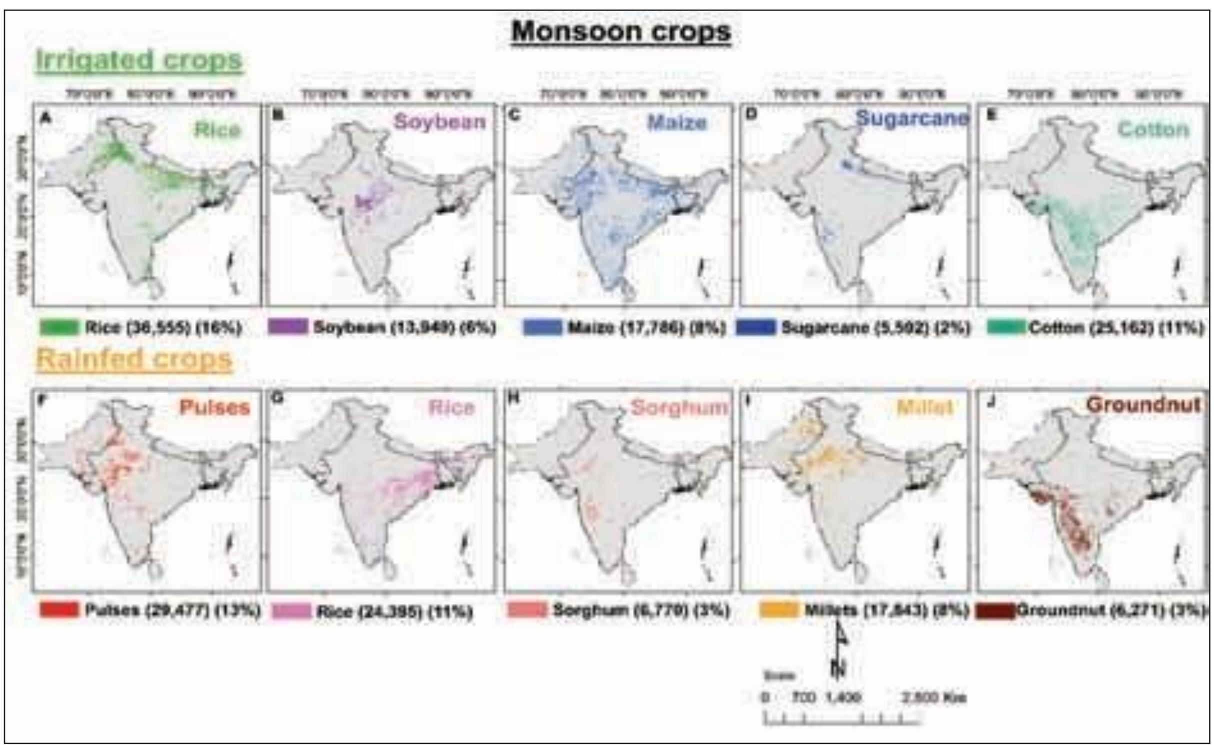

Figure 6: Spatial distribution of crop extent on irrigated and rainfed croplands in India during the *kharif* (monsoon) season of 2014-15. The mapping was done using MODIS time-series data. The 8 crops named above occupy 184 Mha (80.4% of the net cropped area) during the *kharif* season.

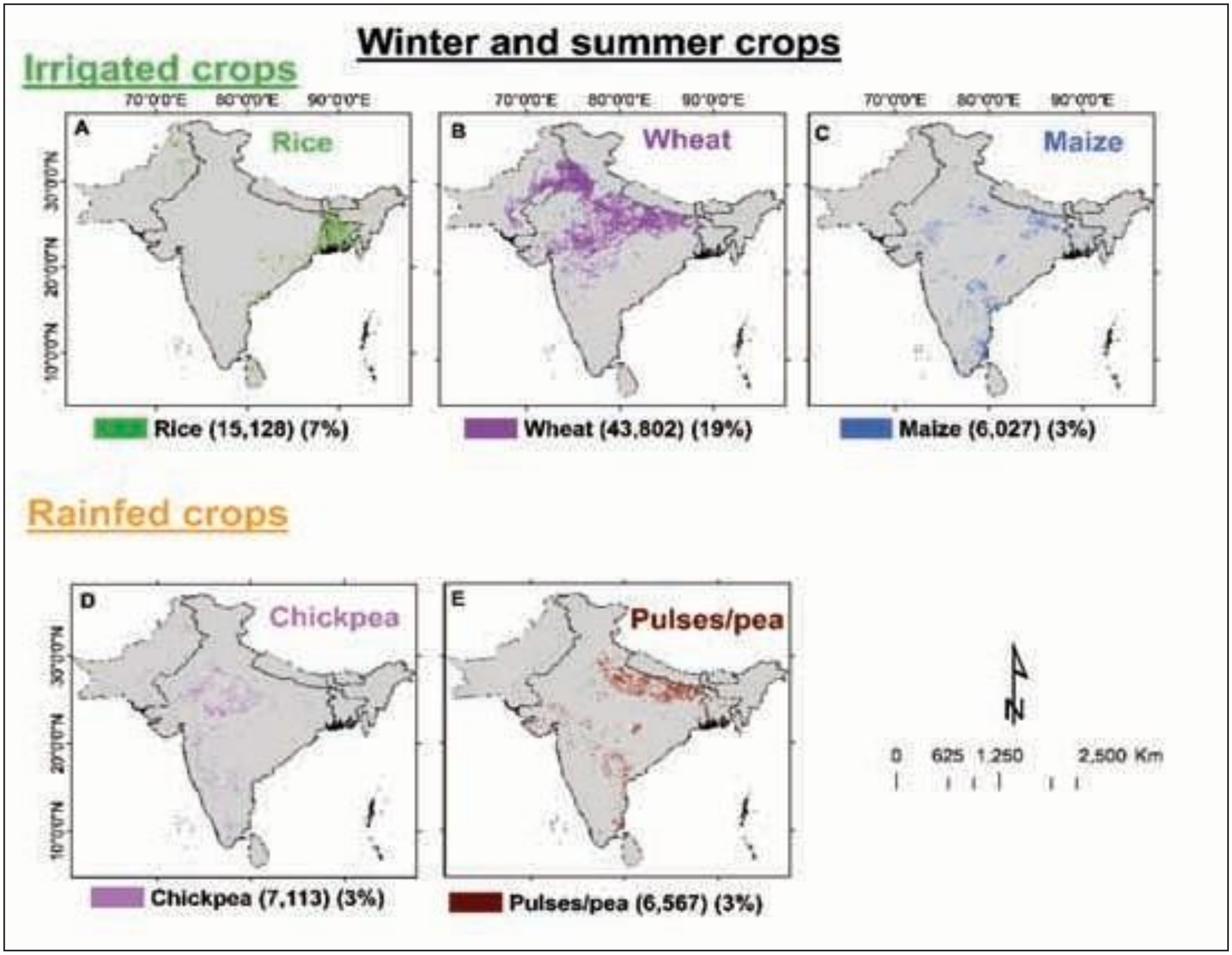

Figure 7: Season-wise crop type map, made by using MODIS time-series data, showing cropped area and percentage of total cropped area for India for the *rabi* season, 2014-15. The five crops shown above occupy 78.63 Mha or 34.4% of the total net cropped area.

The map in **Figure 8** shows that of the 160 Mha of croplands in India, 40.4% is in single crop, 55.3% double crop, and 4.3% triple crop. Single crop is mainly rainfed, double and triple crop is overwhelmingly irrigated. There is also significant irrigated areas in single crop. Triple crop is almost all in North East India. Double crop is in Ganges river basins and along other major rivers such as Mahanadhi and Krishna and Godavari. Rainfed areas are dominant in the Deccan Plateau and in the Rajasthan desert fringes.

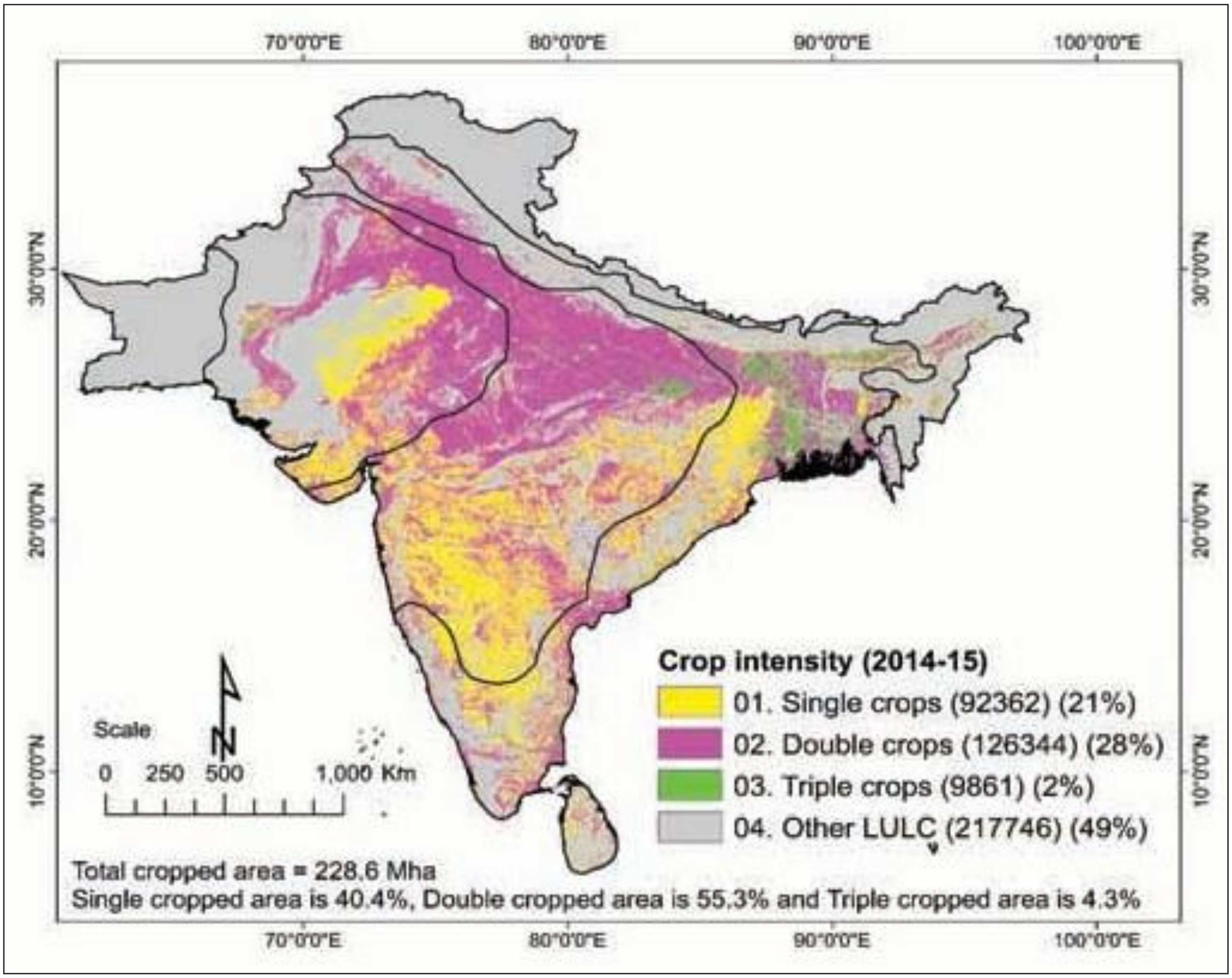

Figure 8: Cropping intensity map of South Asia (2014-15) produced by using MODIS 250 m NDVI time-series data.

Comparison of remote sensing-derived crop area statistics with national statistics

The crop type statistics derived from this study were compared with the crop type statistics obtained from traditional National statistics as shown in Figure 10. For major crops like rice, wheat, soybeans, cotton, sugarcane, and chickpea the areas derived in this study explained 82-98% variability relative to the National statistics **(Figure 9).** This clearly emphasizes the ability of MODIS 250 m time-series remote sensing data to accurately derive crop type areas. However, maize, groundnut and sorghum areas derived from remote sensing explained only 60-65% variability in National statistics. In case of ground nut and sorghum, there is wide range of variability in crop growth characteristics of these two rainfed crop depending on the rainfall variability. All irrigated crops, except maize explained over 80% variability. Irrigated maize, however, explained only 60% variability.

Overall, it can be stated that irrigated crops are mapped with significantly higher accuracies than rainfed crops, resulting in significantly better correlation of irrigated areas derived from remote sensing with the National statistics than with rainfed areas derived from remote sensing with National statistics **(Figure 9).**

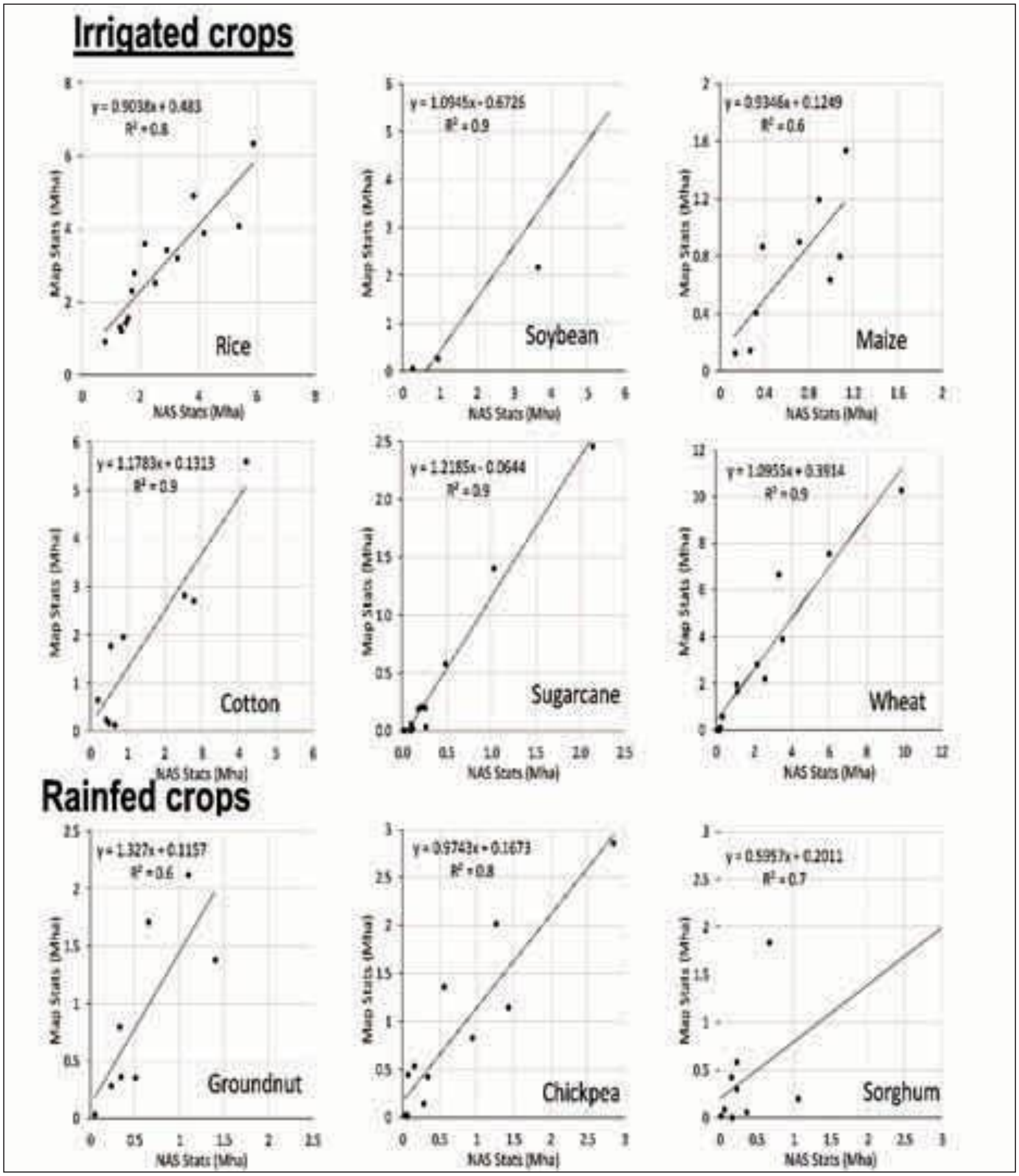

Figure 9: Comparison of remote sensing-derived crop areas with national statistics.

Conclusion

This study developed three distinct cropland products of India for the year 2014-2015 in support of food and water security assessments and management. These three cropland products were:

1. Irrigated croplands versus rainfed croplands using Landsat 30 m data;
2. Crop types using MODIS 250 m data and
3. Cropping intensity mapping using MODIS 250 m data

Time-series Landsat 30 m and MODIS 250 m analysis-ready data (ARD) cubes were developed and analyzed. The methods used employed machine-learning algorithms to identify irrigated and rainfed cropland areas, cropping intensities using phenological matrices, and crop types using quantitative spectral matching techniques (SMTs).

The computations were performed on the GEE cloud platform for the first product and on the workstations for the other two products.

The study established that the irrigated area in the whole of India was 55% o and rainfed areas amounted to 45% of the total net cropland area. The irrigated *versus* rainfed 30 m product has an overall accuracy of 79.8% whereas Crop types were mapped with accuracies ranging from 72% to 97%. The remote-sensing-derived crop type data explained 63-98% variability in the national statistics. Crop types were, generally, mapped with high degree of confidence, especially for irrigated crops where 80% or higher accuracies were achieved. Rainfed crops have higher uncertainty due to rainfall variability across large areas.

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Data Availability Statement

All data pertaining to this research are available on the public domain in the ICRISAT data portal (http://maps.icrisat.org/). These data include reference ground data used for training and validation as well as the cropland products presented in this paper. The cropland products released for the public include: irrigated and rainfed, cropping intensities, and crop types.

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Engineering Inputs for Mechanizing System of Rice Intensification (SRI)

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Introduction

Marking the grid of 25x25 cm points to transplant 12-15 days old seedlings of rice on the puddle field and weeding are the two major challenges in SRI. Appropriate implements suitable to the varied field conditions are needed to be developed. Furthermore, these implements have to be affordable and within the reach of the small farmers. Keeping these considerations in mind, Faculty of Agricultural Engineering, IGKV, Raipur is working to support the SRI farmers of Chhattisgarh since 2005. Manual grid making for transplanting and weeding / interculture operation for SRI were mechanized through three row Rotary marker, Bamboo marker, Cono weeder and Gender friendly rice weeder. Performances of different weeders were tested under system of rice intensification under Matasi (Inceptisol) soils of Chhattisgarh during the Kharif season of the year 2005, 2006 and 2007. There were six treatments namely Conventional transplanting + two hand Weeding [T_1], SRI + Gender Friendly rice weeder(One Way) [T_2] , SRI+ Gender Friendly rice weeder (Two Way) [T_3] , SRI + Cono weeder (Two Way) [T_4] , SRI + No weeding (Control) [T_5], SRI+ Two manual weeding [T_6]. Manual weedings were done at 25 and 45 DAT, whereas mechanized weedings were done at 15, 25 and 35 DAT. Compost @ 10 tons/ha with green manuring with Sasbania Rostata was used as organic source of nutrient. Fourteen days old seedling of Patel super variety were transplanted singly at 25x 25 cm grid created with the help of a three row rotary marker fabricated at Faculty of Agricultural Engineering workshop and Alternate Wet and Dry Irrigation (AWDI) was given during vegetative phase using drains provided at every 3 meter space. Physiological response, field capacity and performance efficiency of marker and weeder were recorded. Micro channels in transverse direction were formed during weeding in the rice field transplanted in grid pattern supported irrigation as well as drainage of the field. Results showed that yield increment under treatment $T_{2,}$ $T_{3,}$ $T_{4,}$ T_6 are 29.7, 31.7, 33.1 and 20.9 percent over treatment $T_{1,}$ whereas yield increment under treatment $T_{2,}$ $T_{3,}$ $T_{4,}$ T_6 are 59.9, 62.4, 64.1 and 49 percent over treatment T_5.

Preparation of SRI Field

For the preparation of the SRI Fields the conventional method of puddling was used. Sasbania Rostata was incorporated with soil as green manure to make soil organically rich. Bullock drawn disc harrow was used to incorporate green manure crop with soil. Puddling operation was carried out by the use of pair of bullock with traditional country plough two passes and planking + pair of bullock with lug wheel puddler two passes. Prior to flooding one summer, ploughing was done at friable moisture condition (18.6% db) and the tilled soil was flooded to saturation (24 h). Field was evenly leveled and there were no standing water in the field during transplantations.

Manual grid making

In SRI method, seedlings are widely spaced (25X25 cm) and only one seedling is transplanted per hill. Sixteen hills are accommodated in one square meter area. For easy weeding by mechanical weeder row-to-row and plant- to-plant distance are maintained. To maintain uniform spacing, different methods were tried.

Engineering input to increase working efficiency of human labour in SRI

Different types on “Markers” are being developed for this purpose. These markers were run over the prepared field lengthwise and widthwise. Transplanting at the marked intersection gave the required 25 X 25 cm spacing. Marker developed by the Faculty of Agricultural Engineering, IGKV, Raipur in Kharif 2005 can draw 3 rows and columns simultaneously. The marker covered width of 75 cm in a single pass. It was made by 10 mm MS round rod. Five rings were provided in a shaft with bush arrangement. To have the lines straight a rope was tied and marker was pulled along the side of the rope. For smooth transplanting, field operations leveling and marking with marker were completed a day before the transplanting. It was noticed that for efficient marking, marker need to be pulled at an even pace. The average operating speed of the marker in the puddle field was 1 km/h. Further marker was performed properly only in the field where uniform consistency of puddle soil was maintained. The grid 25X25 cm maintained in lengthwise properly but to maintain it in widthwise was found difficult. Therefore in Kharif 2006 a simple wooden marker made of bamboo was tried in SRI field. It was made by bamboo having length of 2 m. 9 pegs made of bamboo of 20 cm height were provided in 25 cm distance apart. For easy mobility 15º backward directions inclined pegs. It was found that a man could make grid of 25X25 cm in 0.6 to 0.8 ha/day. This marker performed grid in length and width wise properly. It can perform satisfactorily even if the field is not maintained uniform of puddling in entire field.

Bamboo marker

Nursery preparation for SRI

To maintain 5-6 kg of seed rate SRI need special nursery. Therefore, nursery was grown by using friable soil. The soil was collected in dry condition before the season. It was mixed with 20% FYM. The soil manure mixture was dried and sieved by a 4 mm sieve. Certified seeds with 96-98% germination were used for nursery raising.

Nursery for SRI

Transplanting of seedling

Young, 8-12 days old seedlings are transplanted in SRI method. Care should be taken to see that the plant does not experience shock during transplanting. The farmers and farm labour need to be educated on this aspect. Care should be taken to prevent any harm to seeding while pulling them from nursery or at the time of transplanting.

Weed Management in SRI

Dry and wet field condition in SRI provides a congenital environment for weeds to proliferate. Weeding is the major challenge in SRI. Appropriate implements suitable to the varied soil and weed condition are needed to be developed. Furthermore, these implements have to be affordable and within the reach of the small farmers. Keeping these considerations in mind, manually operated Cono weeder and gender friendly rotary rice weeder were used for effective weed management in SRI. In these weeders, weeds can be incorporated by moving the weeder between the rows. If these weeds are incorporated into the soil, they serve as green manure. First weeding operation was performed 10-12 days after transplanting. Later, depending on the need, weeding can be done once every 10 days. These weeders help in green manuring due to incorporation of weeds into soil, increase soil aeration, assist in enhancement biological activities of soil and increased nutrient availability and uptake. The performance result of Cono Weeder tested in SRI field during Kharif 2006 is given below

Cono Weeder

Specification of weeder		
Make	:	Faculty of Agricultural Engineering, IGKVV, Raipur (CG)
Type of weeder	:	Manual, floating type
Type of mounting	:	Offset mounting of cone pair
Total weight of the weeder	:	9.5 kg
Overall Dimensions	:	
Cone length	:	11.5 cm
Larger diameter of cone	:	13 cm
Smaller diameter of cone	:	5 cm
Length of handle	:	130 cm
Length of float	:	30 cm
Width of float	:	12 cm
No. of blades per cone	:	12
No. of serrated blades	:	6
No. of plain blades	:	6
Field performance		
Traveling speed (km/h)	:	1.6
Weeding Efficiency (%)	:	64.46
Plant damage (%)	:	12
Depth of cut (cm)	:	2.4
Field capacity (ha/h)	:	0.018
Field efficiency	:	56.25

Cono weeder

Cono weeder in operation

Performance evaluation studies on gender friendly rotary rice weeder and physiological response on female farm workers

Performance of weeder

To evaluate the performance of the weeder the weeding operation was performed by all the three subjects in the row seeded and transplanted field. The field operation of each operator was made for 4 h/day. The data given in Table 1 is the mean values of three replications. There was not much plant damage (1.5 to 2.5%) was reported during weeding operation by the weeder. The field capacity and speed of operation of the weeder were ranged between 0.0138 to 0.0177 ha/h and 2.28 to 2.64 km/h respectively (**Table 1**). This range in field capacity may be attributed partly to the subject's capabilities and partly to the moisture variation and weed intensity in the field.

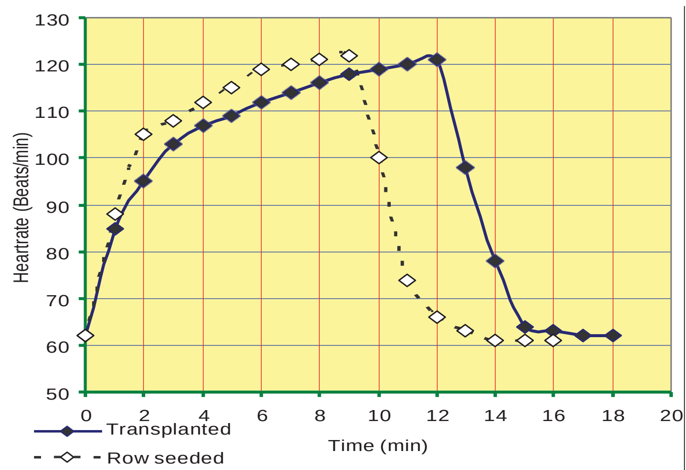

Figure 1: Stress stabilization of Gender friendly rice weeder

Table 1: Field capacity of developed rotary rice weeder in clay loam soil at saturated moisture condition

	Observation	Rice cultivation practice							
		Transplanted				Row seeded			
		Subject			CD (5%)	Subject			CD (5%)
		S1	S2	S3		S1	S2	S3	
(A)	**Field performance data**								
	Depth of operation (mm)	27	26	26	1.9	25	26	24	2.1
	Width of operation (mm)	120	120	120		120	120	120	
	Height of crop (mm)	223	220	219	11.3	252	244	253	9.4
	Traveling speed (km/h)	2.64	2.56	2.37	0.24	2.35	2.38	2.28	0.24
	Weed intensity (weeds/m^2)								
	(a) Before test	44	39	43	3.2	233	237	234	8.5
	(b) After test	6	5	5		44	36	39	
	Weeding efficiency (%)	87	87	89		81	85	83	
	Plant damaged (%)	1.7	1.5	1.9		2.0	2.3	2.4	
	Field capacity (m^2/h)	177	165	152	12.4	156	149	138	14.6
(B)	**Physiological cost in field operation**								
	Heart rate (Beats/min)								
	(a) Rest	62	63	63	2.1	64	63	62	1.9
	(b) Work	116	114	117	5.8	121	119	123	4.1
	Heart rate recovery (min)	4 ± 1	4 ± 1	4 ± 1		4 ± 1	4 ± 1	4 ± 1	
	Oxygen consumption (l/min)								
	(a) Rest	0.18	0.17	0.18	0.02	0.18	0.18	0.17	0.02
	(b) Work	0.628	0.603	0.647	0.04	0.736	0.715	0.749	0.03
	Body part discomfort rating	21	18	23	2.3	25	27	27	1.7

S_{1-3} – Subject 1 to Subject 3, Plot size – 20mx5m

The data given are mean values of 3 replications

Study of Physiological response of Gender friendly rice weeder


Gender friendly rotary rice weeder

Conclusion

It is concluded from the results of this study that the developed gender friendly rice weeder was found suitable for farmwomen. The physiological workload of farmwomen in operation was within the capability of average female farm workers. The work output of developed rotary weeder depends upon the operator capacity, ambient conditions and weed intensity. Energy expenditure for performing weeding operation varied from 12.5 to 16.5 kJ/min. The drudgery initiation was observed shorter intervals of 9-12 minutes but the operator could continuously work on the weeder for 4 h after giving 15 minutes' rest by each task. Field capacity study showed almost constant field capacity in first two hours of work however linear decrease in work out with the advancement of working hours were observed after 2-3 hours of working.

LEAD LECTURE https://doi.org/10.58297/QJMZ4684

Mechanization for Precision Rice Farming Systems: A Success Story from Andhra Pradesh, India by Praanadhaara

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Introduction

India is predominantly a Rice producing country. Yet, unlike countries like Japan or Korea, Rice production in India is labour intensive and drudgery-based crop, which requires around 850-900 man hours for cultivating 1 hectare of Rice. Just 3 operations of this crop production require about 90% of the total labour input, viz., Transplanting (38%), Weeding (19%), Harvesting and Threshing (32%). Large scale migration of villagers to urban centres, especially the working class, has resulted in severe shortages in farm labour availability. This has in-turn led to unviable labour pricing, typically during the peak operations period. The situation has thrown the farmer into a complex paradox of the compulsion to grow rice, due to the canal irrigation system, while returns from rice production have only been depleting the farmers' capital resources. Cost of labour for these three operations have reached an astronomical 65% of the crop cultivation costs, from what was 15 to 20%. Yet, due to lack of administrative and institutional support, technological interventions and mechanisation in rice cultivation, suitable for the Indian scenario, continued to be at a very low levels.

Present Status of Mechanisation in Paddy Cultivation

Tractors, used mostly for land preparation, constitute about 60% of the total machinery used in the Rice farming systems in India. Extrapolating this figure with a total of about 5% of the labour requirement for this operation, mechanization for this operation accounts only for 3% of the total labour replacement. Similarly, with about 5% mechanization in transplanting and 23% in harvesting & Threshing, machines have so far replaced only about 2% and 8% of labour from these two operations.

The paradox therefore continues. Whether to cultivate and perish or perish without cultivating their land is the dilemma facing the Indian farmer. Lack of pricing support either for inputs or output adds to the complexity.

Development of new machines and technological innovation are therefore imminent, in order to save the farmers and the crop, since readymade solutions are not yet available to the small and marginal farmer.

The Major Impediments to Increasing Mechanization

The adverse pricing and adaptability of mechanized transplantation, non-availability of inter-cultivation equipment in deep-puddle-wet-crop conditions and the inflexibility of the large sized combine harvesters to fit into to small farm units, are the main impediments for large-scale adoption of mechanization of the Rice farming systems in India.

The Success Story - A Case Study from Andhra Pradesh India

Extensive research was conducted by Praanadhaara Foundation during the last 7-8 years, on the three specific areas of reducing usage of human labour, while increasing mechanization, with the sole intent of reducing the cost of human labour input to less than 10%.

Researching with the farmers at Jammulapalem Village, Bapatla Mandal, Bapatla District, Andhra Pradesh, India, Praanadhaara successfully demonstrated that direct sowing of rice (DSR) seed, instead of transplanting pre-grown seedlings, not only reduced the cost of labour by about 20% of the transplanting costs alone, it actually produced better yields, contradicting the belief that transplanting seedlings would increase tillering and yields.

DSR to Replace Transplanting Operations

In over 6000 acres, at the behest of Praanadhaara, farmers of Jammulapalem village had adopted the standardized mechanized D-DSR practices, during the 20-to-30-day window, between the 1st monsoon showers and release of canal irrigation water.

Initially, D-DSR was adopted by using bullock drawn seed drills and later adopted and standardised tractor drawn seed drills.

Simultaneously, modified primary tillage techniques were adopted, which required east-west directional ploughing followed by north-south directional ploughing and spreading of basal doses of fertilizer and soil borne insecticides, through mechanical spreaders.

Compaction and smoothening of the soil along with seeding operation, with tractor drawn blade/bar compactors, mechanised application of pre-emergent herbicides.

These 4 operations were conducted by tractors specifically designed to undertake single specific operations independently, as 1 set of mechanization drive, covering about 8-10 hectare in 10 working hours. A total of 160 tractors (40 sets) were used to complete rice seeding in about 400 hectares per day and completing the 2400 hectares of D-DSR operations in just 6 -10 days.

It was realised that, through such collective operations of D-DSR, farmers had saved about Rs.12,500/- of crop production cost, per hectare.

1. Cultivatow with Blade Harrow

2.Rice Hill Drop Drilling Machine

3.Soil Compactor (Adda)

4. Pre-Emergence Herbicide Application

5. Furrow Opener in AWD Practises

6. Crop after 20 days

W-DSR (Wet Direct Seeding of Rice)

Realizing the fact that, it would not be always possible to undertake D-DSR throughout the Rice growing belt of Andhra Pradesh, covering over 6 districts, with varying rainfall periods and release of canal irrigation water, Praanadhaara experimented with direct sowing of rice (DSR) seed under wet conditions too. This was achieved by suitably modifying the seed drill equipment to suit the wet post-puddled conditions and undertake the direct sowing of seeds.

Under W-DSR, primary tillage was undertaken with Puddling the field with rotovator and levelling the puddled soil with wooden compactor. A technique for providing intermittent drain channel furrows with tractor drawn Double Furrow Opener was used, for providing improved drainage system.

In the absence of readily available machinery or technology, extensive and challenging research was done to undertake appropriate modifications to the tractors and their drive mechanisms, to suite the wet and sinking conditions, while retaining their power and traction abilities.

1.Puddling

2.Wooden ladder for levelling

3.Double Furrow opener

4.wet Seeding

5. Herbicide Spraying

6. Crop after 20 days

Inter-cultivation operations in Rice Crop:

Apart from undertaking the W-DSR operations efficiently, technological modifications to the tractors helped achieve the much-needed reduction in labour use and drudgery, in the weeding operations too.

By designing a whole set of tractor drawn inter-cultivation equipment such as aerator cum weeder / roto weeder, fertiliser and pesticide applicators, Praanadhaara had helped the farmers of Jammulapalem achieve huge reduction in the cost human labour for undertaking the weeding, fertiliser & pesticide applications also.

Compact Tractor

Modified Compact Tractor

Weeding in wet condition by Roto Weeder

Weeding in wet condition by Aerator cum Weeder

Weeding in dry condition using blade harrow

Fertiliser Spreader

Boom Sprayer

Double Furrow opener for AWD practices

Single Furrow opener for AWD Practices

Benefits

Farmers of Praanadhaara have not only realised increased yields due to DSR, but also had saved huge amounts of crop production costs, thereby increasing their net revenues from cultivating Rice.

Conclusion

Praanadhaara has proved that "Easy Rice Farming" by using modified mechanization is possible in India, with sustainable results.

Theme V

SCI Adoption and their Socio-Economic Impacts including Gender, Labour and Institutional Dynamics

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Scaling Up SCI: Social Capital-Centered Integrated Strategy for Enhancing Production with Equity and Climate Resilience

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Abstract

The major barriers associated with the scaling up of SCI, especially in the small farm sector, are interwoven. These include lack of proper coordination of activities of many farmers operating on small holdings, inadequate economic capacity & poor input-output services. Therefore, up-scaling efforts should not focus only on a single barrier or just on knowledge building and dissemination. Moreover, environmental degradation such as erosion and pollution are caused by the cumulative effects of non-point sources or the individual decisions by many small farmers. These cannot be effectively dealt with through point source control mechanisms. For example, unless these users are informed, motivated, and organized to collectively adopt conservation-based production, environmentally inappropriate decisions will continue to be made. Therefore, investing in Social Capital is beneficial for managing Natural Capital. FO-managed Collective Action, CA would capture economies of scale, initiate a commercialization process, and develop mutually beneficial partnerships with the private sector promoting small farmers to actively engage in market economy while maintaining equity. Hence, the paper explores the scope for enhancing resource use efficiency and overall production to ensure equitable food security and climate resilience through the combined effects of SCI and CA by farmers. Organized CA and an integrated approach can play a key role in widening SCI adoption through coordination and minimizing conflicts. In this context, the paper proposed an integrated strategy centered around social capital for enhancing production with equity and climate resilience.

Key words: Upscaling, collective action, Resilience, Conservation, Social Capital

Introduction

"The merit of an agroecological approach for achieving more productive phenotypes from given genotypes of rice has been validated through a number of well-designed agronomic studies (e.g., Lin, Zhu, Chen, Cheng, & Uphoff, 2009; Thakur, Rath, Patil, & Kumar, 2011; Thakur, Rath, Roychowdhury, & Uphoff, 2010; Thakur, Uphoff, & Antony, 2010; Zhao et al., 2009) as well as for wheat (Dhar, Barah, Vyas, & Uphoff, 2016)" (Adhikari, Prabhakar, *et al.,* 2018).

The present paper addresses the question "how social capital could be invested in scaling up of SCI to enhance production and climate resilience in the small farm sector". The proposed holistic strategy blends a few crucial components classified under two broad categories. The presentation is organized under these aspects. A brief conclusion is submitted at the end.

1) Why social capital? - Small farmer collective action and social equity
2) "Production with conservation": Enhancing productivity and climate-resilience
3) Conclusion

Why social capital? - Small farmer collective action and social equity

"Following the lead of economics, we regard any capital as referring to certain assets that produce definite flows of income, also referred to as streams of benefit. The benefit that we and most generally associated with social capital is mutually beneficial collective action (MBCA)…. (Social capital) benefits individuals and is expected to produce goods that are more collective than just individual (Uphoff and Wijayaratna, 2000, p.1876).

An integrated approach focusing on small famer profits to accelerate the scaling up of SCI: Crop yield and profit of (small) farmers practicing SCI depend on a variety of complementary factors including the adoption of other technologies, input-output markets (and prices) etc. Collective Action, CA by multi-functional Farmers' Organizations (FOs) including Farmers' Companies and Farmers' Cooperatives can scale-up conservation-based production focusing on ecologically-sound, high-productive water and land saving practices specially SRI, SCI, if they are combined with other complementary agronomic practices/technologies, input-output services including extension and credit. Moreover, the government line agencies can expand their services, such as agriculture extension and input services more effectively if they work through FO networks. ADB-supported Chhattisgarh Irrigation Development Project, CIDP, adopted such an integrated strategy based on CA and, within 3 seasons, SRI adopters increased from 52 to 5378 (Area under SRI increased from 29 to 4286ha). *"Catalyzing and facilitating a strong, vertically and horizontally integrated network of FOs (can) manage collective action for enhancing agronomic efficiency, farmer incomes, and agroecological sustainability"* (Wijayaratna and Uphoff, 2017).

Economic strength for small farmer to "mechanize" and move beyond on-farm activity: CA managed by a strong network of FOs would enable small farmers to move beyond on-farm activity, for example, to enhance their profits through post-harvest management, including processing and value-addition. When SCI is adopted for perishable crops postharvest losses can minimized through CA. FO-managed CA will capture economies of scale and initiate the commercialization process. This will widen the use of mechanization, such as motorized weeders, thereby accelerating SCI scaling up while enhancing social equity. Commercialization of small farm agriculture is important not just as a survival strategy but for them to become active partners of a market economy. The strategy would develop mutually beneficial partnerships with the private sector to facilitate small farmers' engaging more fully/fairly in market economy

More inclusive growth: In addition, an inclusive FO Network paves the way towards a powerful mechanism for gender and weaker sections of society. For example, for the first time in India, under the ADB-supported Chhattisgarh Irrigation Development Project (CIDP), seats were reserved for women and disadvantaged groups (Scheduled casts and tribes and other backward classes, SC, ST and OBC). These targets have been achieved in the 2007 Water Users' Election, country-wide (1324 WUAs) (ADB 2012).

Diversified farming systems organized through CA: This would enhance nutritional security (and enhance diversity of nutrition), increase income for more people due to CA and ensure equitable distribution of benefits. Diversification has additional benefits including sustainability of conservation-based production, contributing to cost-effective pest & disease management (P&D), year-round cropping and associated continuity in productivity / supply (and therefore income stream), reduction in expenditure on food while improving the quality (partly due to micronutrients which would otherwise be "missed") and access to different food items (and, perhaps diversity in "taste" as well), nutrient recycling, enhancing water productivity (for example, due to different root zones of different crops). Reducing malnutrition too is an added advantage of diversification.

Collective Action, CA would address the crucial questions: "*Once farmers are successful on the agronomic side, how can they be as successful on the economic side? Or how can they avoid agronomic success leading to economic setbacks? Good answers to these questions are crucial for food security and eradicating poverty* (Wijayaratna, Mishra and Uphoff, 2018).

"Production with conservation": Enhancing productivity and climate-resilience

In the small farm sector, where the farming decisions within a given agroecological zone are taken by many individuals with varied interests, knowledge, skills and attitudes, it would be difficult to achieve substantial environmental benefits without coordination and cooperation and unless the interventions are widely adopted. For example, pollution by the excessive use of hazardous agrochemicals or erosion due inappropriate land use are caused by non-point sources (or the actions by many small farmers) cannot be effectively dealt with using the point source control mechanisms. Without organized CA, for adopting conservation-based production collectively, environmentally inappropriate decisions will continue to be made. Therefore, investing in Social Capital in Protecting Natural Capital or a participatory approach involving organized CA is proposed. Such an approach of agroecological crop management, primarily based on SCI (and SRI where applicable) can contribute to sustainable "production with conservation".

FAO recommended stepwise process (originally suggested by Gliessman, 2006) can be adopted widely through FO-organized CA. For example, the use of environmentally damaging high-cost chemical inputs can be minimized as the first step. FOs can "own" soil-testing kits" and the use of chemical fertilizer can be reduced. Next, substitutes can be promoted collectively. CA is necessary for redesigning ecosystems in the small farm sector. A strong FO Network can establish direct links with the consumer. Mutually beneficial partnerships with the private sector too can be established.

Ecological agriculture is a promising approach for sustainable terrestrial carbon sequestration. Combined with its positive effects for sustainable development, *"organic agriculture is a strategy particularly suitable for degraded areas and communities with limited access to external agricultural input. Creating access to carbon markets for these communities could be a way to combine climate change mitigation with food security and rural development in a synergistic and efficient manner"* (FAO, 2009, p22).

Watershed-based multi-level organizational structure

A watershed is a hydrological unit composed of sub-watersheds. Micro and mini watersheds are nested within sub-watersheds. How the land and water in the upper parts of the watershed are used affects its use downstream. Therefore, an integrated participatory management approach can consider linkages between these "nested" subsystems aiming at optimizing watershed-wide (land and water) use efficiencies. It can adopt plan and implement a process involving the hierarchically nested hydrological units and, a "matching network" of users' organizations. The planning and implementation method and strategy needs to cover the complete network of hydrological units including sub-watersheds and even up to its highest order, namely, the river basin. It is beneficial to link the users' organizations of the upstream watershed and downstream or irrigation command areas. This provides a robust framework for natural resources management. It is also essential to establish an institutional framework that satisfies the interests of resource users in all segments of the watershed while conserving the natural resources.

A multi-level organizational structure of FOs is envisioned. At the base level, community involvement can be based on mini or micro watersheds-level FOs. These can act as building blocks of institutional framework. These can be federated upwards to sub-watershed-based FOs and ultimately to form a strong Watershed (or River Basin) FO Network. FOs can be strengthened through participatory methods, specifically experiential capacity building. These organizations can manage land & water and undertake the construction of minor water and soil conservation and water harvesting, organize the adoption of an improved and environmentally friendly package of practices (POP) for production (e.g., crop and livestock).

There is a need for changing attitude and behavior and most importantly organizing the activities of watershed resource users. Hence, a catalytic or mobilization effort would be required at the initial stages to a) create resource users' awareness, b) enhance knowledge and skills on production, conservation and related services, and c) to organize CA for adopting conservation-based production.

FOs can strengthen themselves through the process of experiential capacity-building; what is required would be a process of planned intervention/social mobilization. Introducing and internalizing self-monitoring and evaluation as well as participatory action research would be integral components in the FO development process. In the scaling up process of SCI, farmers will share experience and learn from each other. Therefore, members with differences in skills (and knowledge) would mutually benefit. All the members will benefit from FO-managed input-output services and other business including value added industry. FOs will have legal recognition, bargaining power, the ability to reduce transaction costs and better access to credit (for example from Banks and by pooling members' contributions).

Conclusion

The major barriers associated with the scaling up of SCI and achieving climate resilience such as inadequate knowledge and skills, lack of proper coordination of activities of farmers operating on small holdings, inadequate economic capacity & poor input-output services are inter-linked. Therefore, up-scaling efforts should not focus only on a single barrier or just on knowledge building and dissemination. Addressing this issue is extremely important because the success of agroecological approaches like SRI & SCI depends much on "achieving more productive phenotypes from given genotypes". On the other hand, small farmers can be mobilized and assisted towards an integrated strategy centered around Social Capital or Collective Action (CA) for enhancing production with equity and climate resilience. Farmers' CA can deal with most of the factors influencing the scaling-up of SCI (and SRI). Then the overall productivity and profit will be greater, and farmers can capture the full benefits of SCI. Moreover, Farmers' Organizations would capture economies of scale, initiate a commercialization process and develop mutually beneficial partnerships with the private sector promoting small farmers to actively engage in the market economy while maintaining equity. This should help to accelerate its rate of adoption. The strategy is illustrated in Figure 1.

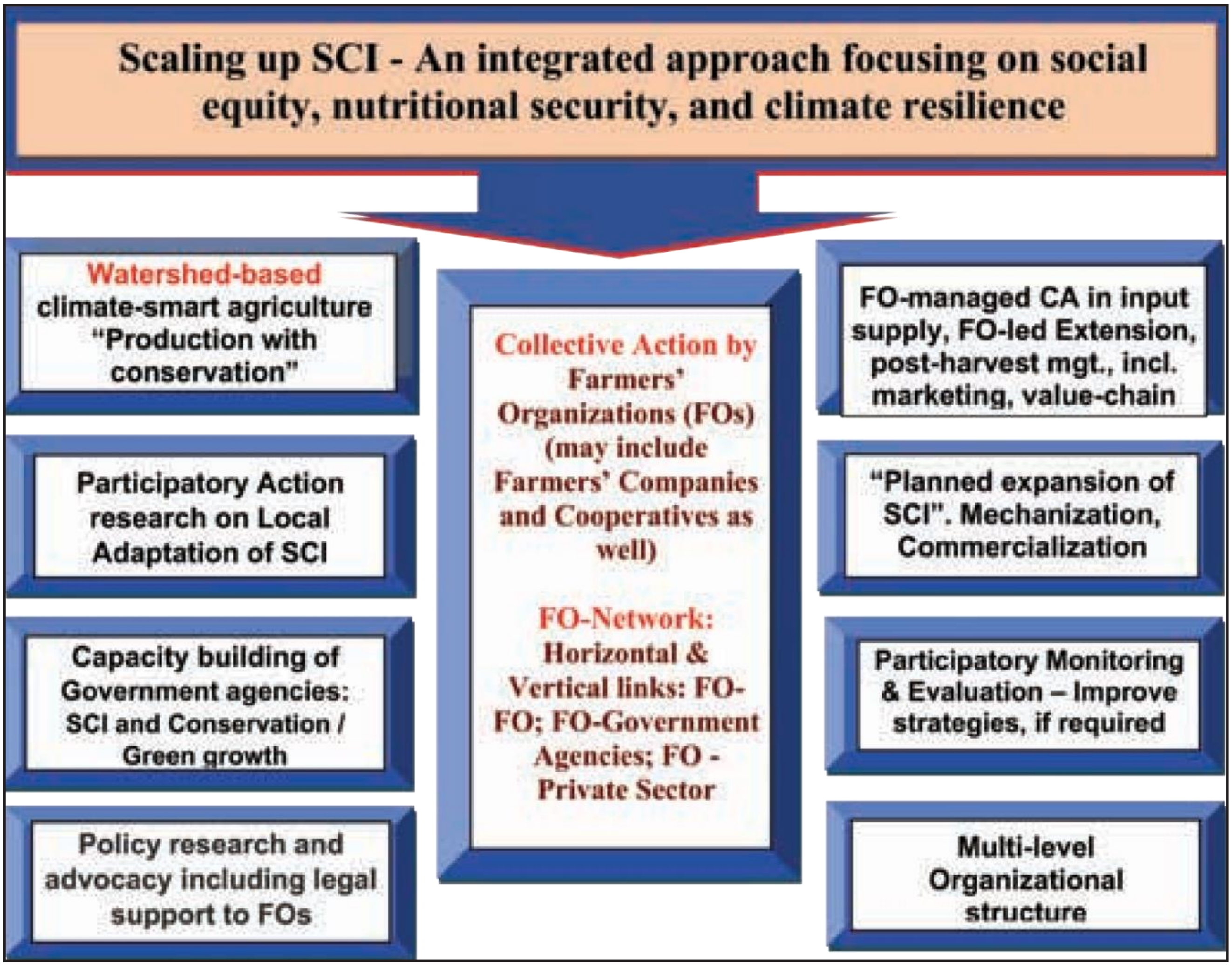

Figure 1: Scaling up SCI: Social capital-centered integrated strategy for enhancing production with equity and climate resilience

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SRI Adoption through Innovative Alliance-Building: Learning from the SRI-LMB

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Abstract

Given the challenges presented by climate change, water shortage, and land degradation, sustainable agriculture strategies that increase farming systems' resilience are needed more than ever. This is especially true for sustaining rice production which is the staple food for hundreds of millions of people. Agroecology-based System of Rice Intensification (SRI) is seen as a way forward in transforming food and agriculture systems, especially for the smallholder farmers to build an inclusive, safe, sustainable and resilient society. The findings reported here are based on the engagement that the Asian Center of Innovation for Sustainable Agriculture Intensification (ACISAI), Asian Institute of Technology (AIT), Thailand had in the Lower Mekong River (LMB) basin countries (Cambodia, Laos, Thailand, and Vietnam) using a regional project commonly known as "SRI-LMB". Using a local, national and regional innovation platform that was designed to systematize engagement and strengthen communication for fuelling innovation, more than 15 institutions were involved in the six-year-long farmers' participatory action research (FPAR) trial located in the 33 districts of 11 provinces in the LMB. The SRI was used as an 'entry point' for such engagement-led-transition. Average yield along with factor productivity increased by more than 50% with a significant reduction in cultivation costs, energy use, and greenhouse gas emission. The purpose of this paper is to share results, and also to detail three key processes that led to innovations in different areas for better adoption: 1. the multi-stakeholder platforms used for action; 2. The FPAR that led to community development; the evidence-based policy and strategies that can support the sustainability of rural livelihoods.

Keywords: System of Rice Intensification (SRI), Lower Mekong River Basin, Smallholders, Climate-Smart, Innovative platform

Introduction

Globally, there are some 608 million small farmers who produce more than 80% of the world's food contributing to national and even global food security (FAO, IFAD, UNICEF, WFP and WHO, 2021). Particularly in Asia, majority of farmers are smallholders who own and operate the majority of farmland, but they hold less than 5 hectares per farm. FAO explained that food, health, trade, and climate change are interdependent and the pandemic has revealed the fragility of these linkages. The crisis has threatened progress towards achieving the Sustainable Development Goals (SDGs), which promises to bring about a better world for all people by 2030. Redesigning sustainable food systems with active engagement with farms and farming communities is one of the offered solutions which is gaining momentum in Asia and beyond.

Redesigning sustainable food systems demand integration of political and social dimensions along with ecological and economical dimensions. In this context, the role of agroecology (AE) is evolving and gaining momentum. Agroecology is seen a way forward in transforming food and agriculture systems to build an inclusive, safe, sustainable and resilient society.

Keeping this in mind, the Asian Center of Innovation for Sustainable Agriculture Intensification (ACISAI), Asian Institute of Technology (AIT), Thailand implemented an EU-funded regional initiative in the Lower Mekong River (LMB) basin countries (Cambodia, Laos, Thailand and Vietnam) from 2013 to 2018 using a regional project commonly known as "SRI-LMB'. This six-year long project engaged more than 15 institutions (academic, research and development), 30,000 farmers (58% women), 78 ministries staff, 40 researchers, 15 faculties, 25 students, and 12 development professionals in a farmers' participatory action research trial located in the 33 rainfed districts of 11 provinces in the LMB.

The System of Rice Intensification (SRI) principle was used as an 'entry point' for such engagement-led-transition. The main objective of the project was to engage farmers' participation by educating themselves about the System of Rice Intensification (SRI) practices and to facilitate building strong farmer networks at the community level. In contrast with traditional methods of rice cultivation, SRI techniques require less water, seed, manure, and labour and promise higher yield and economic returns.

Methodology

As a part of this FPAR intervention, the common issues and interests expressed by farmers producing under rainfed conditions in all four countries were to achieve higher yield with reduced costs of production by reducing input use for cost saving and for making rice cultivation more efficient and profitable.

Major activities included exchanging ideas on new or alternative agro-ecological farming techniques, developing low-cost location-specific technologies through farmer's participatory action research with profitable harvesting and economic advancement through better market opportunities for rainfed farmers. Documenting the results and sharing them within farming communities and with communities at large through an inclusive participatory process, from local to national and regional levels, was the modus operandi of the project. Evidence-based policy options for more supportive policies were generated through a participatory consultation process working closely with all relevant stakeholders, including policy-makers in the countries.

Results and Discussion

With the support of ministries and governmental agencies in all four project countries, Cambodia, Laos, Thailand, and Vietnam, the project functioned well in building capacity and confidence among farmers. More than 15,000 farmers (> 50% women) participated directly in the farmer-led field trials located in 33 districts of 11 provinces of the four countries, and another 30,000 were reached indirectly. The number of farmer-participatory experiments conducted was more than 1,500: 121 at 60 action-research sites in 2014; 465 at >173 sites in 2015; and then 1,134 at >582 sites in 2016-17.

The results showed that in comparison with the pre-project baseline, SRI practices helped to improve livelihoods and the environment across the LMB region in numerous ways (Figure 1):

- Average rice yield increased by 52%, and net economic returns by 70%,
- Labour productivity was increased by 64%, water productivity by 59%, and fertilizer use-efficiency by 75%.
- The total energy input required for farming operations was decreased by 34%, along with significant reductions in per-hectare net emission of greenhouse gases, respectively by 14% with irrigated rice production, and by 17% in rainfed cropping (Mishra *et al.,* 2021, 2022).

Monitoring of the adaptation response of farmers showed that across the region, a majority of farmers applied two major principles of SRI after receiving season-long training: (1) fewer seedlings or seeds per hill hole, and (2) wider spacing. The average yields reported from farmers' fields after the FPAR training was in the range of 7-18% more, and average net economic return ranged from 15% to three times more. In comparison to male farmers, women farmers reported higher yields and higher economic returns (Mishra *et al.,* 2019).

Some of the key innovative processes that were used to fuel agroecological transition and SRI adaptation and adoption at farmer's field along with some initiatives to support such transition are detailed here. They are categorized under three groups:

1. Multi-stakeholder networks & platforms (academics, researchers, Farmers Organizations) enabling co-creation of knowledge & participatory research for supporting family farming & food system transformation
2. Enhancing rural communities' initiatives and development, and transfer of technologies
3. Policies and strategies (from regional to local levels) to support family farmers & sustainability of rural livelihoods/communities.

In addition, the programme also supported the process that led to innovation in higher education institution curricula to better address agroecology-led sustainable food system transition in Asia.

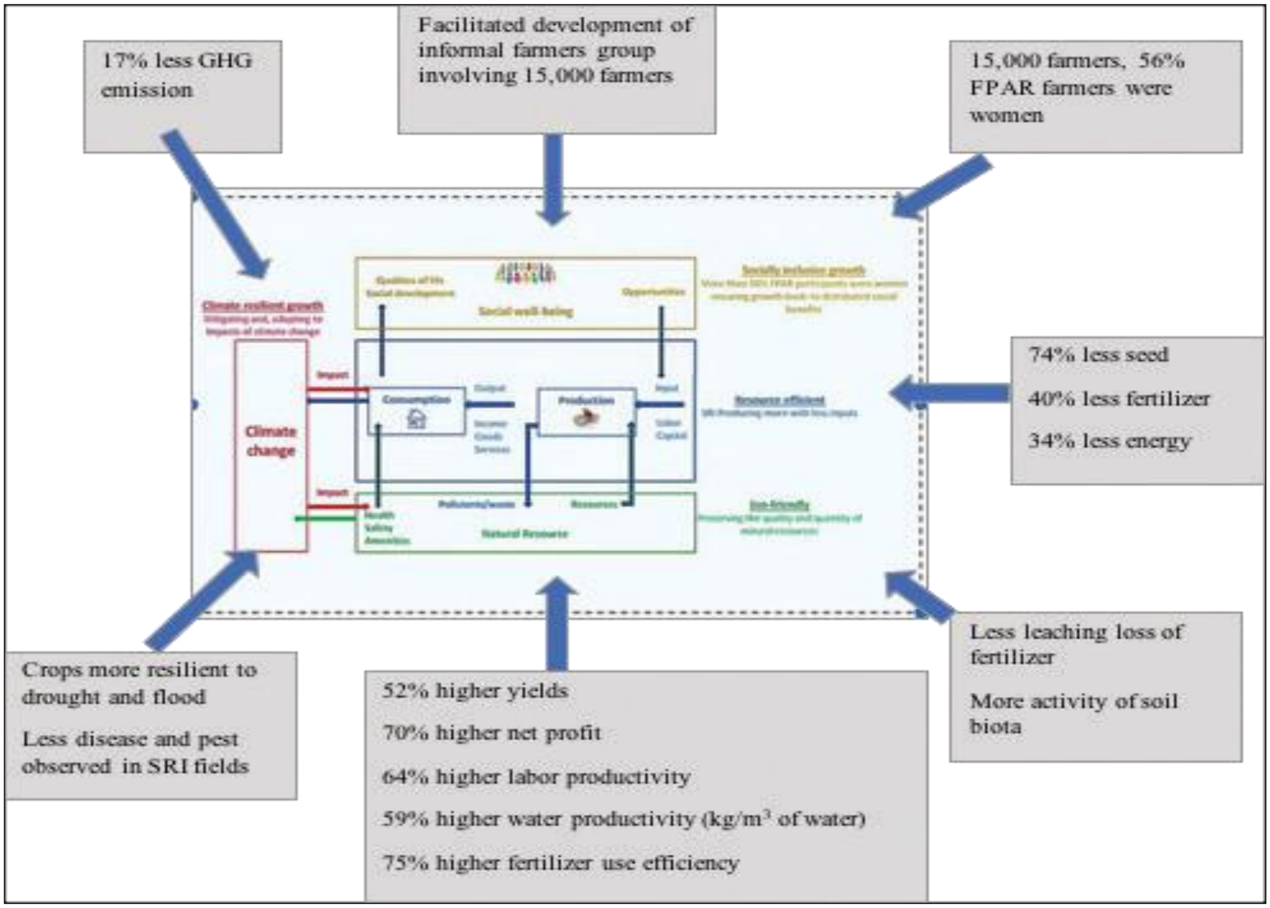

Figure 1: Green growth in agriculture with System of Rice Intensification practices using the farmers' participatory action research approach

Multi-stakeholder networks & platforms (academics, researchers, Farmers' Organizations) enabling co-creation of knowledge & participatory research for supporting smallholder's farming & food system transformation

To achieve the project objective through better collaboration at all levels, the SRI-LMB established local, national and regional project management unit (Local Management Unit (LMU at province level), Programme Management Unit (PMU at country level) and Programme Coordination Unit (PCU at regional level), respectively) that led to the development of innovation platforms at all level for implementation, knowledge-sharing and dissemination (**Figure 2**). These processes of network building and strengthening that were initiated by the project were expected to continue as a common meeting-point at all levels, serving as platforms for facilitating policy dialogue on food security, research for development, marketing improvements, and extension capacity for the rainfed LMB region. During the tenure of the programme, the individuals and organizations that worked with these LMUs, PMUs and PCU got first-hand opportunity to engage in knowledge management and dissemination. Particularly at local levels, farmers, farmer-trainers, and district trainers, along with NGOs and GO staff, were facilitated to articulate local needs and aspirations of farmers into the conduct of the Farmers Participatory Action Research (FPAR) via their respective local management units (LMUs). Similarly, LMUs supported the development of ways and means to educate more farmers in their respective communities on the results and outcomes of their participatory action research (PAR). They also facilitated wider diffusion of knowledge through various means. In addition, these local groups through their experiences of working with the project acquired greater skills of management, bookkeeping, and various tools and techniques of extension, as well as the art of analysis and interpretation of their own experimentation process and results.

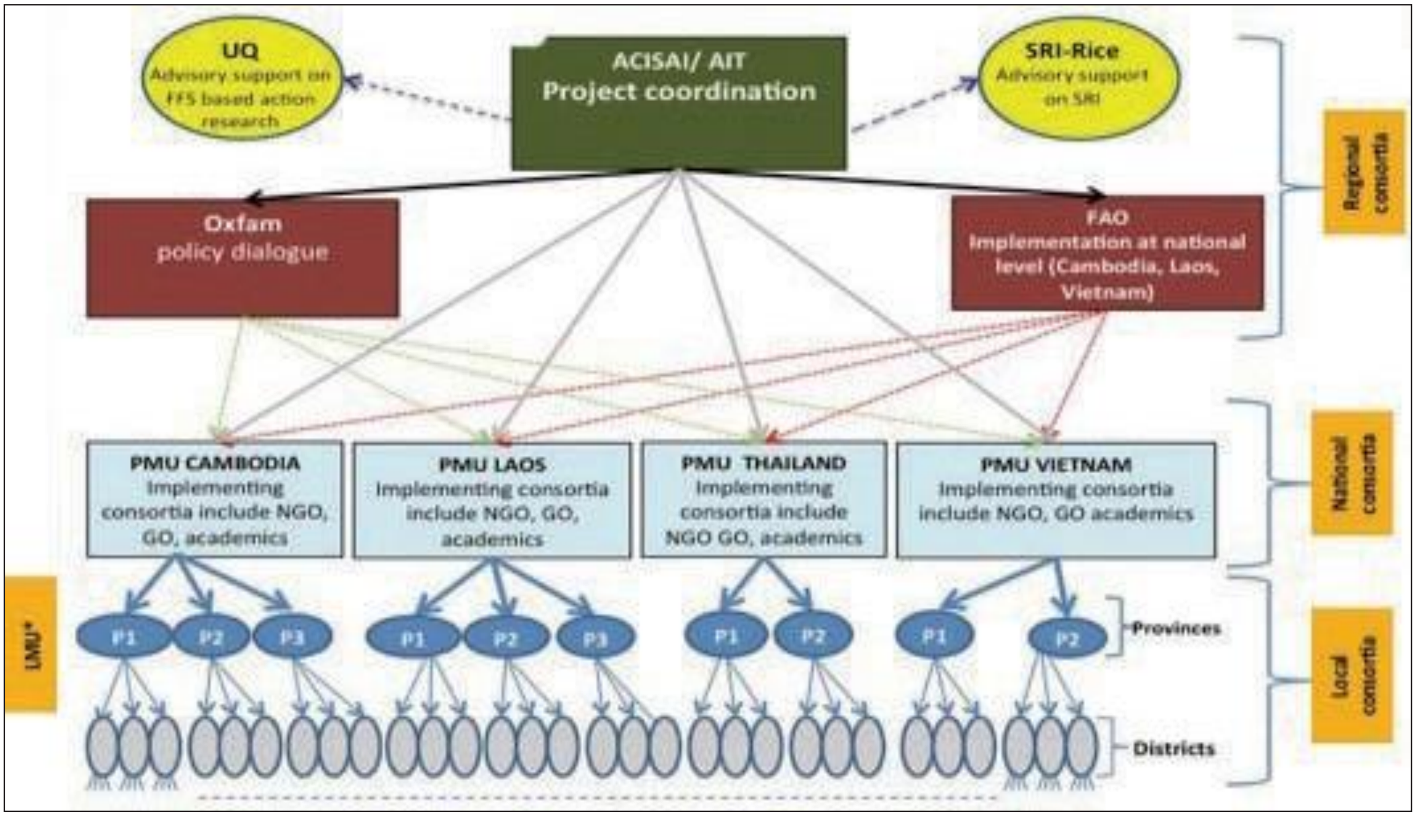

Figure 2: Programme Implementing consortia

ACISAI – Asian Center of Innovation for Sustainable Agriculture Intensification; AIT – Asian Institute of Technology; CFPAR – Central Farmers' Participatory Action Research; FAO-IPM – Food and Agriculture Organization – Integrated Pest Management; FPAR – Farmers' Participatory Action Research; GOs – Government Organizations; LIP – Local Innovation platform (possible outcome of the proposed processes); LMU – Local Project Management Unit; NGOs – Non-Government Organizations; NIP – National Innovation Platform (possible outcome of the proposed processes); P1, P2, P3 – Province 1, Province 2, Province 3 PCU – Project Coordination Unit (coordinated by AIT); PMU – Project Management Unit (coordinated by country offices of FAO-IPM in Cambodia, Laos, and Vietnam, and in Thailand by AIT); RIP – Regional Innovation Platform (possible outcome of the proposed processes); SRI-Rice – SRI International Network and Resources Center, Cornell University, USA; UQ – University of Queensland, Australia*

Enhancing rural communities' initiatives and development, and transfer of technologies

Using Farmers Field School approach, below structure was established (**Figure 3**) but at some places, the structure was adapted based on the existing local government extension departments' programme implementation structure and also according to the farmer's needs and requirements. The design involved 50% women (at least) and 10% landless to have an inclusive intervention.

This structure facilitated the systematic introduction of SRI/FFS approaches for the development of knowledge-intensive and location-specific technologies by bringing farmers, researchers, trainers and other stakeholders together, and by fuelling their innovative capacity. Apart from these tangible and quantifiable direct benefits to the target groups of farmers, locally-developed technologies for rice and other crops could take a horizontal spread pathway and reached to other farmers in proximate communities (approx. 50,000 farmers, based on past FFS experience in the region) through field day. Through this learning-centred approach, we also refined the curricula options for women and landless in order to capitalize of the opportunity that the action presented for furthering the leadership of women, especially in household decision-making and economic accomplishment. The process of engagement led to the development of informal farmers groups and network in all four countries.

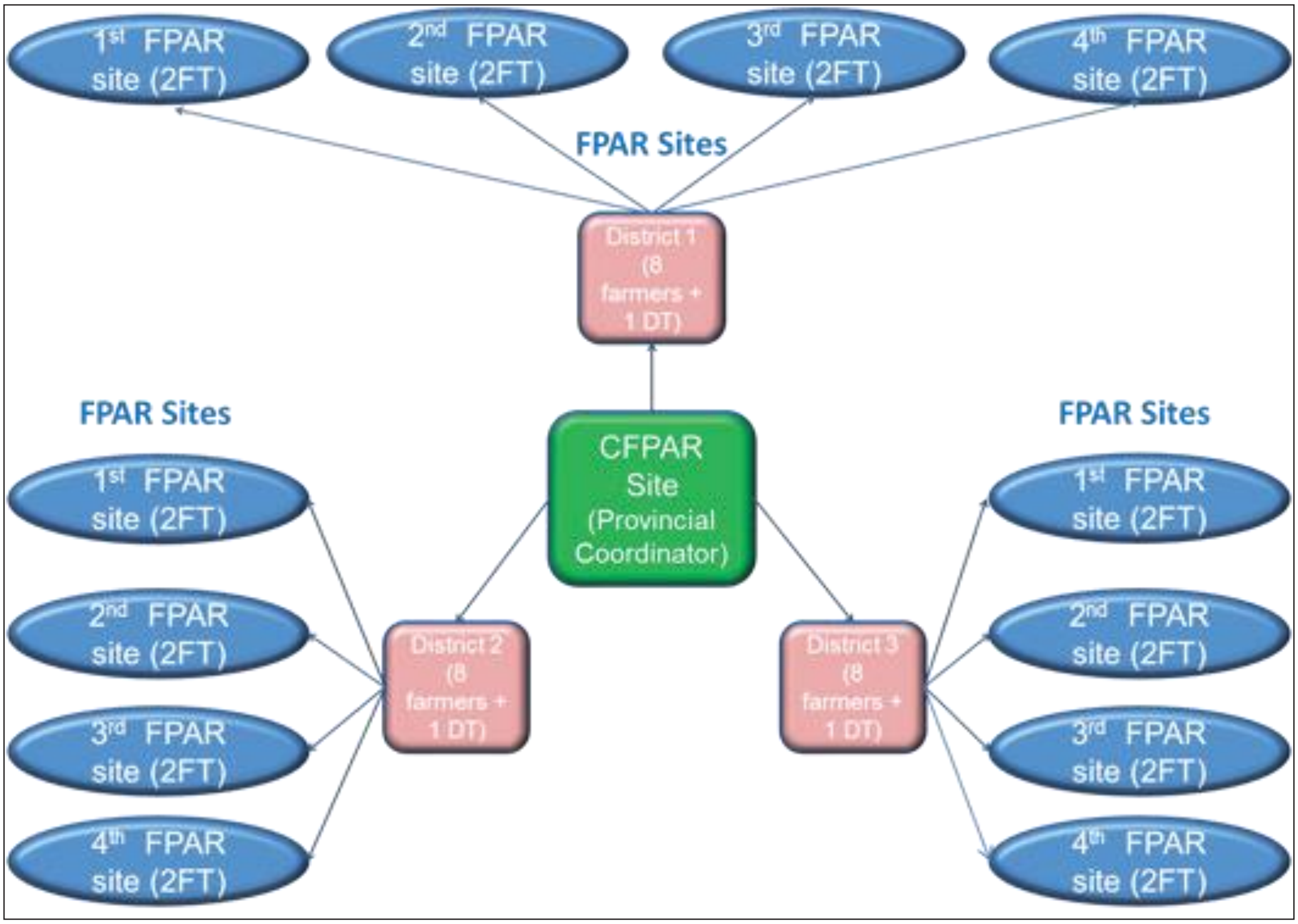

Figure 3: Structural diagram of CFPAR and FPAR in one province

CFPAR = Central Farmers' Participatory Action Research (at the provincial level); DT = District Trainer; FT = Farmers' Trainer; FPAR = Farmers' Participatory Action Research (at the village level, 4 sites/district); One FFS site = run by two FT, set up two experiments involving 60 farmers (30 farmers in each experiment).

It was perceived that such community-led engagement should enable the small farm producers to diversify their market-driven activities "creating" more opportunities for women, including in input-output services and value-chains (through FO- managed Collective Action), with proper policy and institutional support. These measures, if promoted along with the provision of performance-based incentives, such as credit, and infrastructure like storage /processing, would help attract the rural youth and thus reverse the rural-urban migration and support the sustainable transition.

Policies and strategies (from regional to local levels) to support smallholder farmers & sustainability of rural livelihoods/communities

As a part of key policy recommendations, the outcome of this project was seen as a foundation for 'green growth', and a way forward for participatory policy and programme development for ensuring better market access, price, and returns, also as a step towards NDCs contribution under Paris Agreement along with achieving SDGs. The project further noted that the ASEAN Food Security Policy (2015-2020) recommended SRI and CA integrated agroecological practices to benefit smallholders under the climate-smart initiative, however, there has not yet been much visible action taken on the ground. The research done on the policy environment and the institutional responses to the adaptation revealed that the adaptation and adoption of agroecological practices like SRI in the region need to be further strengthened realizing that the macroeconomic situation across the LMB countries is at different stages of development and yet evolving (**Figure 4**).

For example, where self-sufficiency is still a concerned, an intensification strategy can be applied to help small-scale farmers become more self-sufficient. At some point scaling

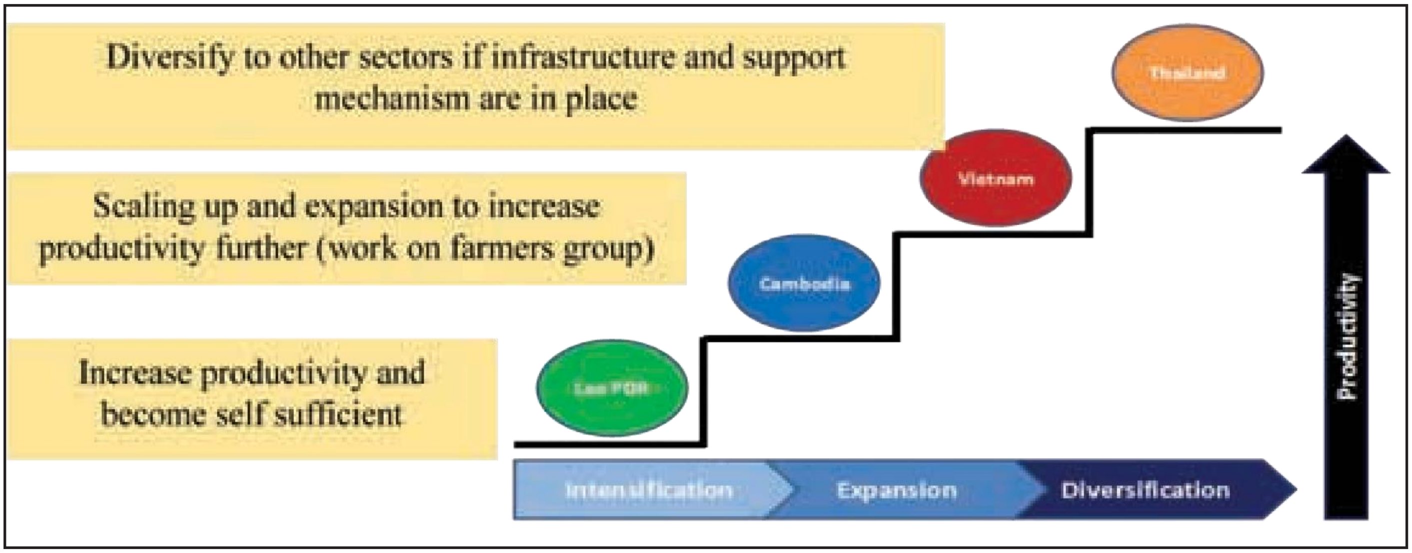

Figure 4: Macroeconomic situation of all four LMB countries and possible next steps towards economically efficient Green Growth and sustainable intensification in agriculture (Oxfam 2018)

up and expansion strategies may become relevant and can help the farmers to expand and increase productivity further. As farming develops and the macroeconomic situation improves, some farmers may diversify into other industries and/or link to market (initially local and then international), provided infrastructure and other support mechanisms are in place.

Innovation in HEIs curriculum to better address agroecology and smallholder farming

A transition to sustainable food systems requires interdisciplinary knowledge and cross-departmental collaboration drawing from social sciences rural development, agronomy, extension, biology, botany, artificial intelligence, etc. It is well perceived that such integrated academic courses and formal training programmes on agroecology could be useful for government staffs, policy makers and other development professionals who take lead in implementing the development programmes in these areas. The SRI-LMB innovative alliance was able to set an example on how mutually inclusive education, research and outreach activities can create conducive environment for such transition. No doubt that conventional disciplines receive more policy support and resources at academic institutions, yet there is interest evolving to initiate dedicated programme in this direction. Taking this further, AIT and FAO joined their hands through formal collaboration to deepen their engagement to support the transition for agroecology based sustainable food system in Asia.

Following areas were suggested to explore for joint research, education and trainings: 1. Joint research project for mapping out and identifying the gaps in the area of agroecology and sustainable food systems (integrating the Tool for agroecology performance Evaluation (TAPE) in academic curriculum as a practical tool to engage students. 2. Establishing regional network of HEI; 3. Involve faculties in global and regional technical and policy consultation processes; 4. Internship/fellowships programme for Master and PhD students (engage students in FFS); 5. Gather consensus on innovations that have a significant impact among various stakeholders in the region and disseminate the selected innovations for wider implementation; 6. Develop a curriculum that helps to understand the growing demand for healthy and nutritious foods (market demand, consumer percept's); 7. Link CSO/community institutions with university education; and create a programme that prepares rural youth to be professional managers of land, water and other resources to support the transition and reverse the migration.

To strengthen it further, there was a recommendation to form a non-formal but structured SRI regional alliance, with an appointed secretariat and subgroups to be established based on topics such as research, equipment, and marketing. These alliances are evolving. With some external funding support, such institution building can be possible. The International donor community should align their support to facilitate such a transition sooner than later.

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System of Rice Intensification: Impacts on Crop Productivity and Saving Water in Africa

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Abstract

The System of Rice Intensification (SRI) is a package of practices that changes how rice is grown in paddies, which incredibly increases yields. Rather than fully flooded paddy systems, SRI involves among its practices, the alternate wetting and drying of paddies which saves water, use of less seeds, wider crop spacing, transplanting one seedling per hill and use of organic fertilizers, all of which result in a sturdier rice plant. Other benefits include better grain quality, healthier work environments through reduced water-borne disease vectors and as a climate-smart practice. Data from several African counties shows that SRI increases rice yields by between 20% to 80% depending on variety and local conditions, saves water by about 39% and reduces seed requirement by 66%. SRI has been adopted by millions of farmers worldwide, while within Africa, some 25 countries are documented to have adopted SRI. This paper presents the opportunities inherent in enhancing and promoting SRI adoption of the in Africa. To facilitate this, the SRI-Africa knowledge portal was launched in 2018. The portal collates and shares data, information, publications and happenings in SRI from African counties, thus facilitating promotion of SRI in Africa and worldwide (visit https://sri-africa.net/).

Key words: Rice, Intensification, climate change, Africaplatform

Introduction

Importance of Rice to Africa

Rice is grown in 40 African countries and is the principal economic activity for over 35 million smallholder rice farmers. Although Africa accommodates only 13% of the world population, the continent accounts for 32% of world rice imports, amounting to 14-15 million tonnes per year (Africa Rice, 2022). Furthermore, rice is rapidly becoming a major food staple in much of sub-Saharan Africa and is set to overtake maize, cassava, sorghum and other cereals in the future. The demand for rice is growing at over 6% per year, driven by population growth as well as by urbanization. In addition, the high cost of fuel makes rice attractive as it cooks faster, tastes delicious, feeds large groups well and is one of the few foods in the world which is entirely non-allergenic and gluten-free. But increasing rice productivity in Africa faces a number of challenges. Generally, rice yields are low Africa attaining about 0.49 to 4.43 t/ha (Diagne *et al.,* 2013).

Conventional rice production utilizes too much water

For thousands of years, rice has been grown under flooded paddies utilizing too much water. Generally, rice production in flooded paddies utilizes between 3,000 and 5,000 litres of water for each kilogramme of grain produced (Molden *et al.,* 2007). Most irrigation schemes for rice in Africa practice the traditional method of continuous flooding of paddies, taking up about 1-meter depth of water. This is because it is believed that rice is an aquatic plant or at least a hydrophilic one (Satyanarayana *et al.*, 2006). But sometimes, the reason could be simply that flooded paddies conform to the convention or tradition, handed down over generations since it helps to control weeds. The flooded paddies are breeding grounds for water-borne of disease vectors, such as mosquito which spreads malaria (Namfumba *et al.*, 2005).

Climate Change is Set to Impact on Rice Production

In some rice-growing countries in Africa, the challenges of water scarcity will be exacerbated by climate change. This could affect rice production differently, as increasing CO_2 concentrations in the atmosphere has a positive effect on crop biomass production, but its net effect on rice yield could be negative. For instance, for every 75 ppm increase in CO_2 concentration rice yields will increase by 0.5 t ha^{-1}, but the yield will decrease by 0.6 t ha-1 for every 1°C increase in temperature (Sheehy *et al.,* 2005). Furthermore, within Sub-Saharan Africa (SSA), rice production is increased by expansion of irrigation schemes rather than intensification. Yet rice could grow and yield well with less water. This is because, whereas the rice plant can withstand water-logging and indeed, it does not have to be grown under water all through. Producing more rice with less water on the same paddy, using the same seed varieties, by the same farmers is possible. This is the promise of the System of Rice Intensification (SRI), a "win-win" climate-smart agronomic practice for growing more rice.

THE SYSTEM OF RICE INTENSIFICATION (SRI)

The System of Rice Intensification (SRI) is a package of practices especially developed to improve the productivity of rice grown in paddies (Uphoff, 2005). SRI was developed with small-scale farmers in Madagascar in the 1980s with the aim of improving paddy yields and reducing poverty and hunger in that country (Laulanié, 1993). Since then, the practice has spread to many countries all over the world. SRI increases the productivity of irrigated rice by changing the management of plants, soil, water and nutrients (Shambu, 2006). The system has also been associated with increased yields in a number of countries where it has been tried (Uphoff, 2005). In practice, SRI involves some combination of the following changes in rice agronomic practices:

1. Raising seedlings in un-flooded nurseries and well-supplied with organic matter. This produces a studier seedling which establishes easily once transplanted.
2. Transplanting young seedlings, i.e. 8-14 days old seedlings, instead of the conventional 21-30 day old ones. Early transplanting optimizes the rice plant tillering potential.
3. Transplanting one seedling per hill (instead of the conventional clumps of 4-12 seedlings). It is the number of tillers a single plant produces which results in good yields, not the quantity of seedlings planted.
4. Transplanting seedlings at wider spacing, in lines and in a square pattern, giving roots and leaves and more space to grow.
5. Alternate wetting and drying of the paddy field (do not continuously flood the soil) to ensure aerating of the root zone, which is beneficial to plant roots, while saving water.
6. Weed control using a mechanical/rotary weeder. This eliminates weeds, aerates the soil and gives better results than either hand weeding or herbicides
7. Use of soil organic manures and fertilizers to improve soil fertility and crop growth.

Evidence from African Countries

A desk study was conducted to gather evidence on the impacts of SRI on rice productivity, utilizing the SRI-Africa knowledge portal, as well as other databases. t was found that compared to conventional flooded paddy systems, SRI has many benefits to the farmer, the irrigation scheme, the environment, to the country and to Africa; for example:

Increased Yields

One of the main benefits of SRI is the fact that the practice increases the yield of rice**,** by various factors depending on crop variety, management and climatic conditions. An assessment of 14 African countries (**Figure 1**) obtained that on average, SRI yields were significantly higher than flooded paddies ranging from 3.9 t/ha under conventional flooded paddies to 7.1 t/ha under SRI, equivalent to an increase in average yields that varied of 81% attributed to SRI. This agrees with another study in Kenya, where 71% increase in rice yields under SRI were obtained (Nyamai *et al.,* 2012). That SRI results in higher yields with has been recorded world-wide (Stoop *et al.,* 2002; Kabir and Uphoff, 2007; Thakur, 2010; Mati *et al.,* 2021).

SRI Saves Water

The wetting and drying practiced under SRI results in less water being applied, and thus savings in water. Data from six African countries, i.e. Burkina Faso, Egypt, Kenya, Morocco, Mozambique, Niger and Tanzania (**Figure 2**) shows that SRI reduces the amount of water used to grow rice by between 30-63% compared with conventional flooded paddies. The wetting and drying of rice paddies has the beneficial effect of enhancing root growth. The rewetting facilitates nitrogen mineralization and this is made available to the plant for growth (Ceasey *et al.,* 2006). Studies in Kenya (Omwenga et a, 2014) showed

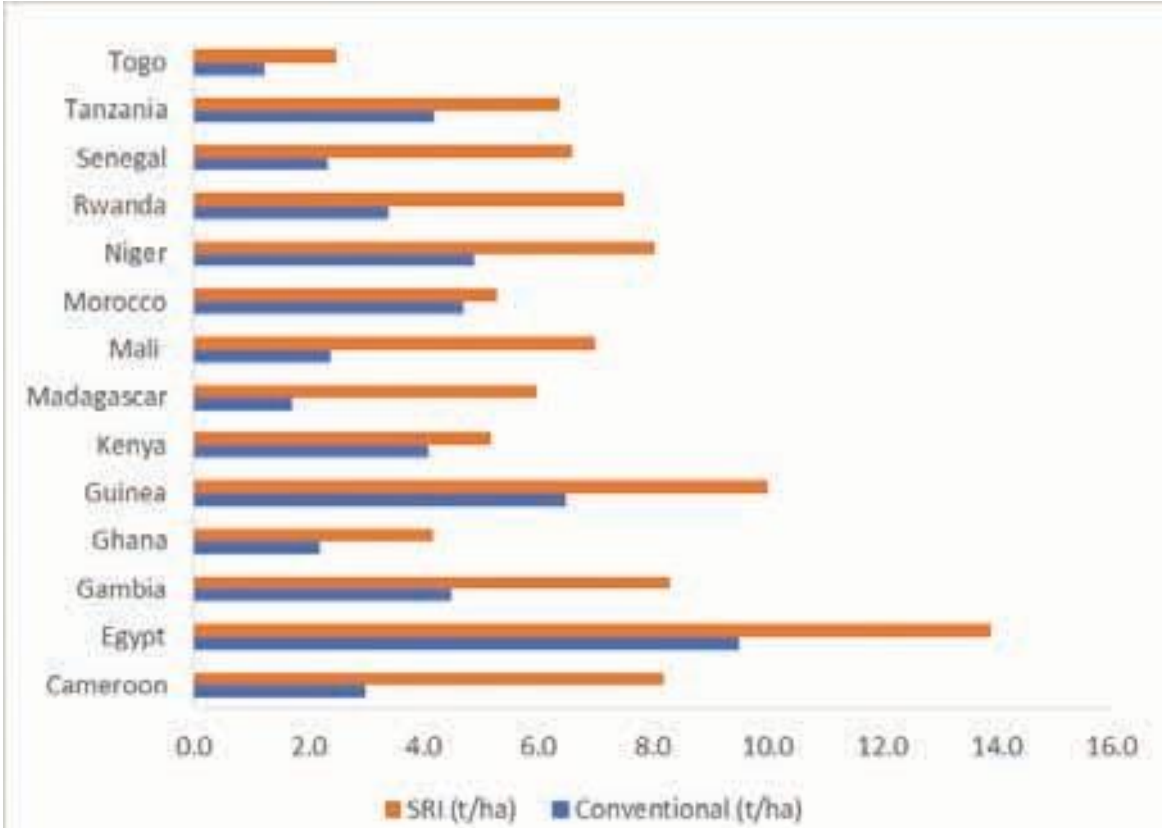

Figure 1: Rice yields from SRI and conventional practice in selected African countries

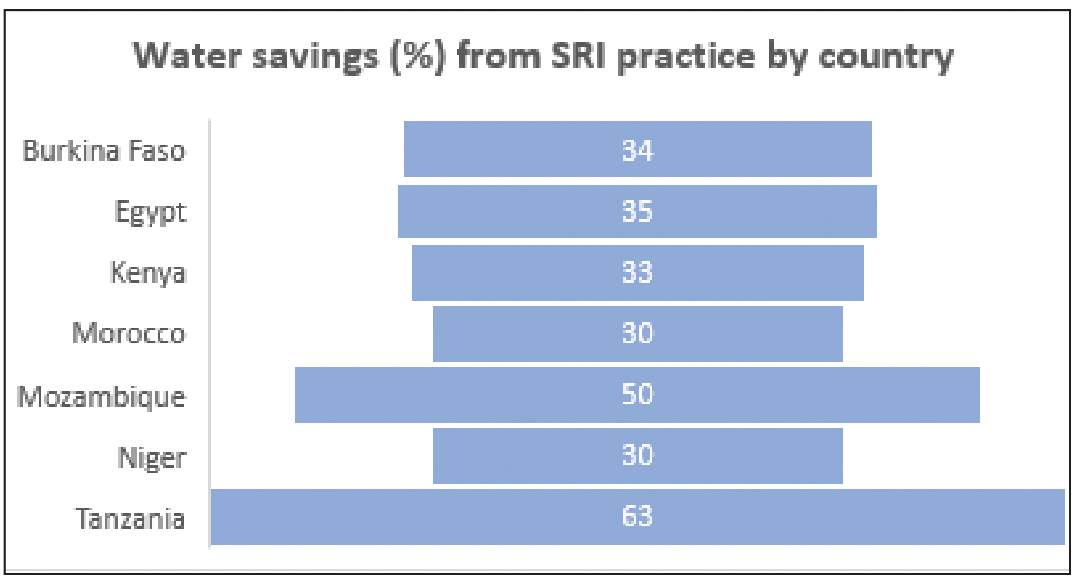

Figure 2: Water savings from SRI practice in selected African countries

that the drying of rice paddies for between 4 and 12 days under SRI has positive impacts on rice yields, resulting in water savings of between 27% and 42%. Ndiiri et al (2012) obtained that SRI crops were irrigated fewer times than with farmer practice because its grain matured earlier by an average of 10 days.

SRI Utilizes Less Seed

SRI uses less seed compared to conventional flooded paddies (Mati *et al.,* 2021). Data from some 14 African counties (**Figure 3**) shows that on average, SRI required only 16 kg/ha as compared to conventional systems that used 73 t/ha. By transplanting just one seedling per hill, it means that less seeds are required in the nursery, and this saves on costs of seeds by about 78% in Africa.

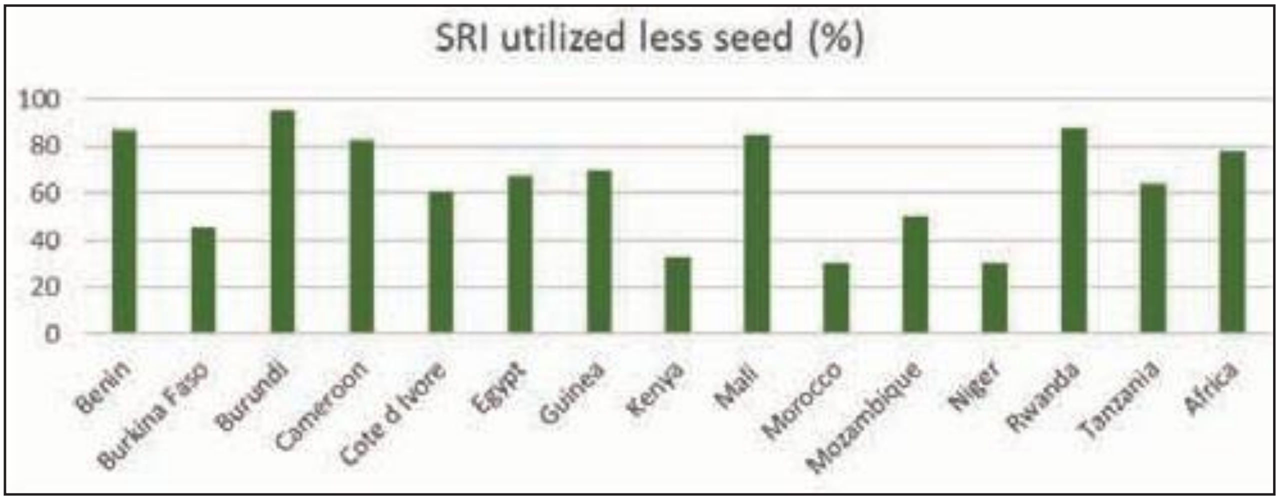

Figure 3: Use of less seed under SRI practice in selected African countries

Weed control under SRI

Although weeds proliferate under SRI, control can be made easier as SRI utilizes mechanical/ rotary weeding. Mechanical weeding has been proven to stimulate root renewal and hence faster root development and crop vigour, further improving tillering of the rice plant. Different viewpoints exist about comparative labour inputs in the SRI method of paddy cultivation. SRI may require more labour in the beginning but once farmers master the technique it leads to labour savings (Uphoff *et al.,* 2002). Studies in Kenya showed that mechanical weeding reduce the cost of weeding by 75% compared to manual weeding under conventional flooded paddies (Kathia *et al.,* 2019).

Better Grain quality

SRI practice results in a harder grain which does not break on milling resulting in a more whole, good quality grain which has higher market value. The cumulative effect of these methods is to raise not only the yield of paddy (kg of un-milled rice harvested per hectare) without relying on improved varieties or agrochemical inputs, but also to increase the outturn of milled rice. This bonus on top of higher paddy yields is due to having fewer unfilled grains (less chaff) and fewer broken grains (less shattering). The harvested SRI paddy is heavier than conventional paddy. Farmers in Kenya have found that the normal bag of paddy weighs about 100-110 kg for SRI, compared to conventional paddy which weighs 80-90 kg per bag of equivalent size.

SRI increases net farm-gate incomes from Rice

SRI increases the overall economic returns to the farmer from rice production. Research at Mwea in Kenya has found that net farm-gate incomes increase by about 20-50% from SRI compared to conventional paddy production. This is due to not only due to higher yields, but also the lower inputs costs. Ndiiri et at (2013) in an economic assessment of SRI and conventional paddy, obtained that a significantly higher benefit–cost ratio of 1.76 and 1.88 compared to 1.31 and 1.35 for flooded paddy in the first and second seasons, respectively. Barah (2009) reported similar ratios and even higher values in some of the districts that he studied in India. A wide range of reductions in cost of production with SRI for different countries is elaborated in Uphoff (2005) and Sinavagari (2006).

Reduction of disease vectors in paddies

SRI reduces the incidence of disease vectors found in conventional rice paddies. Research at Mwea has shown that due to the wetting and drying of paddies under SRI, mosquito larvae are completely eradicated in paddies when left dry for about two days. Omwenga et al (2014) showed from plots studies that alternate wetting and drying of rice paddies under SRI practice interfered with the development process of mosquito larvae, completely eliminating the larvae from SRI plots compared to conventional flooded paddies

Gender equity and youth employment

Gender equity and youth employment in farm labour is enhanced under SRI. This is because in some African cultures, weeding of rice is done by women as bending to pull out weeds is considered "un-manly". With introduction of mechanical/rotary weeding, men and youth find it easier and culturally acceptable to do weeding and thus relieve the women of some of the burdens of farm labour. Moreover, SRI makes use of what the farmer has (land, seed, labour, inputs) and all that is required in the knowledge and a change of attitude to adapt.

Conclusions

In Africa, recurring droughts affect nearly 80% of the potential 20 million hectares of rainfed lowland rice. Therefore, since SRI saves water and results in increased yields, there is need to upscale the practice. Overall, SRI is a better practice scientifically, because it promotes climate-smart practices. The rice plant is a "water loving plant". But SRI has proved that a rice plant requires just adequate water. There is no need to waste water flooding the paddy unnecessarily. SRI can be practiced on nearly all sizes of farms and is especially beneficial to smallholder rice farmers. The SRI-Africa knowledge sharing portal has been useful for collating data, information, publications and happenings in the SRI sub-sector in Africa. Knowledge transfer is a tool through which SRI can be promoted in Africa, as an option to grow more rice to feed the continent, while also saving water. For more details, please visit https://sri-africa.net/

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LEAD LECTURE https://doi.org/10.58297/NYTB8422

Improving Productivity and Profitability of Rice-Based Cropping Systems in Eastern India

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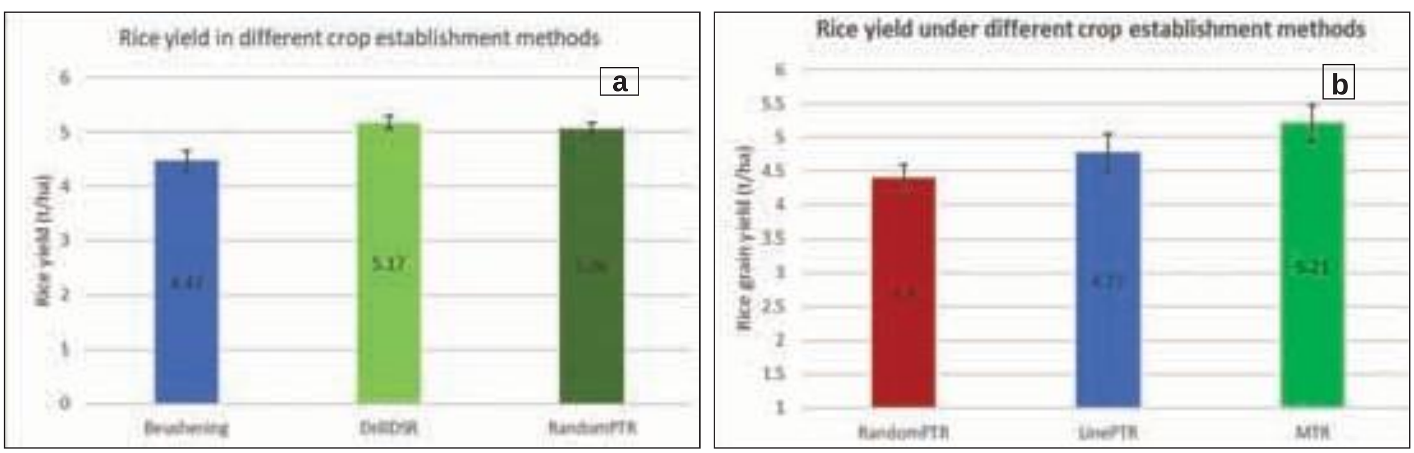
Introduction

Rice is a staple food for 65% of the Indian population and contributes to 43% of food grain production. Rice plays a central role in culture, rituals, diet and employment, and is considered as an instrumental crop that changed India's status from food-deficient to the exporter (Yadhav *et al.,* 2017). Eighty-three percent of rainfed rice in India is from eastern states. The plains of Assam, Bihar, Chhattisgarh, eastern Uttar Pradesh (EUP), Jharkhand, Odisha, and West Bengal are among the states in eastern India which covers a total area of 72 million hectares, representing nearly 22% of the country's area, and supporting about 34% of the country's population. Eastern Indian states have fertile soils and ample water resources but the productivity and profitability of rice farmers in eastern India is low compared to other regions in India. This is mainly because of sub-optimal adoption of improved varieties and technologies in addition to extreme climatic variability including frequent drought and floods. After harvesting the rice, farmers leave their fields fallow rather than planting a second crop in the same year due to physical and socio-economic issues. Utilizing fallow lands effectively can offer enormous possibilities and potentials for raising the system productivity, profitability and sustainability of the rice-based systems. Hence, developing and promoting location-specific sustainable rice production technologies and management practices is of prime importance in rice-based systems. It is highly crucial to improve the rice-based cropping systems (RBCS) by adopting sustainable crop management practices in rice during the *kharif* season which consequently can result in bringing more rice-fallow areas under cultivation through water-efficient and short-duration pulses or oilseeds in the *rabi* season. Altogether, these interventions may enhance the productivity and profitability of RBCS in the region.

Resource-efficient alternative crop establishment methods *in rice*

The crop establishment (CE) method is the most critical for ensuring a good crop stand as well as productivity, particularly under rainfed situations. Rice is commonly established by manual transplanting. A huge amount of water and labor requirements for transplanting reduces profit margins. Since the conventional (manual) puddled transplanting of rice (PTR) is highly input-intensive, precision dry-direct seeded rice (DSR) and mechanical transplanting of rice (MTR) have emerged as alternatives to reduce dependency on farm laborers, reduce cost and input use while increasing the profit (Pannerselvam *et al.,* 2020).



A study in Odisha showed that direct sowing of rice with the use of seed drill increased rice grain yield by 0.7 t/ha over beushening systems (broadcasting followed by beushening) (**Figure 1a**). However, the grain yield of DSR was on-par with manual PTR. The *beushening* method consists of broadcasting ungerminated rice seeds using high seed rates (> 100 kg ha^{-1}) in the field before the onset of monsoon rain, followed by cross-ploughing and laddering (leveling using flat wooden plank) at 4–6 weeks after emergence when 10-15 cm of rainwater has accumulated in rice fields. Cross-ploughing and laddering helps to control weeds, thins the crop stand, and distributes rice seedlings more evenly. These operations are labor-intensive, tedious, and are largely carried out by women. The inclusion of drill-DSR can address the challenges associated with the labor scarcity because DSR reduces the labor requirement by 40% (Pandey and Velasco, 2002) and thereby reducing the labor cost (Yadav *et al.,* 2017). A prime reason for higher yields is timely and effective weed control achieved through herbicide-based IWM. In *beushening*, early weed competition is generally higher as weeds are not controlled for the first 30-40 days prior to the *beushening* operation. Another reason for higher yield in drill-DSR is due to more efficient use of applied fertilizer as fertilizers were applied at the recommended time (at sowing, 25-30 DAS, and panicle initiation stage). Net benefit were significantly higher by 166-550 US$/ha in drill-DSR compared to *beushening* due to the combination of increased yield and/or lower variable cost in drill-DSR (Panneerselvam *et al.,* 2020). However, insufficient availability of seed drills poses a major bottleneck to the broad adoption of drill-DSR. Moreover, drill-DSR in very lowland area under rainfed situation is also difficult if there is an excess rainfall.

In another experiment, we tried to compare mechanical PTR with manual PTR (random and line) in Odisha. Our results showed that mecahical PTR increased grain yield by 0.81 and 0.44 t/ha than manual random PTR and manual line PTR, respectively (**Figure 1b**). The higher rice yield in MTR could be attributed to the use of young seedlings (Uphoff, 2002). For instance, under manual transplanting, 25 to 30-day old seedlings were used, whereas for MTR, 15 to18-day old seedlings were transplanted which might have resulted in the early adaptation of the seedlings. Moreover, seedlings in the mat type nursery have less damaged roots resulting in less transplanting shock which is a major problem in the manual-PTR, and consequently leading to higher yield. Additionally, along with the improved yield, the MTR better manages time and reduces the production cost by reducing the labor cost for transplanting. Both drill-DSR and MTR not only produce higher yields, but also address the labor scarcity problems, decrease the input costs, and also reduce GHG emissions such as methane (Pathak *et al.,* 2013). However, there are also major challenges in the adoption of drill-DSR and MTR due to the lack of awareness of the technology, limited availability of the machines, inadequate mat-type nursery, and lack of skilled workers (Yadav et al., 2017).

Integrated weed management for sustainable intensification

Weeds are considered as one of the major constraints to wide-scale adoption of dry-DSR and yield can be reduced from 50 to 90 % if weeds are not properly controlled (Chauhan and Johnson, 2011). When weeds are effectively controlled, DSR yields are similar to that of transplanted rice (Gathala *et al.,* 2013). Manual hand-weeding is becoming difficult and uneconomical due to labor scarcity at the critical time of weeding (Kumar and Ladha, 2011). Hence, effective herbicide based-integrated weed management (IWM) practices are needed to reduce variable costs and labor use/cost. Our results suggest that drill-DSR out-yields *beushening* by an average of 1.5 t ha^{-1} in two out of three districts and increases net benefits by 166 to 550 US$ ha^{-1}. A prime reason for higher yields is timely and effective weed control achieved through herbicide-based IWM. It has been found that the integration of herbicides (PRE or tank-mix application of POST) with one hand weeding can save labor and is more profitable and productive than hand-weeding, herbicide, or mechanical weeding alone. IWM in dry-DSR saved 17-25 labour/ha, saved 28-57 US$/ha and increaded net profit by 68-82 US$/ha over hand weeding alone. Similary, IWM in broadcasing method also saved labour (38-48 labour/ha), saved cost (57-81US$/ha), increased yield (0.4-1.2 t/ha) and profit (114-312 US$/ha). The results of the current research are also in agreement with previous reports of superior weed control in DSR with sequential application of PRE (pendimethalin) followed by POST (bispyribac-sodium) over hand weeding (Walia *et al.,* 2008).

Harnessing rice fallows in eastern India

More than 50% of the *kharif* rice area in eastern India is left fallow after rice harvest due to the lack of irrigation facilities/residual soil moisture, lack of knowledge and access to high-yielding varieties of short-duration pulses and oilseeds, animal grazing, and outmigration of labor during *rabi* season. However, most of the rice-fallow areas have suitable climatic conditions to grow short-duration pulses and oilseeds. Pulses are ideal for the rice-fallow system since they require less water for cultivation and have a deep-rooted system to tap the available soil moisture up to 0.4 m of soil depth (Hazra and Bohra, 2020). Our results showed that green gram and black gram can be grown successfully in the rice-fallow areas under rainfed conditions (**Table 1**). Rice equivalent yield (REY) of green gram and black gram was 2.2 t/ha and has potential to grow after rice harvest with residuel soil moisture if timely sowing is done. Toria has less potential compared to green gram due to less yield, less price and low availability of soil nitrogen after the harvest of *kharif* rice. In contrast, pulses are less dependent on nitrogen fertilizers because they fix atmospheric nitrogen and increase soil health (Tonitto *et al.,* 2006).

Table 1. *Rabi* season yield and REY under rainfed situations in rice-fallow areas of Odisha

Cropping system	Yield of pulses/ oilseeds (t/ha)	REY (t/ha)
Rice-Green gram (N=18)	0.65 a	2.27 a
Rice-Black gram (N=20)	0.64 a	2.20 a
Rice-Toria (N=20)	0.43 b	1.17 b

Under the irrigated situations, Rabi rice yield was significantly higher followed by green gram and toria (**Table 2**). Although enhancing productivity is important, protecting the environment and the sustainable use of natural resources is also highly crucial. It has been established that the continuous cultivation of rice can lead to the depletion of soil nutrient and an increase in GHG such as methane and nitrous oxide emissions (Kritee *et al.,* 2018). Our results showed that REY of sunflower was higher after rice. As seen with the rainfed conditions, toria performed poorly under irrigated conditions as well indicating that toria is not a suitable crop for the rice-fallow region in Odisha. Although sunflower yield was higher than green gram, growing pulses in rice-fallow can be beneficial because of short duration 60-65 days to mature whereas sunflower matures in 85-88 days (Mahapatra *et al.,* 2021) and provide nutritional benefits to human in addition to improving soil fertility.

Table 2: Yield and REY under irrigated situations in rice-fallow areas of Odisha

Cropping system	Yield of *rabi* crops (t/ha)	REY (t/ha)
Rice-Rice (N=20)	5.5 a	5.5 a
Rice-Green gram (N=20)	1.0 c	3.3 b
Rice-Sunflower (N=10)	1.8 b	5.1 a
Rice-Toria (N=20)	0.8 c	2.1 c

Conclusions

Bestowed with high rainfall and fertile soils, RBCS in eastern India are challenged with declining factor productivity, input use inefficiencies, and environmental and social insecurities. Efficient use of residual soil moisture by growing resource-efficient diversified crops (pulses, oilseeds,) layered with appropriate sustainable intensification (SI) technologies help in improving cropping intensity, farm income, and nutritional and food security, besides addressing these challenges. Conservation agriculture along with innovative crop establishment methods like direct seeding of rice, mechanical transplanting of rice, etc. can improve water use efficiency, soil health, and system productivity. Converting monocropped areas into double or triple cropped ones through utilization and exploitation of rice fallows, and/or intensification with short-duration rice and climate-resilient varieties of other crops, coupled with improved management practices and scale-appropriate mechanization are the potential strategies to achieve SI in eastern India. Focussed attention also needs to be given to the deployment of alternative crop establishment methods as well as improved agronomic practices in these ecologies.

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SCI – Building Climate Resilience for Achieving Food and Livelihood Security – Experience from Contrasting

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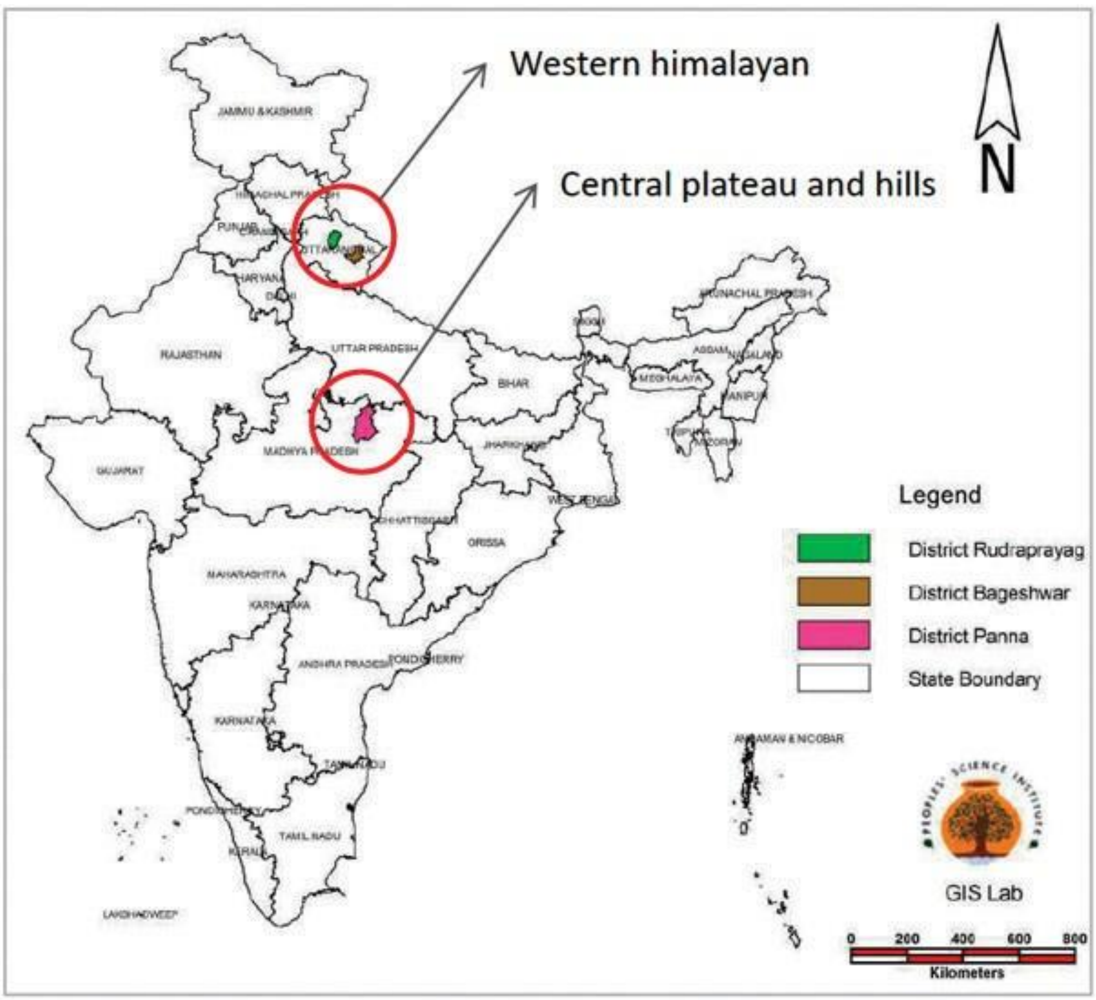
Introduction

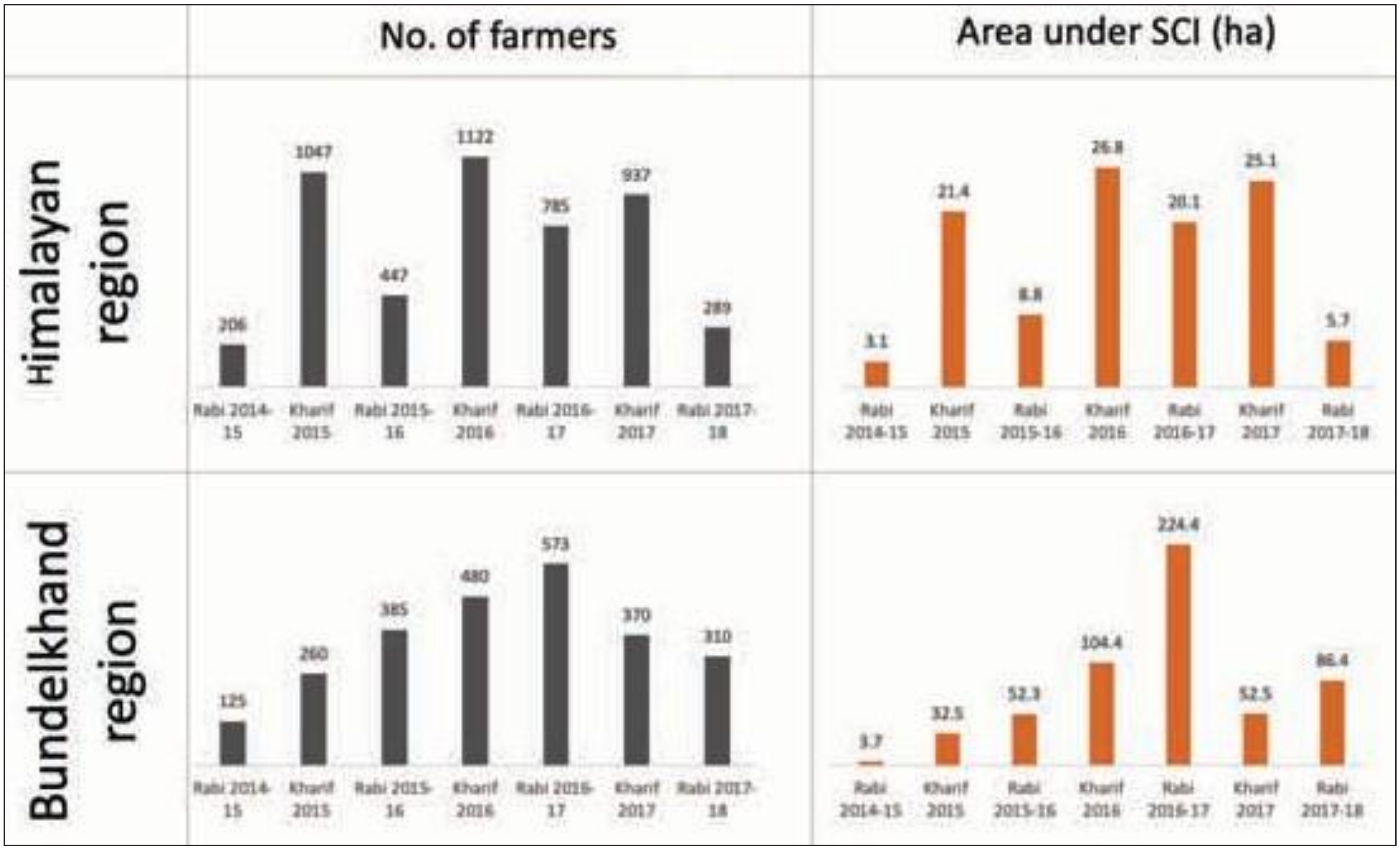
The Bundelkhand and Himalayan regions of India, representing two stark contrasting agro-ecological conditions with different climate change effects, bear similar vulnerability characteristics in terms of fragility, marginality, and inaccessibility. Climatic effects are further exacerbated by specific socio-economic factors like gender inequalities in the Himalayan region whereas a vicious cycle of indebtedness in Bundelkhand. Based on a decadal experience with System of Rice Intensification (SCI) and its applications on other crops by more than 50,000 farmers under varying agro-climatic conditions that include drought and flooding, this paper reports how agro-ecological methods help build climate-resilience for farmers in contrasting agro-ecological zones. The socio-technical approach building upon the experience and innovative capacities of farmers has proved to be effective in bringing multi-dimensional sustainability at household level.



Study area – Rudraprayag, Bageshwar in Uttarakhand and Panna, Madhya Pradesh

Methodology

This paper is based on action-research conducted in the given project locations. The timely empirical data over the period of 2014-2017 was collected at farmers' field level. The data for more than 1000 farmers from Himalayan region and 500 farmers have been collected through-out the cropping cycles of all the crops mentioned. The crop.



Summary of seasonal sample data collected from 2014-2017

Result and discussion

Analysis of 100 years' rainfall data for both regions shows high spatial and temporal disparity, increasing rainfall intensities and longer dry spells. In last decade, Himalayan region has witnessed frequent floods and cloudbursts. Bundelkhand has witnessed recurring droughts between 2000 and 2010 and erratic, high-intensity rainfall in 2011 and 2016. Despite extreme climatic conditions, SCI with appropriate variations proved to be promising climate-smart technique helping farmers minimize crop failure risks as well enhance yields.

Even in droughts and floods, average enhancement in grain yields has been in the range of 30 to 50 percent for rice (direct seeded and transplanted), wheat, kidney beans, chickpea, maize, etc. based on standard crop cutting exercise. Reduced production costs and increased production provided food security for an additional 3-6 months annually for small and marginal farmers. For Himalayan region, it was found that SCI practiced on only 0.5ha land on crops rice and wheat could bring the year-round food sufficiency (in terms of cereals). SCI practiced on cash crop like Kidney bean on 0.2ha per family can increased the annual income by Rs.50000 plus. Additional income was earned by farmers by reducing the production cost by 30%.

These experiences highlight the need to recognize and build upon farmers' innovative capacities to enhance their cropping resilience under varying climatic conditions. Experiments conducted by farmers illustrate that introduction of SCI involves many socio-technical

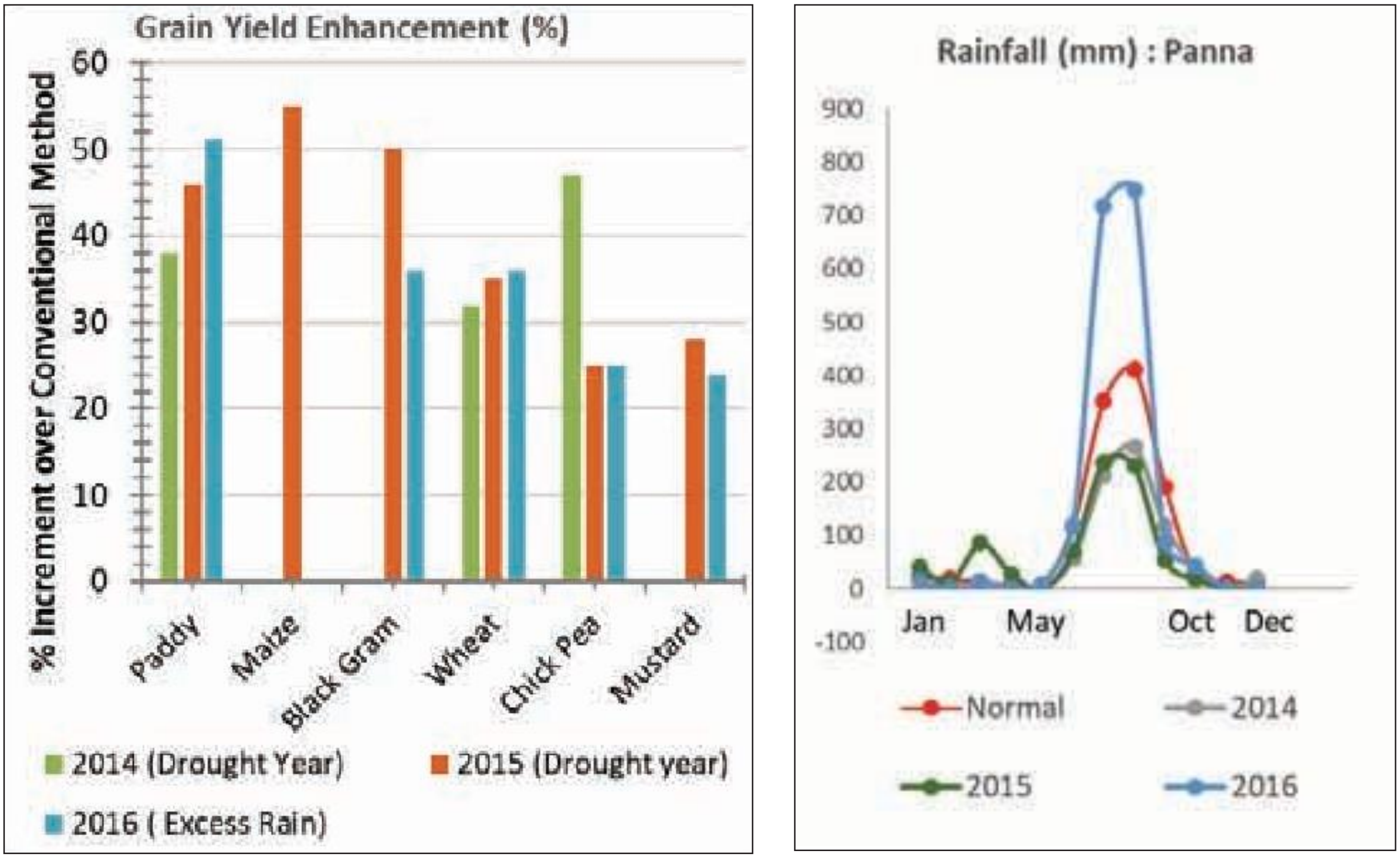


Figure 2: Grain yield enhancement from Bundelkhand region against the rainfall in those years

adaptation processes that are highly location-and farmer-specific. Any agricultural intervention needs to account farmers' existing practices and build upon their knowledge, experience, and skills. The **socio-technical approach of SCI** provides a foundation which with appropriate policy support can achieve the national goal of food and livelihood security.

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Rice-Based Integrated Farming System for Sustainable Coastal Agroecosystem of India

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Abstract

In comparison to industrial expansion, agriculture growth in recent years has been extremely slow. Future food demand is being impacted by the declining production of primary crops. Due to a modest shift of acreage for other purposes mainly industrialization and urbanization, net sown area in India has slightly declined in last two decades. A holistic approach is urgently required to generate positive growth rates in agriculture, particularly in coastal ecosystems. Sustainable agriculture aims to preserve the basis of natural resources, safeguard the environment, and promote wealth over a longer period. A farming system is a collection of agro-economic activities that interact and are connected in a specific agroecosystem. The term "Integrated Farming Systems" (IFS) refers to a strategic combination of one or more enterprise with crop production that produces complementary results through efficient waste and crop residue recycling and generates extra sources of income for farmers. The interdependent, connected, and interlinking production systems based on crops, animals, and related ancillary professions are what make up the IFS activity. Abundance of species diversity aids in improving soil health especially organic carbon, besides enhances ecological conditions, both of which are necessary for long-term sustainability of production system. Additionally, it inhibits the spread of pests and improves soil nutrient cycling. IFS approach with site-specific models offers gainful employment and is extremely profitable and sustainable in all environments. Along with IFS, other practices that promote fertilizer use efficiency include agroforestry, integrated nutrient management, and soil and water conservation.

Keywords: Ecosystems, Integrated Farming Systems, Rice, sustainability.

Introduction

Despite India fast economic growth, the rate of agricultural growth remained around 3 to 3% in last 20 years. This has been mirrored in the fact that major crop productivity is either stagnant or decreasing in majority part of India. With the espected population of over 1.6 billion and annual food demand of 400 Mt by 2050, the country requires minimum 4% annual growth in agriculture. The changing macro and micro-economies will also impact the demand and behavioral changes for food. There would be substantial increase in demand for quality products of fruits/vegetables and livestock. The challenges of environment protection and globalization shall put tremendous pressure on Indian agriculture. Climate change induced impacts on agricultural productivity pose the most imminent of such challenges.

Over 85 million out of 105 million of India's working farms are smaller than 1 hectare, and this number is falling (Paramesh et al., 2022). There is essentially no scope for horizontal growth of land for agriculture due to the country's declining per capita available land and ever-increasing population. The only way to expand vertically while providing farm families with decent returns is to integrate farming components that require less space and time. In order to increase farm output, lessen environmental degradation, enhance the quality of life for resource-poor farmers, and ensure sustainability, the Integrated Farming Systems (IFS) gain more relevance. A holistic approach is essential if agriculture is to maintain a positive growth rate. Conservation of the natural resource base, environmental protection, and increased prosperity over an extended period of time are the three main objectives of sustainable agriculture. A farming system is a collection of interconnected agroeconomic activities that interact with one another in a specific agrarian setting. The term "farming system" refers to a collection of farm businesses to which farm families allocate resources in order to effectively use the businesses already in place for the productivity and profitability of the farm. Crop, livestock, aquaculture, agroforestry, and agri-horticulture are the types of farms involved (Paramesh et al., 2019). Although crop and other enterprises coexist in such diversified farming, the main goal is to reduce risk, whereas in IFS, a thoughtful combination of one or more enterprises along with cropping has a complementary effect through efficient recycling of wastes and crop residues, which includes an additional source of income for the farmer. The primary focus of IFS activity is on a small number of interconnected, interrelated, and interlinking production systems based on plants, animals, and related auxiliary occupations. According to Paramesh et al. (2020b), the IFS would naturally produce more sustainably because residue from one sector becomes the input for another, virtually eliminating waste as a source of environmental pollution.

Rice varieties suited for lowland situations of west coast region

The farmers select the rice varieties depending upon the suitability to the ecology and local needs. In general farmers prefer coarse grain rice varieties due to their suitability to parboiling and milling in local mills (Manohara et al. 2020). ICAR CCARI has developed four salt tolerant rice varieties *viz*., Goa Dhan 1, Goa Dhan 2, Goa Dhan 3 and Goa Dhan 4 which are medium duration rice varieties, coarse grained, with yield potential ranging from 30-35 q/ha. These improved salt tolerant rice varieties giving 80-100 % more grain yield compared to traditional rice variety like Korgut and inturn increasing the net returns of the farmer (Manohara et al. 2019). Similarly, in rainfed shallow lowland ecology/medium lands, farmers mostly grow varieties *viz*., Jaya and Jyothi. The Jyothi rice variety is fetching premium price in market due to its red colour, and suitability for parboiling.

Table 1. Salient features of the four salt tolerant rice varieties developed at the Institute

Variety	Year of release	Duration	Grain type	Grain yield
Goa Dhan 1 (KS 12 / IET 25055 / IC629221)	2017 (SVRC release)	130-135 days	Short bold	Under high salinity condition - 30-35 q/ha Under normal condition- 40-45 q/ha
Goa Dhan 2 (KS 17 / IET 27825/ IC629222)	2017 (SVRC release)	125-130 days	Long bold	Under high salinity condition - 28-30 q/ha Under normal condition - 40-45 q/ha
Goa Dhan 3 (GRS 1 / IET 25051 / IC629223)	2019 (SVRC release)	120-125 days	Long bold	Under high salinity condition- 30-35 q/ha Under normal condition- 55-60 q/ha
Goa Dhan 4 (JK 238 / IET 27840 / IC629224)	2019 (SVRC release)	125-130 days	Long slender	Under high salinity condition - 30-35 q/ha Under normal condition - 50-55 q/ha

Integrated farming system in coastal ecosystem

Rice-based integrated farming systems

The wetland ecosystem that includes rice fields in the coastal region provides a variety of important ecological and economic activities that are advantageous to mankind. Diversified cropping is constantly on the rise, largely due to economic factors. Crop diversification is a useful strategy to boost crop productivity under various circumstances. It is meant to provide a larger range of options for production in a specific area to increase production-related activities on different crops (Manjunath et al., 2018). The frequent approach of expanding the system's base by including more crops in it is known as horizontal diversification. With a 300–400% increase in cropping intensity, this multiple cropping has allowed realizing a production potential of up to 30 t/ha/year (Varughese *et al*., 2007). The factors that influence crop diversification: I resource-related factors, such as irrigation, rainfall, and soil fertility; (ii) technology-related factors, such as seed, fertilizer, storage, processing, and marketing; (iii) household-related factors, such as the need for self-sufficient food and fodder as well as investment capacity; and (iv) institutional and infrastructure-related factors. The above is additionally impacted by farm size, tenancy agreements, research and extension programs, marketing strategies, and government regulatory laws. Farmers have long-established cropping systems for various agro-climatic zones based on factors like soil compatibility, profitability, market accessibility, and water control (irrigation/drainage) (Paramesh et al., 2020a). Relay cropping, intercropping, mixed cropping, reduced tillage, weed control, and the use of chemical inputs are just a few of the techniques that have assisted in cutting production costs while ensuring sustainability over a longer period. By enhancing the physical, chemical, and microbiological properties of soil and boosting soil fertility, scientific cropping techniques can raise soil productivity.

Integrated farming system for enhancing farm income, productivity, and employment

IFS offered scope to improve farm productivity by crop-livestock intensification and diversification in a small and marginal landholding. Differences concerning farm productivity between control systems and IFS were mainly due to higher crop intensity and livestock productivity. The IFS establishes linkages between components such as livestock, fishery, mushroom cultivation, apiary, and further leads to synergisms resulting in greater production efficiency. the IFS is a potential option in resource-deprived small and marginal land holdings to increase the system productivity and to meet the food and nutritional requirement of the farm family. Bringing crop diversification including cereals (energy), pulses (proteins), oilseeds, fruits and vegetables, and animal diversification in a small piece of land at the same time is imperative for achieving family needs.

IFS is considered a potential approach for rural bio-entrepreneurship and also an important tool to double the farmer's income in India. It attracts rural youth to adopt IFS as a potential entrepreneurship option (Behera and France, 2016). The IFS model involving different land-based enterprises generated net returns of INR 3,78,784 with about 3 times higher employment (628 man-days) than the conventional rice-wheat system. The by-products/wastes of one component in the system served as an input for the other which reduced the reliance on off-farm inputs aiding in strengthening sustainability. Rautaray et al. (2005) reported that the rice-fish model under lowland ecologies of Assam with vegetables, fruits, ornamental plants, and agroforestry components in dyke area produced 2.8 times higher income than rice alone. Nayak et al. (2018) observed structural variation in soil microbial diversity due to nutrient recycling (organic manures) with the production of planktons and macro-benthos in rice-fish-duck, rice-duck, and in the rice-fish system over conventional rice production system. In IFS, farm activities are continued around the year, thus the farm family is effectively engaged in farming. The adoption of such systems avoids the migration of farmers and rural youth to nearby cities and towns for the search of contractual employment. The specialized agriculture practices and mono-cropping increased production costs, risk of crop failure, and lower market price (Manjunath et al., 2017). Due to this, the small and marginal farmers migrated to neighboring cities in search of jobs and livelihood. In this scenario, IFS will be a solution to reduce economic risk with improved employment generation. Das et al. (2018) reported significant improvement in employment generation, income, and livelihood of the farmers in crop-fish-pig (pig-based IFS) and crop-fish-duck systems over crop alone.

Conclusion

It is concluded that the productivity of major crops is either static or declining in many parts of the country owing to various reasons. To sustain food security the approach of IFS is positive and will conserve the resource base through efficient recycling of residues within the system. Therefore, a farming system is a set of agricultural practises that are coordinated to preserve the ecological stability and desired degree of biological diversity while also protecting the productivity of the land and the quality of the environment. Sustainable agriculture would boost farm income, maintain ecological balance, make food easily accessible, provide social benefits, and improve the quality of life for agricultural communities through the efficient use of natural resources for higher productivity and production. The success of sustainable agricultural systems may be understood and strategies to increase production, profitability, and resource usage efficiency can be found by using an agro-ecological approach. The IFS models developed on ecosystems and sub-systems can be fine-tuned through farmer participatory trials with multilevel interventions of experts. The dissemination of such models will help in anchoring sustainability in agriculture.

Future thrusts

- Measurement of the amount of biomass produced by Integrated Farming Systems and its general effectiveness in achieving sustainability.
- Finding effective cellulolytic microbes for recycling crop waste.
- The effect of IFS on carbon sequestration and carbon buildup.
- The advancement of local farming communities' existing indigenous technology know-how (ITK), as well as its scientific validation and popularisation.
- Creation of on-farm research to find and use technology to address site-specific issues.
- Investment in community soil and water conservation; research and development of organic farming; establishment of small-scale companies; development of rural youth and farm women's skills

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Farmer-Scientist Interface for System of Crop Intensification in Maize and Finger Millet

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A pilot project on System of Crop Intensification was initiated in two agro-climatic regions of India, *i.e.,* The Western Himalayan Region (Solan, Himachal Pradesh) and Eastern Plateau & Hills (Koraput, Odisha) during *Kharif* 2019, to develop farmers' friendly approaches for finger millet and maize production through a farmer-scientist interface.

Concerned KVKs in the selected districts were involved in undertaking the SCI trials in their research farms while at the same time farmers in selected clusters of villages were motivated and trained to apply SCI practices in their own fields. Package of Practices (PoPs) and trials for different crops were developed with the help of IARI and KVK scientists.

The crop -cutting data from the trials undertaken is presented below.

Table 1: Results of SCI Trials on Maize from KVK, Solan, Himachal Pradesh

Plot No.	Plot Area (Sq. M.)	Practice Followed	Grain Yield (T/ha)	% Incremental Grain Yield
M1	200	Conventional	2.53	-
M2	200	Grid Spacing Line to Line: 60 cm Seed to Seed: 20 cm	2.62	4
M3	200	Grid Spacing Line to Line: 60 cm Seed to Seed: 30 cm	3.02	19

Table 2: Results of SCI Trials on Finger Millet from KVK, Koraput, Odisha

Plot No.	Plot Area (Sq. M)	Practice Followed	Grain Yield (T/ha)	% Incremental Grain Yield
F1	170	Conventional	1.102	-
F2	170	Line Transplanting Line to Line: 25 cm	1.444	31
F3	170	Grid Transplanting Line to Line: 25 cm Plant to Plant: 25 cm)	1.467	33

Table 3: Results of SCI Yields for Millet and Maize from Farmers' Fields

S. No.	Crop	Location, Farmers, Area	Average Grain Yield (T/ha)		SCI Practice Followed	Incremental Yield in %
			Conventional	SCI		(Average)
1	Maize	Solan, Himachal Pradesh Farmers: 216 Area: 4.01 Ha	2.58	3.06	Grid Spacing R-R: 30 cm P-P: 20 cm	18
			2.40	2.89	Grid Sowing R-R: 45 cm P-P: 30 cm	20
2	Finger Millet	Koraput, Odisha Farmers: 125 Area: 49.15 Ha	0.78	2.04	Grid Transplanted R-R: 25 cm P-P: 25 cm	162
			0.78	1.54	Line Transplanted R-R: 25 cm	97

Significant findings include:

- Incremental crop yields under SCI ranged from 4-20 per cent in Maize (Solan, HP) and 31-162 per cent in Finger Millet (Koraput, Odisha).
- All recommended SCI practices were not followed on a timely manner in the KVK farms resulting in lower yields than obtained from farmers' fields.
- Wide range of yields were obtained because of variation in adoption of SCI practices according to farmers' situations and field conditions.
- Limited weeders and their unsuitability to soil conditions hampered regular and timely weeding
- Sowing of seeds at prescribed space was a big challenge because of lack of equipment for grid/ line sowing.
- The cross visits of KVK scientists motivated them to undertake trials in their research farms while cross visits across villages provided a learning platform to farmers

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Scaling up of SRI (SCI) Method of Crop Cultivation in Bihar and Elsewhere in the Country

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Brief Overview

The Preservation and Proliferation of Rural Resources and Nature (PRAN) is an offshoot of the PRADAN, a nationally recognized public charitable Trust registered under Indian Trust Act 1882. It piloted a resource conservation technology and an Agro-ecological Innovation as a pro-poor option of food production locally called Sri Vidhi method of crop cultivation in Bihar. System of Root Intensification as called in Bihar or System of Crop Intensification called globally is a resource conservation technology in agriculture which has multiple benefits (tangible as well as intangible) over the Conventional Management Practices in agriculture (CMP). The intensive methods of CMP being nurtured by main stream institutions in agriculture through its research, extension and education, has been facing several negative externalities viz, productivity decline, inefficiency in resource use, severe market dependency, degradation of resources like land, water and biodiversity, which led to unsustainability. The salient features of SRI, a principle of "More with less" are as follows.

- It requires less inputs in agriculture such as seed, labour, water.
- The potential sustainability of the natural resources such as land, Water, Forest, animals, humans, i.e., the environment does not degrade.
- It produces more with less in agriculture.
- It enhances food security and enhance livelihood of small and marginal farmers of the country.
- It is an agroecological method branded as a climate smart practice, conducive under changing climatic situation due to global warming.

Figure : SRI method of Paddy cultivation bringing food security among millions of farmers

Figure : SRI-Rapeseed (RP-09 at Maturity)

Figure : Intensification of roots in wheat

Figure : Big panicles under SRI-wheat

Figure : Left (non-SRI-Wheat and right (SRI-Wheat)

Figure :Root of SRI-Rapeseed and Non-SRI rapeseed

Principles of System of Root /Crop Intensification method of crop cultivation

As the rural natural resources are declining, the rural livelihood is under threat. Adding to the worry is the declining land resources and of productivity land other factors of production. On account of unabated population, rural life is at stake. Therefore, a holistic approach is needed for increasing productivity in a different way. Because response to green revolution technology is confronting diminishing return.

The cutting-edge technology targeted the crop life above ground, and the mainstream R&D ignored the precious aspects of below ground activities. One of the bypassed factors is the root system and microbial life. Root means centre of core of life (as crop has life)/also the common meaning of root which is the mouth of the plant. The holistic approach of System of Root Intensification (SRI) is based on providing conducive environment to all parts of plant in special attention to its roots enabling full exploitation of genetic potential of the plant. It integrates all agronomic principles and practices with the specific crop at its critical stages (provided by nature and not by educated mass only), which is the primary consideration of promotion of System of Root Intensification method of Crop cultivation.

The entire method of SRI consists of following considerations as experienced by farmers/ practitioners. All seed/planting material/rhizomes/tubers/leaves are source of living creature that is plant. Detailed protocol is given below:

- The soil is the heart of these planting material needs to be honored and owned by practitioners /promoters/farmers also scientists the same way the human beings treat and conduct with animal kingdom and themselves.

- The innovative grading and selection of quality seeds should be done after its procurement from the source. It means that only quality and healthy seeds/planting material should be considered under the method.
- Since root is the main mouth of the plant the seed or planting material should get proper space, aeration, nutrition, moisture, microbial population, etc to grow close to its potential. The more the growth of roots and its consortium more nutrition and other items /factors it can take up and transfer to the plant for robust production. The size of the pit varies from crop to crop and plant to plant depending upon its nature and physiology.
- The package of practices should be integrated with phyllocron of crops. Young age seedlings/Sprouted seeds should be used spped up phyllocron. Priming of seeds/Beej Sodhan along with treatment should be integral part of Package of practices.
- The land is the mother of most of living beings including plants. The soil needs to be healthy and nutrient supplementation should be sustainable hence natural and organic nutrient management should be essentially integrated in the package of System of Root intensification method of crop cultivation. Like the nursery beds may be treated with Sribeejamrit and Srineemastra.
- Horizontal and vertical growth spaces should be appropriated by capturing its potential in local agro-ecosystem, genotypic characters, and soil and water conditions.
- The plant, right from planting material procurement, nursery raising and till harvesting should be in organic/emotional relationship with its promoters/ practitioners. It happens when the promoters / farmers/scientists/others regularly visit and take care for whole life period of the plant (sustained supervision).
- The enhancement of microbial biodiversity should be maintained to help every part of plant (stem, leaves, branches also) for its sustainable genetic expression.
- The plant should be transplanted/sown at a shallow depth to enable roots for proper uptake of nutrient and moisture which guides roots for early expansion of its rhizosphere in the soil.
- intercultivation cum weeding should be done at critical periods to ensure aeration, availability of nutrients in natural forms such as Srijeevamrit, Srighanjeevamrit and tonics made from natural extracts, moisture as this activity enhances tillering /branching ability of the main crops. Depending upon the crop/plant type the earthening up should be done to provide supportand better environment around roots and shoots.
- The pruning of leaves and early branches should also be done as per requirement of crops. For example, in Sugarcane the dry leaves should be discarded as it restricts thickening of canesett.
- In tuber crops eyes/nodes should be extracted and used for direct sowing after initial treatments. The seedlings may also be used as per nature and type of crops.
- There should be optimum moisture only andthe field should not be flooded. Water stagnation is harmful for SRI crops.
- Without compromising with food security and cash surplus to small and marginal communities in initial period integrated doses of natural, botanical extracts, natural pesticides, Plant Growth regulators and naturallyprepared fertilizers should be used.
- The diseases and insect-pests should be managed by physical, mechanical, natural and cultural control measures. In no case any chemical fertilisers or other inputs should be ever used during the cultivation of the crops.

Theme Building on SRI method of life and livelihoods

PRAN as a public Charitable Trust build capacity of large local cadres in various regions to take low cost and resource conservation technique to large number of farmers across India.

Capacity Building of grass root organisations on SRI: To spread knowhow about SRI, the PRAN trains stakeholders including staffs and farmers associated with different organisations. We run five days to ten days training programmes for grassroots organisations in situ and farmers on SRI method of crop cultivation as well as fertiliser and pesticides preparation for promotion of SRI method of natural farming system. The training includes motivational and technical components. Linking Principles of development as well as principles and practices of

SRI method of cultivation of various crops is important components of training. Practical demonstration on preparing local fertilisers and pesticides in villages is also a part of this training. Three to Five days in-house and two to Five days' field training are imparted to the participants. Many farmers and grass root workers from different civil societies are benefitted from the training modules.

Capacity building

PRAN gives special focus on building local cadres. For this the best practicing and socially prominent persons (male and female) identified by community are given rigorous training in four phases. In these 4 phases 75% training is imparted on motivational aspects and the rest 25% on technical aspects of SRI. This includes principles of development, principles of SRI method of crop cultivation, package of practices of SRI method of various crops, land measurement, positive attitudes and human behavior. All these trained cadres and officials are spreading SRI method of crop cultivation in various states of our country.

The students from Harvard University, Boston, USA; Gottingen University, Germany, Universities from France and Netherland sent their students to equip their skills and knowledge in SRI and working with the small and marginal farmers. Indian universities also like Amity University, TISS Guwahati, South Bihar Central University(Gaya), State Agricultural University sent their students to learn and acquire skills in SRI method of crop cultivation. The premier research institute of the country i.e., Indian Agricultural Research Institute (IARI), New Delhi under the chairmanship of Dr. B.C. Barah; NABARD chair professor, IARI New Delhi with group of scientists from agronomy soil science irrigation carried out experimentation on SRI paddy and SRI wheat for couple of years and found the method beneficial and climate resilient for the farmers.

Dissemination of SRI knowledge

PRAN rendered services in various kisan melas organised by department of agriculture and agricultural universities. Institute generates various materials on SRI in local languages of Hindi and English to various stakeholders targeting government and civil societies in state of Bihar and elsewhere, in villages and block headquarters PRAN distributes various pamphlets relating to SRI method of crop cultivation and organic products for fertiliser and pesticides preparation using the principle of local product using local resources. Various research institutes also get in touch with us and ask for SRI package of practices.

Awareness Events: Campaign

This year we were extensively engaged in capacity building of farmers through various events. First of all, we spread awareness among farmers in new villages through ricksaw Yatra, women promoters so that they can start SRI. In awareness events a group of 3-4 women in uniform of yellow sari go to a hamlet with big fur and pamphlets of SRI with prior information These Yellow Sari SRI farmers hang the fur on a wall or tree, sit below and start singing SRI-song. They start singing with a few but after listening to the songs the other women also join the SRI cultural event. After one song these yellow sari women discuss on experience and principles of SRI. Again, they sing a different SRI song there after they share the SRI methods in other crops. The audiences both women and men watching and listening to these women feel excited and ask for help from them in the coming season. The SRI vidhi songs which are the majorly used tools for campaigning are actually the step wise PoP of various crops and benefits from them. Therefore, the awareness spreading events are in themselves capacity building measures for farmers.

State Level Workshops

PRAN organizes State Level Workshops in Bihar Agricultural University, Sabour, Bhagalpur and also two state level workshops. The scientist in large numbers participate and get all documents and extension materials prepared by PRAN. Director Research, Director Extension Education along with scientists from all faculties participated in the programme. Representatives from civil society organisations also participated in the workshop. In Rajendra Prasad Central Agricultural University, Pusa, Samastipur also one state level workshop on SRI was organised where researchers and teachers participated actively.

District Level workshops

We organize district level workshops to sensitize the local officials. In all district level workshops Joint Director(agriculture), District Agriculture Officer, DDMs from NABARD and KVK scientists along with civil society organisations participated. In all these workshops we share most of the documents on SRI method of crop cultivation and also local fertiliser and pesticide preparation.

SRI cluster Adhivesans

We organise SRI Vidhi cluster adhivesans in operational districts and states. Public representatives, SRI farmers and officials participate in these events. Between 200 and 500 women farmers participate in each adhivesan.

SRI Vidhi Jhanki on Republic Day

On every Republic Day farmer, VRPs display innovations in agriculture in Gandhi Maidan, Gaya and in project blocks. We are happy that there is a public recognition of the effort, every year we are ranked among first three Jhanki. Jhanki display of all of our innovations in agriculture draws attention of minister, higher officials and public in general. All SRI implements, fertilisers, pesticides, solar irrigation model are part of our Jhanki.

Figure: Women farmers along with their male counterparts participating in SRI Vidhi Jhanki on republic day.

Public Policy Acceptance

The Government of Bihar adopted this policy

The BRLPS organized a big meeting of women SHGs with the Chief minister of Bihar on the occasion of 2nd October 2009 in S.K. Memorial Hall,Patna. The honorable chief minister for the first time saw a manual on ***SRI vidhi*** Genhun (SRI method of Wheat cultivation). He said "***are sri vidhi se gehun bhi hone laga hai"*** (aha, wheat is also grown through SRI method!). He spent 70% of his time allotted for stall visit on SRI stall. In his address to the SHGs and referring to the SRI method he said ***Khadyan samasya ka hal hi nikal ayega*** (It will serve as solution to our food security issue in the state).

During rabi season of 2009-10 ATMA, Gaya invited PRAN (the then PRADAN) to pilot one refinement, validation and adoption of technology of enhancing yield of oilseed through System of Root Intensification method of crop cultivation. The growth and progress of the crops were quite exciting. Again large number of various stakeholders visited the SRI-Rapeseed plot. Dr Poswal from Wheat Research Institute and other scientists from Directorate of Rapeseed Mustard Research Institute at Bharatpur, Rajasthan became interested in SRI methods and there was exchange of experiences with these institutions. The SRI-Rapeseed yield were very attractive to local government and they supported PRAN (then PRADAN) in managing a women farm schools in 11 blocks of Gaya for spreading SRI methods in Rapeseed. During this period Dr. B. C. Barah Chair Professor, NABARD at IARI, New Delhi also visited different villages under SRI programme. During rabi season of 2009-10, 15808 farmers adopted SRI method in wheat cultivation.

In 2010-11 **the chief minister of Bihar** had a plan to visit different parts of Bihar. The CM instructed his cabinet colleague **Dr.(Mrs.) Renu Kumari Kusawaha (the then Agriculture minister, Government of Bihar)** to see the early stage of SRI-Wheat plot in village Shekhwara under BodhGaya block. She visited the plot at late in the evening at 9.00pm. Having known her intention to visit farmers' fields, I had arranged a generator for facilating her to properly inspect the plot of SRI-Wheat and Traditional wheat. She also interacted on experience of SRI-wheat farmers particularly women. After her visit, a high-power group of state level officials including the then Agriculture Production Commissioner, Principal secretary, Planning, Principal secretary, Animal husbandry and Director, Directorate of Rice Development, Ministry of Agriculture, Government of India along with divisional commissioner and district magistrate visited the SRI-Wheat plot and observed closely the low-cost vermicomposting in the field. The experience of all the officials were quite enriching and useful. Then government of Bihar decided to conduct a special experiment of SRI-Paddy with 5 farmers each in every district. The government invited PRAN (then PRADAN) to act as resource in different divisions. We deployed village women to train the farmers and officials of the department. Even adverse effect of severe draught in 2009-10, could not change the excitement and confidence of farmers towards SRI.

Figure: The then Agriculture minister along with state and district officials listening experiences of SRI-Wheat and also visiting SRI-wheat plot in Gaya

Figure: The then state minister of rural development Mrs Agatha Sangma, Government of India also visited the SRI-Wheat during harvesting time.

On January 2011, the chief minister launched SRI kranti programme in Bihar.The programme started with a SRI song sung by our participant families. We had put a stall and acted as technical resource agency on SRI on that occasion. As many as 2600 SMS (subject matter specialist) and District Agriculture Officers of different districts along-with ICAR and NABARD participated in the programme. The government planned to take SRI in 3.5 lakh hectare. The government is still continuing with its programme on SRI methods in Paddy and wheat. The then Director, BAMETI (Bihar Agriculture Management Extension and Training Institute) Dr. RK Sohane (now he is Director, Extension Education at Bihar Agriculture University, Sabour, Bhagalpur, Bihar) played a crucial role in organizing training and workshops in all divisons and districts of Bihar. The print media and the local electronic media played a crucial role in making the environment. At Patna SRI farmers like Jayjeet Kumar, Barati Devi and Sunita Devi and many others shared their experiences at the highest level. In all the thirty-eight districts of Bihar a team comprising of two village women and one man from different villages of SDTT project shared their experiences, provided training on SRI and demonstrated seed treatments before officials and KVKs. In 2011-12 there was a good rain, therefore large number of farmers under SDTT project turned up for SRI-Paddy during kharif.

Figure: The chief minister of Bihar, Mr. Nitish Kumar understanding SRI methods at Patna and inauguration of SRI Kranti at S.K.Memorial Hall,Patna

Scaling up of SRI Crops in Bihar and elsewhere

- Bihar Rural Livelihood Promotion Society (BRLPS), Patna has scaled up SRI/SCI with 1.50 million Small & Marginal farmers in the state.
- Govt. of Bihar through its Deptt. of Agriculture has continuously been promoting SRI since 2011 and has recruited 4000 officers and 8000 Krishi Salahkars for its scaling up. So far, Govt. of Bihar is involved with 2.0 million farmers.
- Civil societies are working with 0.30 million farmers and promoting SRI with them.
- PRAN has prepared 12000 cadres from 10 states and 4000 officials (Govt. & Non-Govt.) from various states to promote SRI of natural farming.
- Bharat Rural Livelihood Foundation (BRLF) through its partners across 0.50 million farmers.
- UPSRLM, Rajasthan SRLM, MPSRLM and NRLM New Delhi are involved in scaling up of SRI/SCI among small and marginal farmers.
- Before introduction of SRI in Bihar the maximum production of paddy in a year was 4.60 million tons whereas after introduction of SRI in 2020-21 it is 10 million tons.

Outreach in direct project by PRAN

PRAN has a direct SRI project being implemented with support from SDTT, Mumbai; TATA Trust, APPI, UNICEF, ASHOKA, IIFL SAMASTA, UN Women, Govt. Deptt. (State & District), United Way etc. It provides training to all stakeholders who are in to SRI work.In our direct project the coverage is as under.

PRAN has promoted SRI method of crop cultivation in Gaya, Nalanda, Nawada, Madhubani, Aurangabad in Bihar; Varanasi and Jaunpur in Uttarpradesh and Simdega & Gumla districts in Jharkhand. In these areas PRAN has worked directly with small and marginal farmers. PRAN has also demonstrated SRI non-directly with Bharat Rural Livelihood Foundation, New Delhi partner organisations spread over in states of Jharkhand, M.P., Chhattisgarh,

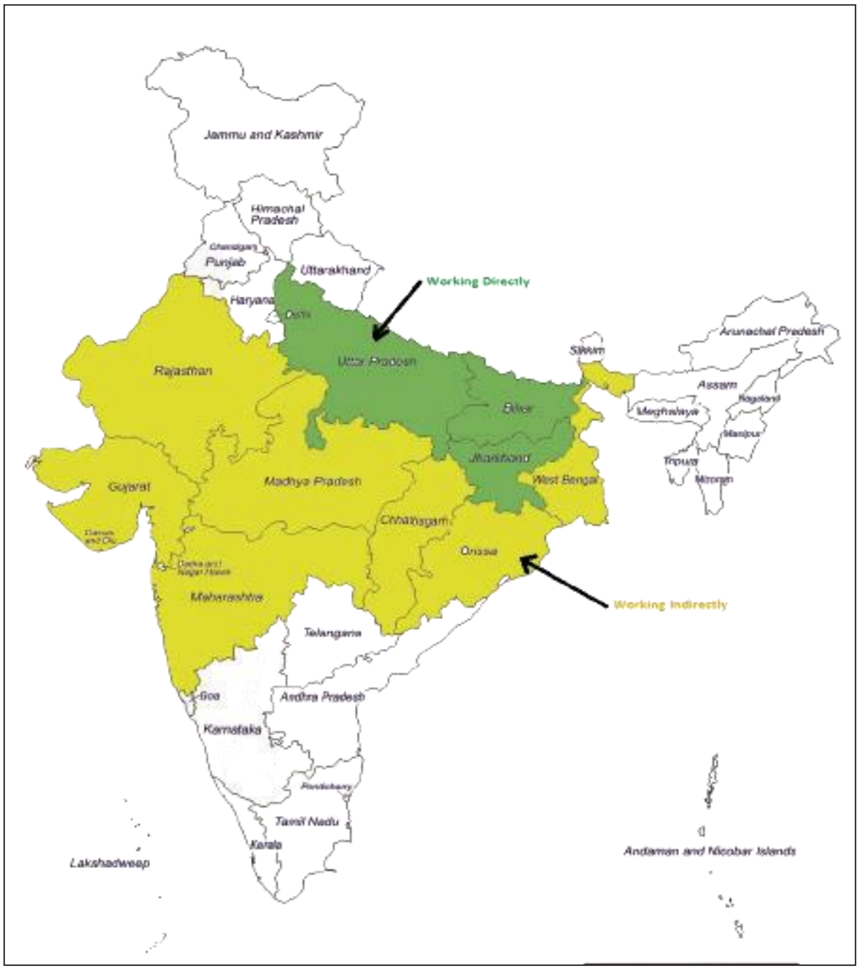

Figure: Map showing location where PRAN has worked directly or indirectly

Rajasthan, Gujrat, W.B., Orissa, Maharastra by placing its staffs and cadres with all the partners of BRLF. PRAN has created 2400 cadres on SRI in all these eight partners' states of BRLF. These cadres and various partner organisations such as BAIF, PRADAN, FES, SRIJAN etc. are involved in scaling up of SRI in their operational districts and states.

Impact analysis

The PRAN is happy to report a highly satisfying social impact with intervention of SRI as illustrated below. Multiple benefits achieved by the farmer communities:

S. No	Pre-deployment of SRI method of crop cultivation	Post deployment of SRI method of crop cultivation
1	Most of the families, food production in their own farm was sufficient for only for 3-6 months	Most of the families getting food grain security round the year
2	Earlier dependent on mahajans for credit in hours of need.	Those who are practicing SRI method of crop cultivation in cereals, vegetables are getting cash income apart from food grain security
3	The indiscriminate use of pesticides and chemical fertilizers.	They reduced the use of chemical fertilizers and pesticides.
4	The farmers were not using locally prepared fertilizers and pesticides	The farmers started using locally prepared organic fertilizers and pesticides

S. No	Pre-deployment of SRI method of crop cultivation	Post deployment of SRI method of crop cultivation
5	The poor farmers particularly Mahadalit were forced to migrate in search of food	SRI has reduced forced migration among SC communities in remote villages.
6	Earlier the farmers were using 40kg of Paddy seeds per acre, 54-81Kg of wheat seeds per acre and 7-8 kg of oilseeds per acre	Now they are using 2kg of Paddy seeds per acre, 10 kg of wheat seeds per acre and 250gm-1 kg of oilseeds per acre.
7	The Mahadalit community were taking only alternate meals to survive.They used to skip the meals.	The mahadalit community adopting SRI are getting balanced and sufficient diet daily.
8	Earlier farmers were purchasing fertilizers and pesticides only from market	In many villages farmers are themselves preparing vermicompost,local fertilizers and pesticides.
9	The women in villages were reluctant in speaking to outsiders	These village women are in the fore front and shown that they are capable of handling outsiders. They are also going to other districts and state to train officials and farmers on SRI.
10	Earlier the farmers were getting poor quality grains and vegetables to eat	The farmers and families are getting quality grains and vegetables to eat
11	Earlier all scientific institutions were opposing SRI	Indian Agriculture Research Institute and several others have started appreciating SRI
12	Earlier Bihar production of rice was only 4.6 million tones in a year	After introduction of SRI, Bihar produced 10 million tons of Paddy and won Krishi Karman award from President of India for high paddy production deploying new method

The SRI method of Paddy, wheat and Parali Integrated SRI Wheat cultivation has helped small and marginal farmers to attain food-grain security. Those small and marginal farmers who were having low productivity of 1.5 to 2 tons/ hec are now getting 6-7tons/hectare. Even if a farmer has half an acre own land is getting sufficient food grains to meet the household requirement.

PRAN builds local cadre through phased training. The best practioners are identified by community and PRAN who in turn undergo phased training on SRI method of paddy cultivation. After 4 phases of training the farmer (Women or men) become Village Resource person(VRPs). One Village Resource Person provides training and handholding support to 50 small and marginal farmers in a village or a hamlet. We have large numbers such village Resource Persons 90% of them are women.

These Village Resource persons in SRI cluster of 25-30 hamlets organize weekly review and planning meeting where our Skilled Extension worker chair the weekly meeting. the status of fields of all farmers of a Village Resource Persons is segregated in to very poor, poor, average, good.18-20 Village Resource Persons are required to attend weekly meeting every week round the year. The group of Skilled Extension Workers are supported by Subject Matter Specialist(SMS) cum Project Managers and Project Supervisors. These Project Managers and Project Supervisors along with Executive/Project Leader/ Executive Director form Technical Resource Team of PRAN.The technical resource team of PRAN reviews the programme monthly.The agronomist of PRAN trains its staff and also builds capacity through training at Indian Institute of Horticultural Research, Banglore and other organizations.

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Adept to Adapt: Closing the Gender Capacity Gaps for Scaling Up System of Crop Intensification

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Abstract

The system of rice intensification (SRI) has been introduced as an alternative system for growing rice with lesser inputs and water. Labour is one of the most crucial concerns in the adoption of SRI by farmers. The adaptation to newer methods of rice cultivation is presumed to be easier if the workforce is adept to adapt. The new skills needed to adopt SRI, are transplanting young and single seedlings and use of mechanical weeders. The present study was therefore, undertaken, to identify training needs of women farmers in SRI cultivation. Line sowing was perceived as a new skill to be acquired and rated as highly skilful. Close attention was needed by women farmers/labour to systematically plant within the square. The paper attempts to apply the components of the community capitals framework (CCF) developed by Cornelia and Jan Flora (2013), for closing the gender capacity gaps in the uptake and scaling up of SCI/SRI**.** The seven forms of capital in this framework are considered not only as individual capabilities and endowments but are viewed as collective resources and are to be considered in the specific order of natural, cultural, human, social, political, financial and built capital. In this paper emphasis is being given to build the Human and Social Capital for closing the gender capacity gaps for scaling up SCI/SRI. There is immense scope of harnessing the potential of training members of women's self-help groups (SHG) to form a SRI task force to help in the wide spread adoption of SRI by farmers

Keywords: gender capacity gaps, SCI, SRI, group approaches, scaling up

Introduction

The adoption of Sustainable Crop Intensification (SCI) and System of Rice Intensification (SRI) technologies is dependent on the farm and farmer attributes apart from the technological innovations. Farming system intensification efforts need institutional innovations to link farmers to markets and other support services apart from technological changes. Technological innovations need to be promoted taking into account the existing cropping systems, natural, social, and economic resource base, skill sets, and risk taking capacity of the farmers. Globally women play a vital role in the food systems as producers, processors, and food providers for the family and are more vulnerable to disruptions in the climate and food systems. The capacity of women farmers to adopt new technologies and cropping practices is constrained by their low access to economic and social resources. Identifying and closing the gender capacity gaps will facilitate the adoption of crop intensification technologies.

The System of Rice Intensification (SRI) is a set of good agronomic practices of growing rice by using less seed, labour, land, and water. Farmers need technical support to adopt the SRI practices as SRI is knowledge-based (Styger *et al.,* 2011). Labour is very critical to the adoption of SRI and skill enhancement of labour for transplanting young and single seedlings is very important.

Capacity as defined by UNDP is the ability of individuals and organizations or organizational units to perform functions effectively, efficiently, and sustainably (UNDP 1998). The paper attempts to apply the components of the community capitals framework (CCF) developed by Cornelia and Jan Flora (2013), for closing the gender capacity gaps in the uptake and scaling up of SCI/SRI**.** The seven forms of capital in this framework are considered not only as individual capabilities and endowments but are viewed as collective resources and are to be considered in the specific order of natural, cultural, human, social, political, financial and built capital. In this paper emphasis is being given to build the Human and Social Capital for closing the gender capacity gaps for scaling up SCI/SRI.

Human capital entails the literacy level, skills, abilities and knowledge and gendered disparities that exist with respect to human capital based on prevailing social norms. Women farmers in most of the developing countries are disadvantaged by lesser years of schooling due to various socio-economic reasons. Moreover, skills are taught by family members based on gender with emphasis on home care skills for girls even though they are employed in farm activities. With men migrating for work, more and more of the productive activities are being performed by women farmers. There is an urgent need for skilling of women farmers in SCI, SRI and climate resilient farm practices and technologies. The skills for agricultural activities are acquired by women farmers mostly informally and inter-generationally, through non-formal means and by attending semi-structured training programs organized by NGO, KVK (farm science centres), and agricultural universities/ institutes (Soundarya and Nitya, 2022).

Social capital refers to the interactions among people, their shared norms and support groups. Of the two dimensions of social capital *viz* bridging and bonding, women form associations and collectives by using bonding social capital. The bridging social capital is used to link the local groups to receive technical support. The barriers to bridging and bonding social capital are influenced by cultural and political capital. The local bonding and bridging networks of women can be effectively targeted for community adaptation. Women's networks are mostly informal, and often ignored by external agencies providing assistance for adaptation. Capacity building of women's collectives is essential to build the resource base and skills of women farmers and prevent elite capture of training opportunities by male members of the community.

Capacity building approaches for scaling up SCI/ SRI

Closing the gender capacity-building gaps for scaling up SCI/SRI is being proposed based on the community capitals framework (CCF) developed by Cornelia and Jan Flora (2013).

Building Human Capital: Training needs of women farmers in SRI cultivation

The gendered division of SRI activities has been reported by many researchers. Based on the training needs identified for SRI adoption (Waris, 2017) it is highly imperative to train women farmers in different aspects of SRI practices to build their knowledge and skills to ensure the widespread adoption of SRI. Farmers need to pay more attention to crop establishment, the use of younger seedlings, the need for timely transplantation and timely weeding, and better water management (Ravindra and Bhagya Laxmi, 2011). Long-term and comprehensive skill-based training in the specific SCI/SRI activities are to be organized to build the capacity of women farmers

Creating a skilled SRI task force of women farmers

There are several constraints for farmers to shift to SRI. Some of these constraints can be overcome with training support. Subhashini *et al.,* (2013) opined that training a cadre of women labourers in every village can help spread SRI and also provide a good income for the women. The training institutions like, Krishi Vigyan Kendra, Farmers Training Centre, and other research institutes need to design skill-based training programs for labour to develop their expertise in pulling out and transplanting young seedlings. There is immense scope of harnessing the potential of training members of Women's Self-Help Groups (SHG) to form a SRI task force by

- Providing long-term and comprehensive skill-based training especially in line sowing and uprooting very young seedlings.
- Training a cadre of women laborers in every village can help spread SRI and also provide a good income for the women.

Building social capital: Group approaches to scale up SRI cultivation

The collective action of women SHG members could be harnessed for faster and widespread adoption of SCI/ SRI as the group approach is being perceived to have the potential to reach women directly for the dissemination of improved technologies. There has been ample evidence to show that strong women's groups contribute substantially to the development and convergence of services and activities. Women farmers can be trained to supply skilled labour for seed preparation, nursery, transplanting, and also using mechanical weeder through the formation of SRI-SHGs

- Self Help Groups (SHGs) are playing a major role in poverty reduction and women's empowerment through financial inclusion.
- SRI can help them in meeting their food grain requirements along with the conservation of resources

- SHG monthly cluster meetings are an important avenue to train farm women in SRI practices
- Training of selected members from each SHG in batches

Gender norms, resources, and agency in inovation uptake

The design, development and promotion of improved technologies and interventions has to consider the differential needs, priorities and barriers faced by both men and women in the adoption of these technologies (Doss, 2001; Kingiri, 2010; WB, FAO, and IFAD, 2008). Moreover, a farmer's gender can affect the adoption of new technologies and crop varieties (Doss, 2001). Intra-household gender dynamics, responsibilities, knowledge level and position in the household also have an influence on the adoption/dis-adoption of technologies. Young women farmers, in the presence of older women at home may have very less or no agency in technology adoption decisions. Women farmers are constrained in adopting new technologies and interventions primarily due to restricting gender norms, lack of access to land, capital, credit and information (Krishna *et al.,* 2020; Nyasimi and Huyer 2017, and Zonibel Woods, 2022).

Gender targeting of extension and advisory services/remodeling the dissemination systems

Women farmers need to be provided with extension and advisory services as studies have indicated their positive influence on the innovativeness of women farmers (Badstue *et al.,* 2018). Acknowledging women as farmers and not as helpers of men farmers and counting them in the design of technological interventions is essential (Devkota *et al.,* 2015; Badstue *et al.,* 2020, Soundarya and Nitya, 2022). The lack of access to extension services by women farmers needs to be addressed to design programs based on their needs to upgrade their knowledge and skills (Zonibel Woods, 2022). Gender-specific barriers to technology adoption need to be studied for increasing the adoption of crop intensification practices and technologies.

Promoting labour-saving and productivity-enhancing technologies

The gendered division of agricultural activities necessitates the development of labour-saving and productivity-enhancing technologies for women. Socially and culturally women have not been encouraged to use mechanical options in planting, weeding and harvest operations. With increasing feminization, the need for women-friendly implements is gaining traction and intensive training is to be imparted to women farmers for the use and repair of agricultural machines. Mechanized SRI operations have been demonstrated successfully and women farmers need to be trained in the use of machinery.

Gender-responsive information services and products

Women farmers often lack access to information and communication technologies like the internet, YouTube, mobile phones, and other social media options which hinders their ability to access information on SCI, SRI, climate-resilient practices and acquire skills and resources to use this information. The differential access to ICTs is primarily due to lower literacy levels, socio-cultural norms, and gendered division of labour. Bridging the gender digital divide may be attempted through roping in mobile service firms to provide low-cost handsets to women's groups as a part of their CSR initiative.

Conclusion

The adaptation to newer methods of crop cultivation is presumed to be easier if the workforce is adept to adapt it. Reskilling and upskilling programmes are important for the capacity building of women farmers due to the increasing feminization of agricultural work. More investments and customized training programs are needed for capacity building of women farmers to adopt SCI/SRI and other climate-resilient practices.

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Theme VI

Policy Needs (at State, National and International levels) for Scaling Up SCI

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Policy Options for Scaling-Up SRI

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Abstract

The challenge of increasing food production, in the context vertical expansion through improved productivity per unit of land area under the situation of adapting to the changing climatic conditions that impose water scarcity and Green House Gases (GHG) emissions from the rice fields. Many research findings showed that SRI method outperforming in terms of yield and reduction in cost of cultivation along with several perceived ecosystem benefits. Finally, the researchers suggest for further promotion and scaling up of the SRI method in suitable regions of India is highly imperative. SRI is knowledge and experience-based method of rice production than input centric technology. The SRI method has been piloted in most of the countries and a section of farmers realized its full or partial potential but they are reluctant to spread their success with their fellow farmers. It is right time to undertake a few studies by the behavioural scientists to nudge this innovative method of SRI among farmers to the niche paddy growing areas. Grain yields reported from field experiments carried out in different parts of India showed yield increases ranging from 9.3% to 68% as compared with conventional practice. The Ministry of Agriculture that included SRI as part of the National Food Security Mission in 133 food-insecure districts. The research wing of SAU should evolve new or modify the available transplanters and weeders for the exclusive mechanization under SRI method. The beneficial effects of SRI like water-saving, use of less inputs and reaping higher benefits by SRI technology should be made aware among farmers through demonstration. The scaling up of SRI needs to be buoyed out by the joint efforts of State Agricultural University Researchers, ministry of Extension personnel's, not for profit organizations with farmers. Upscaling of SRI strategy will help achieve national as well as household food-security. This paper clearly describes the role of every institutional responsibility in reaching the unreached.

Keywords: SRI, Scaling-up, Role of SAU, Department of Agriculture, Yield.

Introduction

India has the world's largest area of rice cultivation area (44 million ha) and is the second-largest rice-producing country after China. Our country will need to produce at least 130 million tons of milled rice per year by 2030 in order to feed the growing population. The current level of production is 124 million tons.

The challenge is not only to increase food production despite the limited scope for expanding cultivated land area and greater constraints on water supply for the agriculture sector, but also at the same time to enable Indian farmers to adapt to changing climatic conditions. These conditions impose water scarcity and more extreme events of flooding, storm damage, extreme temperatures, and pests and diseases without loss of yield. There must also be reductions in the emission of climate-altering greenhouse gases (GHG) from farmers' rice fields.

The System of Rice Intensification (SRI) is a new system to increase food production and security with reduced inputs and lessng with lesser GHG emissions. SRI is neither an improved variety nor a technology. SRI is an amalgamation of Best Management Practices (BMP) relating to seedling age grid planting and to the management of irrigation, weeds, and nutrients. The effectiveness of the changes that SRI introduces into age-old practices is already proven through various research programs and endorsed by the uptake that has started in over 60 countries around the world.

The magnificent transformation can be found, in the roots of crop plants that grow more abundantly and robustly under SRI management, not just for rice crops but in other crops as well. This has prompted some in India to rename SRI as 'the system of *root* intensification.' Changes occur particularly in the rhizosphere region around the roots, enabling roots to use the nutrients that are inherently available and externally-provided in the soil more efficiently.

In most of the Indian states and in other countries, the performance of SRI has been proved beyond any doubt under farmers' actual conditions to be superior as compared to present practices, based on demonstrations laid through central/state Government initiatives and through various international funding organizations. In addition to raising yields, SRI can reduce farmers' costs of production and their water requirements, with crops that can better withstand the growing stresses of climate change - water shortage and unreliability, storm damage, pests and diseases, and extreme temperatures.

The acceptance and sustainability of SRI is mainly dependent on changes in the behaviour of farmers rather than on increasing in applying of external inputs, making better use of the land, labour, water and seeds that farmers have access to. Under SRI, the synergy of its BM practices exploits more fully the genetic potential of the variety of rice. The scaling up of SRI with other farmers requires better understanding, new knowledge and skills, and a more modern management perspective on the tasks of farming, being willing to innovate and to make decisions based on observable, measurable results.

Despite the additional opportunity that SRI gives to produce more output with less inputs, relying more on natural processes and interactions. SRI also to reduce the generation of greenhouse gases, we find that the adoption and scaling up of SRI by rice farmers in different parts of the world and in India remains lower than warranted by economic and environmental considerations. While SRI falls clearly under the Government's commitment to 'natural farming,' there are yet to be nudging the policy-level initiatives that would scale up SRI as Climate-Smart Agriculture practices in a larger way, making appropriate adaptations to local agroecological circumstances.

Based on the experience gained during the rapid expansion of SRI use under a 'mission mode' approach followed under the World Bank-funded IAMWARM project in Tamil Nadu, where this use expanded from very low levels to 3,70,000 hectares within seven years, I would like to put forward a number of suggestions. This methodology is worth expanding in India and elsewhere because of the multiple benefits that SRI use exhibited on a large scale. A thorough third-party project evaluation like M&E, Independent Evaluation Group (IEG) and Inception Completion Results Review (ICRR) by World Bank reported that:

- **Paddy yield** had been increased by **22%** on average, even without all of the farmers using the recommended methods fully or carefully.
- **Water consumption** was reduced by **24%**,
- **Costs of production** were cut by **16%** on average.
- Farmer's **net economic returns** were increased by **45%** as a result of their producing more with less cost.
- Of economic and environmental interest, **energy consumption** was reduced by **37%**, and
- **Expenditure for labour** was diminished by **17%** on average, contrary to the stereotype that SRI is more labour-intensive.
- The project in Tamil Nadu did not focus on climate effects, so greenhouse gases were not measured, but a concurrent study by Oxford and Indian researchers in the neighbouring state of Andhra Pradesh calculated, doing Life Cycle Analysis, the SRI management reduced **greenhouse gas emissions** were cut by **40%**.

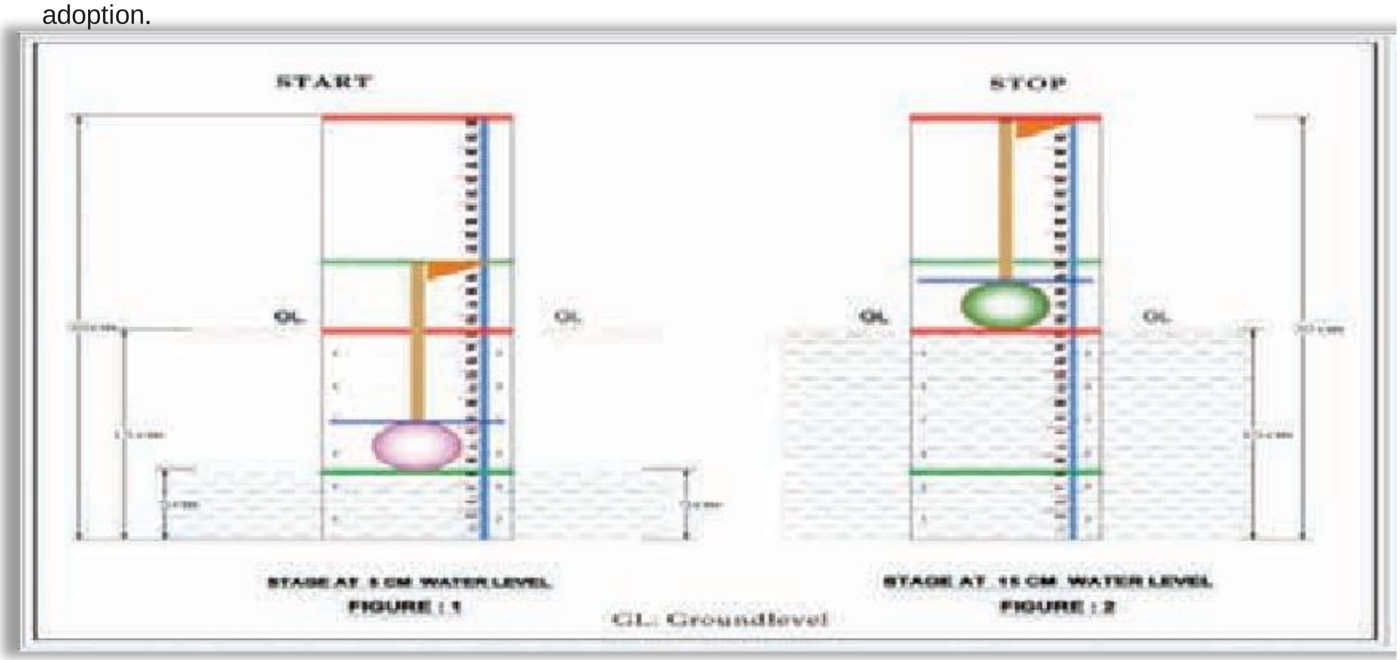
Before going into policy recommendations for the scaling up of SRI, I want to mention some of the constraints that can be identified at the grass root level as affecting the adoption of SRI practices in larger scale.

Constraints to adoption and up-scaling SRI

1. **Changing farmers' perceptions towards SRI:** Planting 10 -15 seedlings per hill is a traditional practice for many decades under conventional rice cultivation. At first, farmers' minds balk at transplanting very young seedlings, even 14 -15 days' old fearing for their survival. Moreover, farmers have a hard time believing that 16 plants per sq. m. can produce more crop than 50 plants, or 75 plants, or 100 plants in that same space. Having wider spacing between plants is perceived as a waste of land area. Farmers' apprehension is not replaced easily by words or even numbers. They need to *see for themselves* that the new practices are beneficial, as probably 20 million farmers in dozens of countries have seen. Persuasion i.e., seeing and believing requires demonstrations rather than lectures or exhortation.
2. **Lack of proper machinery for implementing mechanization:** Even when farmers are willing

to practice SRI, they will face some skilled labour constraints, at least at first. Much of rice production in India right now is quite labour-intensive, and for such farmers, SRI becomes labour-saving, once the methods have been learned, and skill is gained. But both transplanting and weeding are laborious operations, and SRI will become more attractive if there were site suitable transplanters available for planting one or two seedlings, as well as proper implements for inter-row weeding; and laser-levelling to enable farmers to practice alternative wetting and drying (AWD) more efficiently and to save more water, etc. The shortage of skilled labour for grid transplanting at the right time discourages farmers from switching over to this innovative system with confidence. So, there are equipment bottlenecks that need to be addressed as these constrain the practice of SRI on a large-scale adoption.

3. **Supply of irrigation water and power**: As most of the irrigation schemes in the lowland rice areas are partially dependent on drawing ground water using electrical power which is free of cost. Irrigating at the right time is constrained by frequent power cuts in the irrigation areas. This deters farmers from applying AWD (a component of SRI), since they are not sure when the power will come, and for how long it will last. Although SRI requires less total water, farmers need to be confident that the smaller deliveries of water will be *reliable*. The hardware and software of irrigation management need improvement to produce more rice with less water. Installation of Crop Water Assessment Device is a behavioural science-based nudge practice to convince the farmers minds towards water stagnation is not mandatory.



4. **Inadequate extension and climate-change awareness:** The local farmers are generally convinced about its yield increase but lack knowledge of SRI principles and applications, related to its long-run benefits for abating climate change. This reflects weakness in the present extension services and a lack of proper capacity-building. Both training and education are needed to bolster behavioural change.

5. **The unlevel playing field between organic and inorganic soil fertilization:** For decades, Indian farmers have relied heavily on chemical fertilizers, especially nitrogen and phosphorus. These have been heavily subsidized by government, accumulating large fiscal burdens on government. At the same time, the carbon stocks in Indian soils have been depleted, often to less than 1% when levels of 3-5% are desirable. There is no subsidization of organic fertilization of the soil, which would restore higher carbon levels (sequestering carbon in the soil which counters global warming), as well as support better yields and make the use of inorganic soil amendment more productive. Much as the lack of appropriate implements and tools is a constraint on SRI adoption, the lack of such equipment for replenishing the soil's carbon stocks with compost, mulch and other organic materials is a constraint.

Recognizing that there are many benefits to be derived from converting rice and other crop production from current methods that are less productive and costlier, in environmental as well as economic terms, it is important that we give thought to national policy frameworks that can make the transition to more agro ecologically-based food production quicker and smoother.

There are no, or at best weak, national policy frameworks for supporting the dissemination and uptake of water-saving technologies such as SRI in the rice-growing countries of Southeast and South Asia, including India. Although SRI was introduced to India some 20 years ago, there are still some controversial issues raised by farmers, researchers, and policy-makers. These issues should be addressed in open, fact-based discussions, possibly under the auspices of ICAR. Also, SRI and the associated SCI methodologies for other crops like wheat, ragi, sugarcane, mustard, etc. should be considered within the scope of the new national policy for *'nature farming'* which minimizes expenditures and reliance on agrochemical inputs. That is why this international conference has been framed in broader terms than just improving rice production with SRI practices.

SRI's performance in increasing adaptation to climate-change impacts, reducing GHG emissions while increasing yields and food security, makes it more urgent to promote these ideas and practices: The practice of SRI supports the three core principles of *climate-smart agriculture* (CSA), (i) increasing adaptation to climate change (making crop production more resilient), (ii) mitigation of greenhouse gas emissions, and (iii) improving agricultural production and food security.

That SRI qualified as climate-smart agriculture practice has been seen from research results and in-field experience in more than 20 rice-growing countries of Asia, and now extending to Africa and Latin America. Of growing interest is the capacity of SRI practices to reduce the generation and net emission of greenhouse gases, particularly of methane (CH_4), while at the same time increasing crop yield. All countries need to move to more climate-smart agriculture, but for India, this is particularly urgent because of the water shortages already confronted and the silent crisis of soil degradation and soil health that threatens India's future.

Scaling Up SRI : Grain yields reported from ICAR and other field experiments carried out in different parts of India have showed yield increases from SRI ranging from 9% to 68% when compared with conventional current practices. The System of Rice Intensification (SRI) has shown an unprecedented capacity to produce 'more with less'-more crop per drop. The Government has been generally positive in extending its support to the promotion of SRI, starting with the National Food Security Mission and then the National Rural Livelihood Mission, and now with its support for 'nature farming'.

Unfortunately, the process of up-scaling SRI on a massive scale has been relatively slow, owing to multiple constraints in its promotion and the management intensity involved. The integrated nature of SRI also presents multiple challenges in the areas of research, extension, and policy support and there is a need to achieve coherence in these areas. The promotion of SRI in Tamil Nadu is a typical example of convergence of the different organizations in promoting SRI in a big way.

State-level Research Approaches

The tripartite relation that existed among researchers at the state's agricultural university (SAU, in this case the Tamil Nadu Agricultural University, TNAU) with an associated Krishi Vigyan Kendra (KVK) in each district, working with both extension personnel of the state's Department of Agriculture and with farmers was of utmost importance for giving feedback-based fine-tuning and for prioritising location-specific SRI components.

The SRI cannot be compelled to be adopted everywhere on a target-based approach. SRI hot spots/regions or suitable niche areas should be declared by the SAU/KVK based on suitable soils, crop seasons (kharif/rabi), and irrigation sources (surface/groundwater/rainfed). Using GIS mapping, areas suitable for SRI (hot spots) can be demarcated and attention can be paid to popularizing the practice in these priority regions.

The research wing of the SAU should be able to evolve appropriate equipment to reduce labour time and drudgery. Examples would be new transplanters or modification of available existing transplanters so that young seedlings, transplanted just one or two seedlings per hill, can be established in the desired geometric pattern, cutting the labour required for hand transplanting. Multi-row weeders that can cut labour time for SRI because the now-available single-row manual weeder requires walking around 16 km per acre for a one-way pass of weeding. It is indeed timely to develop, test, and promote motorised weeders that can be manufactured by private industries suited to local field conditions. The motorisation of SRI weeders has begun already in some other countries.

Primarily the SAU/KVK should identify and recommend the most suitable machinery for their State or District, involving farmers as users in the evaluation. Besides organizing a contest for 'best weeder designs' with the design made available to any and all fabricators who want to make weeders. A nice prize can get more innovation than 10x that much money spent on Research projects and contracts.

The owning of mechanised transplanters and motorised weeders by all farmers is not easy financially, hence the state Government should extend subsidies or facilities to encourage groups of farmers to purchase and share the equipment since individual smallholders do not need it for very long at one time, or to encourage entrepreneurs to purchase and operate the equipment, extending custom-hire services based on a service-provider mechanism, which could have contracts for raising nursery, transplanting, and weeding for an economic unit-area cost. This requires some local institutional development, but this can be both cause and effect of SRI's wider spread.

Long-term studies comparing SRI with conventional methods in regard to pest and disease dynamics, soil health and nutrient balance, greenhouse gas emissions so as to mitigate climatic changes should be undertaken to document effects of scaling up in a massive way. As long as innovations that have been adapted and are working well in farmers' fields are not well-documented and shared, they will remain invisible to the agricultural R&D community as well as to policy and decision-makers. Hence, it is imperative to gather and discuss the data on agronomic, economic, and environmental benefits of SRI methodology, and the SAU should take a lead for meetings every six months with stake holders along with extension personnel.

Integration of SRI methodology into farming systems approaches, by combining SRI with other climate-smart and agro-ecological strategies such as conservation farming, agroforestry, rotational cropping, and water-harvesting in rainfed areas will derive more benefit for rural households and the environment. Also, extending SRI principles to other crops such as sugarcane, wheat, ragi, and mustard should be considered and supported in every district by the KVK concerned according to what is most productive and highly suitable.

The collector/administrator who is the inspecting authority for the agricultural programme of his or her area should be made aware about the science that accounts for increases in SRI yield, updated once a year by the SAU concerned in every state, so that the program expands based on sound knowledge and makes further improvements. Imparting training and periodic updating to farmers on the SRI components that are important to their particular region is also essential. This will make them more confident in carrying out follow-up tasks.

Long-term field experimentation: As yields vary across regions as well as with different soils and irrigation sources, long-term field experimentation with different SRI practices is important so that well-supported conclusions can be drawn about their sustainability, and policy measures can be taken for sustaining the food security in every state.

Rural artisan training: It should be possible to service small machines involved in SRI like transplanters and weeders at the farmers' fields quickly for effective functioning. Hence, there should be capacity-building given to rural youths/ITI students in every village by persons with expertise in agricultural engineering. Such skills can create new employment opportunities.

State Extension Approaches

SRI is a knowledge- and experience-based method of rice production rather than an input-centric technology. The extension systems at present are mostly designed for input-driven technologies with a targeted approach where success is evaluated in terms of its demonstrated extent without attention to the

impacted area created through demonstration. During the initial days of introduction of SRI, critical inputs were often given free of cost to enable or induce the farmer to apply certain practices in a timely way, to reap more benefit and to reduce farmers' risk or fear of adoption. It is appropriate now to move away from that approach, not relying on subsidies for SRI but demonstrating the financial and other benefits from its adoption that give farmers incentive to change their practices. Farmers' costs of production, for seeds, fertilizer, and agrochemicals, can be reduced or stopped with SRI, so the amount of capital needed for rice growing is diminished.

In some places, large subsidized demonstrations with 'progressive' farmers were conducted during the introductory phase of the SRI era. Now, developing more efficient and effective methods for scaling up SRI is crucial. SRI is a very visual subject, where 'seeing' is very important to gain acceptance of the new methods and to change the mindset of farmers. So, a program of compact demonstrations will be important, in large-scale operations under saturation mode covering cluster of farmers or entire village. Farmer Field Schools have been an effective extension methodology, 'learning by doing' and explaining peer to peer learning. As a nudge practice, paddy seed packaging should be available in either 5 or 10 kg to motivate the farmers to adopt seeding at lower rates.

The success of SRI has been fully or at least largely realised by most farmers who have tried this method. Now the extension department officials should encourage smallholder farmers to carry out all the principles of SRI as recommended through compact demonstrations at block level, which will be having more impact rather than just scattered individual demonstrations. Training provided to all the stakeholders, including laborers, will create further impetus for adoption.

Doing it differently: The results indicated that modifying SRI components to suit farmers' preferences results in comparatively higher yields than conventional practices. This was seen from a large study by IWMI-Tata water policy program, published in 2013 in the *Economic and Political Weekly*. A large sample of randomly-selected SRI users in 13 rice-growing states of India were surveyed for comparison with non-SRI users. Full use of the methods produced average yield increase of 13%, but even partial use raised yields over conventional practice. An important finding in the study was that farmers' average cost of production per hectare was decreased by 29% with SRI practices, making an even larger improvement in net income than the improvement in yield.

Encouraging farmers to follow the basic principles of SRI in their own way will be beneficial, with specific practices like age of seedling varying to suits the local conditions. Farmers should not be forced to follow any single defined method. It should be explained to farmers <u>WHY</u> the recommended methods are beneficial for rice crop growth, not just telling them <u>WHAT</u> to do. Knowing <u>why</u> certain changes in practice are recommended will help farmers to make appropriate adaptations. Modified SRI and other improved practices will enable rice farmers to get more production from their available resources, their land, labour, water, seeds, and capital. Similar improvements can be made for wheat, ragi, sugarcane, etc.

Proper Information, Education and Communication (IEC) measures such as distinguishing SRI fields from conventionally-grown fields with a special-coloured flag can attract attention of neighbouring farmers and passers-by. Farmer-to-farmer exchanges through farmer field schools and exposure visits can spread knowledge and information horizontally, and using digital media as tools for propagating success stories within local communities should be effective for upscaling the spread of SRI.

Repeatedly sensitizing the farmers on SRI principles along with the existing challenges and methods to address the same through nudge practices, using print, digital media, and popularising site-specific case studies will be highly helpful for getting understanding and acceptance of various principles of SRI. Also, the extension staff should play crucial roles in facilitating the adoption of SRI concepts through peer-to-peer learning.

Maintain farmer leadership: SRI progress and improvement shall be driven in large part by farmer initiative and innovation. Farmer-to-farmer spread of the new ideas and practices is important, with extension systems working in more farmer-centred ways. SRI has not been and should not become a top-down and rigid methodology, as *adaptation* is more important than *adoption*. This should be a guiding principle for improving and advancing most if not all climate-smart agriculture

National Level

The Twelfth Five Year Plan approach paper highlights the importance of SRI practices as transitions in agriculture that can enhance water and rice productivity. The Department of Agriculture included SRI as part of the National Food Security Mission some years ago, supporting its introduction in 133 food-insecure districts. But promotion was mostly through the supply of weeders and hybrid seeds, operating within the dominant input-supply paradigm of agricultural extension. The approach taken subsequently under the National Rural Livelihood Mission with the Jeevika program in Bihar was more farmer and learning- centred.

Labour training in weeding and transplanting operations would be of much benefit to farmers. Selected young labourers under MGNREGA should be trained in these operations of specialised SRI transplanting for earning extra income. In every village, this training should be imparted, and skilled groups should be developed for giving rapid and expert service.

In recent years, a lot of Farmers Producing Companies have been effective with vibrant membership. Custom-hiring of the machinery required for SRI, available through a Farmers Producing Company, is also becoming more common and should be promoted.

The drivers and principles of SRI effectiveness should be evaluated and incorporated into agricultural development programmes such as the Rashtriya Krishi Vikas Yojana.

The skills of existing staff need to be upgraded and new expertise should be introduced for SRI management at national level, with KVK scientists working in convergence with different organizations for large-scale adoption of SRI.

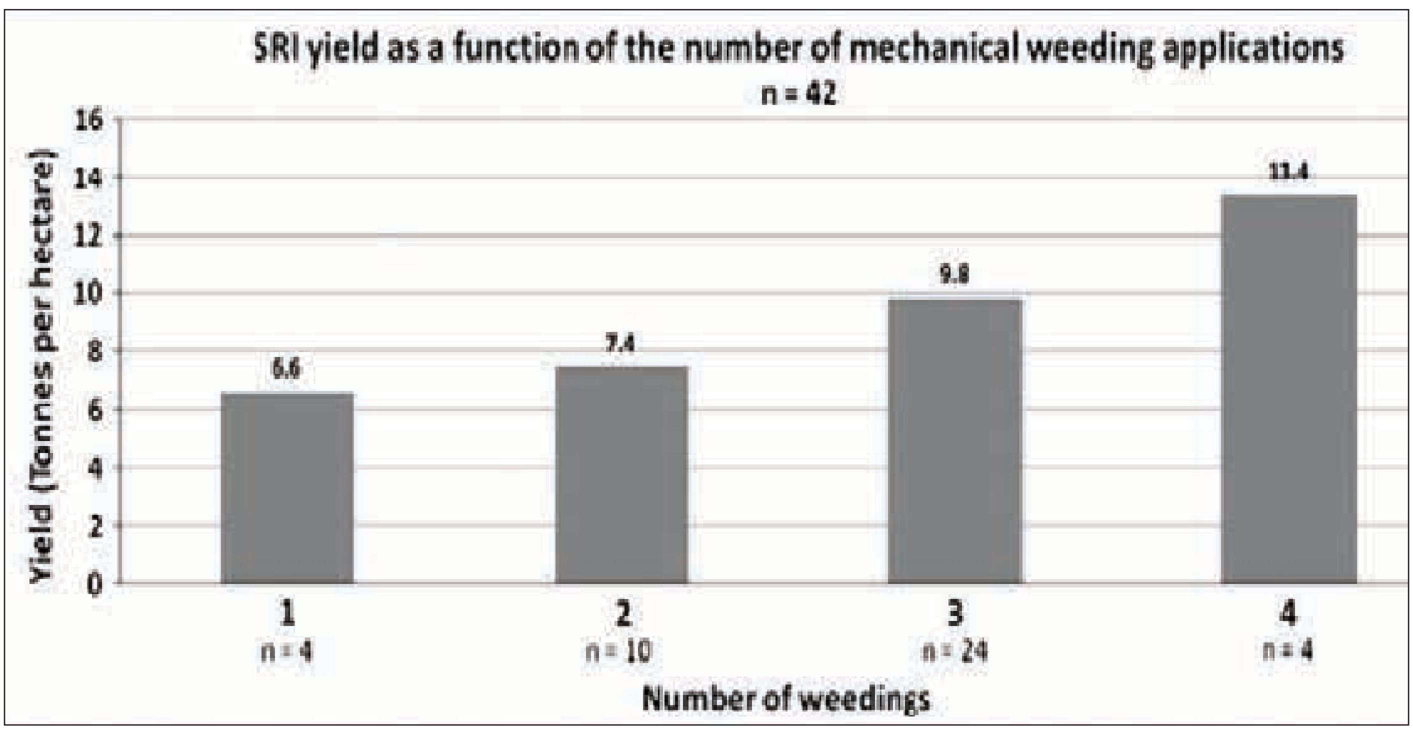
Identifying SRI-efficient zones in each block and demonstrating block-level SRI performance for climate-smart agriculture should show to farmers and other key stakeholders about the merits of these changes for Indian agriculture. Raising awareness through campaigns and training on the principles and applications of SRI and climate change impacts on rice production is also essential.

Some principles of SRI like the planting of young seedlings at shallow depth and raising specialized nurseries need skill and labour, especially in the early stage of adoption. If labourers are trained and experience with SRI transplanting and weeding, this will enhance the crop yield, so one incentive for them to seek training is that it would be justifiable and profitable for farmers to give a higher daily wage in recognition of this skill and the yield enhancement that can follow from best use of SRI practices.

Because farmers in various states of India, e.g., Andhra Pradesh, Bihar, Himachal Pradesh, Tamil Nadu, and Uttarakhand, have been able to market similar gains in the productivity of their wheat, ragi, sugarcane, mustard, pulse and other crops even crops like turmeric, cumin and coriander by adapting these ideas and methods of SRI to other crops, it would be wise for our research institutions and state agricultural universities to do systematic research on these various crops.

The strategy of growing deeper roots and promoting the life in the soil is one that can help our farmers withstand the stresses and strains of climate change, with water constraints and harmful weather. It makes sense for research on other crops through all India national level projects for reaping the benefits of climate-smart agriculture and resource conservation.

The System of Rice Intensification has spread through e-groups, through the exchange of knowledge and experience among actors within and across states, through learning alliances and the like. Making use of modern ICT tools is urgently required for pluralistic extension technology transfer, polygonal skill-enhancement, and primary rural agri-entrepreneurship development.



The 12th Five Year Plan approach paper highlighted the importance of SRI practices in improving the crop productivity. The drivers of SRI adoption should be assessed and incorporated in agricultural development programs such as *Rashtriya Krishi Vikas Yojana* (RKVY). State governments should develop programs and arrangements for smallholder farmers to procure or have access to SRI transplanters and motorized weeders that can save labour and speed up the operations of SRI and SCI practices.

This may also involve subsidies or interest-free loans, but also agri-entrepreneurship for service provision or farmer organisation to undertake group ownership and management. In principle, because SRI methods create gains in productivity for farmers, their adoption should not require subsidization, although some expenditure to get the gains demonstrated and to insure against risk to overcome apprehension is well justified.

International Level

While the principles of SRI are broadly applicable, the specific practices to implement them should be tailored to local conditions and farmers' cropping husbandry techniques, so there should be not be any monolithic presentation or implementation of SRI. In India, we can benefit from learning about the experience with SRI in other countries, and we should share our experience and innovations with others through several Video conferences. The agroecological conditions in India are as diverse as anywhere, and India has been a leader on innovation with SRI thinking, making the most advances with SCI applications. Indian experience should be refined and disseminated by the coordination of the Rice Research Institutes, other ICAR institutions, the Ministry of Agriculture and with the peer farmers.

The SRI 'fire' has been ignited in most of the rice-growing countries around the world, and a large number of farmers have realised its full or partial potential, many of them have undertaken to personally spread knowledge of SRI opportunities to their peers. NGOs like PRADAN and PRAN have trained volunteer farmers to serve as master farmers or as trainers for other farmers' instruction, and surely many participants here could give their own examples of the farmer-to-farmer spread of SRI.

Here is a picture of four farmer-field-school participants in Vietnam who on their own started visiting neighbouring villages to share their experience with others because of their satisfaction with SRI results. And a picture from Cambodia of an elderly farmer who was the first farmer in his country to try out SRI methods. He carried contrasting SRI and conventional rice plants as visual aids, using them to start up discussions of SRI when he walked into other villages.

However, there are probably not so many SRI farmers in India who are spreading information on their successes to their fellow farmers. Providing them with appropriate training materials, videos, T-shirts and embroidered caps could embolden and incentivise them to help change the traditional mindset of other rice farmers.

One simple government action could be provision for the customs-free exchange of SRI transplanters and mechanised weeders among rice-growing countries to contribute to greater global food security and the eradication of hunger.

In some countries, there is a belief that SRI methods are suitable only for organic farming. This preconception should be dispelled. The best results with SRI management often come from organic practices when the other recommended practices are followed, and organic management may be preferred both for the healthiness of the food produced and of the soil. But the other SRI practices also give improved results with some combination, or optimisation, of organic and inorganic nutrients, in what is called Integrated Nutrient Management.

SRI is not only limited to organic production. Such production may be favoured for reasons of both soil health and human health. Perhaps more important, reducing excessive application of nitrogen to the soil increases the emission of greenhouse gases from paddy fields. But SRI was originally developed with the use of chemical fertiliser. So, farmers should make their own decisions. What is important, for all crop production, is to increase the levels of organic matter in our soils as these levels are in many places disastrously low.

Salient successes achieved through SRI and SCI management in various countries should be well-documented and spread throughout the international community. Already there are many hundreds of SRI videos posted on YouTube, Vimeo, and other services, probably over 1,500. We in India can take pride that about half of these have been produced in this country. There is a large body of experience and success in India that can be presented both within and outside the country. There are some particularly interesting experiences that could and should be shared, such as the observation in Southern India that the rat menace is significantly reduced and sometimes even eliminated under SRI field conditions as compared to neighbouring fields with conventional planting. This has been reported also in Sri Lanka.

Perhaps the SRI-Rice centre at Cornell and/or the SRI-2030 centre at Oxford could arrange for regular virtual interaction among scientists and SRI practitioners, biannually or annually, to update knowledge about paddy and other crops under SRI/ SCI/SRI (System of Root Intensification) management. The scientific papers should be published on-line or in regular journals.

Rice is being grown in many different ecosystems around the world, from tropical rainforest areas to the edges of the Sahara Desert in West Africa, and even up to elevations as high as 2,600 meters in Nepal. So, lessons learned within the international SRI community should be shared, especially for adopting and scaling-up the SRI principles for various crops beyond rice.

Policy Support Needed

1. The state-level government support for SRI has been limited to extending subsidies for weeders and markers and putting on field demonstrations. As SRI is more on a behavioural transition than on material innovation, more support should be directed toward the generation and dissemination of knowledge. As the labour needed for weeding is seen as a problem, support could be extended for training and engaging labour during the initial season of adoption.

2. A group/ area-based approach to weeding may be considered rather than an individual farmer-centric subsidy. Labour training in weeding and transplanting operations using small level machineries would be of great relief to farmers.

3. The designs of weeder should be diversified, suitable for different field conditions and differentiated for men and women users, and they should be made amenable to local production. Staggered community nurseries sown at different times at the village level can make available to farmers the required-age seedlings to farmers and reduce labour requirements.

4. State support should be extended to the growing of green manure crops and for production of organic manures such as vermi-compost and bio-fertilizer. It is important for all of agriculture, and not just for SRI, that soil organic matter be raised urgently, to enhance the life in the soil, to make the soil more hospitable for root growth, and to give cropping more resilience against the stresses of climate change.

5. Better control of irrigation in canal and tank systems to be able to deliver smaller but very reliable amounts of water on an agreed-upon schedule will make the

adoption of SRI on a larger scale more feasible. Therefore, irrigation development plans are to be carefully drawn and executed since getting 'more crop per drop' is an imperative for the years ahead.

6. Regulations and enabling laws and policies to address issues and problems of meeting and maintaining water quality standards should be ensured. For the sake of agriculture and for the sake of our people, as we strive to maintain the needed quantities of water, we must also pay attention to safeguarding its quality.

7. Some attention should be given to market development so that farmers who produce rice of superior quality, for which consumers will have a preference and pay a better price, will be appropriately compensated. This would give a big boost to farmer acceptance of SRI methods under pure organic farming which also have social and environmental benefits.

Conclusion

The beneficial effects of SRI suggest that this water-saving technology could and should be up-scaled with some flexible approach. Farmers will only adopt the full components of SRI on a large scale if they are actually benefitted from using the technology. Different from the Green Revolution technology, with SRI farmers should be adapters and promoters, not just adopters.

The interactions among researchers, policy-makers, and stakeholders, including farmers, should be strengthened to increase our science-based knowledge of SRI, enabling the government to develop policy guidelines promoting SRI adoption and, wherever appropriate, up-scaling activities.

These various measures mentioned would help to promote the adoption and up-scaling of SRI at the local level coupled with better governance for improved coordination by both Government and many stakeholders

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Socio-Economic and Ecological Challenges for System of Crop Intensification (SRI/SCI): Sustainable Productivity-Enhancing Innovation for Household Food Security

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The persistent low productivity and wider inter-regional differences in yield in the resource- poor production system is a prime concern. This implies ample scope for a strategy to increase food production and bridge the yield gaps

Rice is an important crop, being the source of main food item of the majority especially in INDIA. Yet,despite increase production, the availability of rice has reached an all-time low of 64 kg per annum per capita in this decade. This amounted to average food availability of a person is lesser by 20kg than the minimum requirement of a normal person (NSSO surveys). Therefore, to meet the nutritional needs of the population, food production has to further increase if not double' in the next decade or two.

The poor production performance, deteriorating health of natural resources (soil, water and biodiversity), fragmented land holdings, and credit facilities, made the situation more precarious. The biotic (pest, diseases and genetic decline) and abiotic stress including problematic weather aberrations due to climate change (such as flooding and drought, temperature snow, frost, submergence and cyclone etc.), put tremendous strains on production system adding more to year to year fluctuation. The worst is that the sector loses about 40% of production annually due to system inefficiency and wastage.

In view of area stagnation under food crops, while increasing consumption demand, and the population and urbanisation unabated, the onus lies on productivity enhancement at Global, National, and Household level. But, the rainfed areas, where the smallholders and the hungriest people live, are the victim of low productivity trap. The low productivity and inter regional differences in yield implies ample scope to exploit untapped potentiality to increase production and bridge the yield gaps.

The System of Crop Intensification, derived from the principles of **SRI,** is a suitable method for enhancing productivity and breaking the yield barrier in smallholders' fields. The novelty is that this pro-poor option produces more with less external inputs while conserving precious water. Realizing its importance, the government, civil society organisation and NGOs are promoting SRI methods for scale and helping farmers' capacity building. Due to tangible virtues of the method, the application of the innovation to other crops proves successful and hence spread widely across ecosystems. It is observed that nearly 1million ha of rice area is brought under SRI in a quick succession of couple of years by 2009-10. Subsequently, more SRI Area expanded at present.

The SRI is an amalgamation of integrated package of agronomic approaches that help exploit the genetic potential of rice plants; create a better growing environment (both above and below ground); enhance soil health; and reduce inputs cost substantially. Hence it suits the resource poor and the phenomenal saving in seed (90% saving) and water upto 40%, to the innovative method, attracted these farmers. Studies in India show that introduction of SRI enables the poor to achieve upto 100 days of additional homegrown food for the household (see Appendix). On achieving food security at household level, the farmers are also encouraged to adopt crop diversification as the method saved crop period. The crops like maize, wheat, mustard, and vegetables have shown adequate reward of improved methods of cultivation.

Professor Norman Uphoff, Cornell University, Ithaca, USA, fully convinced about the excellence of SRI in meeting the food security need of the poor, devoted his time in promoting its adoption and knowledge delivery globally. The origin of this simple technique can be traced in Madagascar where SRI was first practiced while confronting the vagaries of hunger and famine. The method has recently been introduced in India, where farmers improved productivity by using less water and external inputs while incurring no additional cost.

SRI being a set of care-intensive practices, imparting knowledge is essential. Capacity building and stakeholders awareness is crucial for its promotion. Therefore, strengthening the institutional framework including rural credit system, crop insurance, marketing and remunerative pricing policy is an essential booster of rural income.

The Government of India under the ambitious programme of National Food Security Mission (NFSM) has integrated the existing rice initiatives for the promotion of SRI all over the country. Multiple advantages of SRI as observed by governments institutions, NGO, civil society and other stakeholders incentivized the promotional strategies at the farmers' fields. Among the early adopter include the governments of Andhra Pradesh, Tamilnadu, Karnataka and Tripura. They added SRI promotion in right Ernest and allocated required financial resources from the year 2003-04 onward. The record saving of at least 25-30% water, reduced cost of cultivation by 10-15% and increased rice yield by 30-40% was substantial. This has benefited the needed improvement in the production system. The research and development organization and government-owned institutes, as well as CSOs have conducted SRI/SCI research, to provide gainful benefits. This concerted effort proved to be additional milestone strategy for scale up. The advent of stress-tolerant rice varieties (STRV) due to the introduction of sub-1 genes in rice varieties revolutionised the rice production, (for instance Swarna sub-1, Ranjit sub-1, Bahadur sub-1, CR dhan, BINA 11 etc are practiced in flood-prone ecosystems) and the paddies in submergence prone areas helped enhancing productivity.

SRI rice is a preferred method of farmers due to significant seed saving, built-in resource-conserving property, and yield performance. Availability of controlled irrigation (drip irrigation, fertigation of water harvesting system) also incentivised farmers to convert fallow areas into productive purposes especially in the rainfed areas. More significantly, imparting careful management care, resulted in the traditional rice varieties to perform well.

Policy conclusion

The paper attempt to synthesize and shares few observations and reviews the strategy for scaling up SCI/SRI in India. SRI comprises diverse meanings as rice is cultivated in highly diverse conditions. While adopting technology, the farmers enhance productivity within their own agenda in conformity with the local production environments and social systems. This implies that there is no single solution or productivity policy for all situations across the various spatio-temporal dimensions.

The innovation of technology/practice like SRI/SCI opens up a new vista for sustainable rice production and/or revitalize the potential of traditional as well as improved seed varieties that seem to have gradually lost in the green revolution agenda.

The new practice dedicated mainly to small and marginal farmers, has important implication for their household food security. This innovative practice of food production has a chance to revive the shrinking opportunity in rice production systems for resource poor farmers. In particular,

- SRI is a suitable technology for the Rainfed rice system, where the Small & Marginal Farmers (S&MF) benefitted more from the innovation.
- It ensures and satisfies the Food Security needs of the green revolution bypassed population
- Therefore, SRI Awareness & GOVERNANCE (Advocacy model) should be promoted as long term strategy for SRI scale up

The effort requires the following policy steps in its pathways and smoothening road map

1. To re-orienting farmers and create awareness towards intensive management and knowledge in favourable rice agroecology
2. To create cadres of SRI Resource Farmers for imparting training and handholding. This will potentially supplement the conventional extension system
3. To enhance investments for ensuring sustainable land and water resources in large- scale coverage
4. To establish decentralised manufacturing hub of SRI implements and appropriate distribution system among the stakeholders to add to policy regimes
5. Provisioning availability of in-situ organic matter and resources for improving soil productivity and sustain microbial life system.
6. Establish research and development (R&D) back-up and support accompanied by policy advocacy strategy
7 Establish close linkages in mainstream R&D ecosystems, institutional Policy regimes and Practicing Farmer Collaboration: eg. SWI farmers from Rajasthan, Uttarakhand and Bihar participated at On-station experiment at experimental farm fields, which imparted mutual benefits

The process thus demands effective Policy strategy for sustaining SRI reach out. To conclude:

- SRI has apparently become a familiar household name amongst the farmers globally.
- It is the most preferred technological option for small and marginal farmers to ensure household food security who own less than 2 hectares of land. It has been observed that at present, there are instances, of farmers motivated for experimenting convincingly with SRI methods. In fact, these experiences enable scale up by "learning by doing and learning by seeing".
- Farm level studies in India show that introduction of SRI enables the poor to achieve upto 100 days of additional food for the household (NABARD 2008), which is significant.
- On achieving food security, the farmers also adopted crop diversification as the SRI method saved time of stages of crop growth. The crop diversification such as maize, wheat, mustard, and vegetables shown respectable reward of improved methods of cultivation.
- Moreover, it is the most welcome sign that research and policy establishments have accepted its worth in increasing productivity in the sustainable production space and made policy changes.
- For instance, the state of Tripura, Tamil Nadu, Bihar, Jharkhand, Chhattisgarh, Odisha, Andhra Pradesh, and Telangana have modified their work plan policy in favor of SRI. Other states also recognize SRI as alternative method rice cultivation. The civil society organizations (CSO) are credited for their continuous efforts in spreading the message and the method widely.
- According to farmers, the labour constraints however, is a dominant inhibiting factor. But given the time, the problem can be eased out as the practicing farmers acquire more expertized knowledge and become accustomed to the nuances of SRI principles, which make believe that SRI is actually labour saving and save time too.
- The cost benefit analysis shows the traditional mono-culture rice alone can't provide adequate farm income and means of livelihood; realizing this, the farmers resorted to crop diversification and reap benefits.
- Even at aggregative level, by targeting about 20-25% of land holdings, nearly 10-12 million hectares can be brought under SRI in India.
- For increasing income and livelihood, farmer need to adopt farming system approach with crop diversification with SCI as the main focus. The evidence-based experiences with SCI in wheat, maize, mustard, vegetables have shown proven opportunity to improve the produce market as SCI product is organic in nature, believed to be healthier and of superior quality food. Health-conscious consumer preferences are growing and attract premium price
- Therefore, there urgent need for the policy ecosystem to be supported by Research and development system on climate resilient technology (Climate-Smart Sustainable Agriculture-CSSA) and impart its promotion.
- The IIRR may be encouraged to develop and lead a mission mode schemes such as All India Coordinated project on SCI/SRI (AICSRI) emphasizing on technology demonstration at the on-farm and on-field (farmers field)
- More efforts needed on Training and capacity building on continuous basis as the innovation is knowledge intensive rather than input intensive. Seeing is believing attract rural youth to Agriculture.

The state governments experienced record saving of at least 25-30% precious water, reduced cost of cultivation by 10-15% and increased rice yield by 30-40% over the normal practice particularly in Andhra Pradesh. Due to these benefits, the Govt spelt out a detailed plan for SRI promotion and allocated the fund for proper implementation. These benefits of SRI is briefly quantified below

	Normal Practice (2004-05)-CMP	SRI (2004-05)
Yield (More)	5.561 t/ha (30 bag of 75 kg per acre)	7.31 t/ha (40 bag per acre), Difference +32%
Water requirement (saving)	1200mm	750-850 mm, Saving 350-450mm
Seed (saving)	30-40 kg	2 kg
Cost of cultivation (Less)	Rs.8000/acre	Rs.7500/acre
Gross return (Rs.) (More)	12750/acre (@ Rs.425/bag)	17000
Profit per acre (Rs.) (More)	4750	9500 (% gain 100%)

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Policy Planning for Scaling Up of System of Crop Intensification by Adaptation of Climate Resilient Practices Towards Food Security and Improving Agricultural Production

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Abstract

Climate change is one of the most extreme challenges Indian agriculture is facing today and will have to deal with in future. There have been overwhelming and growing scientific evidences to establish that the world is getting warmer due to climate change and such increasing weather variability and worsening extremes will impact the agriculture sector more and more adversely. The sheer scale of involvement of the poor in agriculture calls for an effort to meet the challenge of climate change head-on through resilience building measures that work through a system of adaptive and mitigation strategies. Considering that new approaches are needed, development and deployment of new technologies, advocacy and capacity building have an extremely important role to play not only to build farmer's capability but to help in changing the mind-set as well. Both short term and long terms outputs are expected from the project in terms of new and improved varieties of crops, management practices that help in adaptation and mitigation and inputs for policy making to mainstream climate resilient agriculture in the developmental planning. The overall expected outcome is enhanced resilience of agricultural production to climate variability in vulnerable regions.

Keywords: Climate resilient agriculture, system of crop intensification, custom hiring centers (CHCs), crop residue management.

Introduction

A high-chemical and high-irrigation based modern-day agriculture while giving short-term returns, damages soil-health, eco-balance and agricultural sustainability in the long run. Contemporary strategy for crop intensification that depends primarily on making genetic improvements and increasing external inputs is, however, not the only kind of intensification that warrants consideration - especially given growing concerns about the sustainability of current agricultural practices and about their impacts on climate change. An alternative strategy for intensification that can be broadly characterized as agro-ecological strategy that seeks to make the most productive use of available natural resources. System of Crop Intensification (SCI) refers to an increase in agricultural production per unit of inputs. The input includes labour, land, time, fertilizer, seed, feed or cash. The aim is to achieve higher output with less use of or less expenditure on land, labor, capital, and water. Crop intensification technique includes intercropping, relay cropping, sequential cropping, ratoon cropping, etc. In recent years, something called the system of crop intensification (SCI) has emerged in a number of Asian and African countries, raising the productivity of the land, water, seed, labor, and capital resources that farmers invest can for growing a wide range of crops. System of crop intensification practices enable farmers to mobilize biological processes and potentials that are present and available within crop plants and within the soil systems that support them by altering the traditional practices of crop, soil, water and nutrient management. System of crop intensification principles can be applied for variety of crops which include System of rice intensification (SRI), System of wheat intensification (SWI), System of sugarcane intensification (SSI), and System of mustard intensification (SMI).

System of Rice Intensification

This system is a low water requiring, labor-intensive method that uses younger seedlings widely planted singly and typically hand-weeded with special tools. It is an evolving set of principles and practices which aims to enhance the rice productivity by changing the management of plant, soil, water and nutrient.

System of root intensification

In the state of Bihar, SCI was at first referred to as the system of root intensification. This designation does not, however, give concurrent credit to the contributions to crop productivity that beneficial soil organisms make. These are equally important and interact synergistically with root systems. Through their chemical and physical impacts on soil systems, roots help to sustain an abundance of life in the soil. These organisms, in turn, provide nutrients and protection to the roots and through them to the plant itself.

System of wheat intensification

System of Wheat Intensification which is based on the principles of system of rice intensification is a new wheat cultivation technique which demands to maintain plant of 20 cm × 20 cm. This kind of sowing with proper plant density allows for sufficient aeration, moisture, sunlight and nutrient availability leading to proper root system development from the early stage of crop growth.

System of sugarcane intensification

This system or sustainable sugarcane initiative is yet another practical approach to sugarcane production which is based on the principles of 'more with less' in agriculture like system of rice intensification. Sustainable sugarcane initiative is a method of sugarcane production which involves using less seeds, less water and optimum utilization of fertilizers and land to achieve more yields.

System of mustard intensification

System of Mustard Intensification is the system of transplanting mustard seedlings with wide spacing is similar to the system of rice intensification. Both systems depend on low density of crops and seek to utilize the full potentiality of each plant, rather than on communities of plants as done with high-density planting.

The ideas and practices that have given rise to SCI have derived from farmers' and others' experience with the system of rice intensification (SRI). The principles constituting both SCI and SRI, based on demonstrated agronomic theory and practice, are shared with other agro-ecological domains of innovation such as agro-forestry, conservation agriculture, integrated pest management, and integrated range and livestock management. The common elements involved in SCI crop management, extrapolated by farmers and others from what has been learned from their SRI experience, can be summarized as:

- Establishment of healthy plants both early and attentively, taking care to conserve and nurture their potential for root system growth and for associated shoot growth.
- Significant reductions in crop density, transplanting or sowing individual plants with wider spacing between them, giving each plant more room to grow both above and below ground.
- Enrichment of the soil with organic matter, and keeping the soil well-aerated to support the better growth of roots and of beneficial soil biota;
- Application of water in ways that favor plant-root and soil-microbial growth, avoiding hypoxic soil conditions that adversely affect both roots and aerobic soil organisms.
- *Starting with high-quality seeds or seedlings*, well-selected and carefully handled, to establish plants that have vigorous early growth, particularly of their root systems.
- *Providing optimally wide spacing of plants* to minimize competition between plants for available nutrients, water, air, and sunlight. This enables each plant to attain close to its maximum genetic potential.
- *Keeping the topsoil around the plants well-aerated* through appropriate implements or tools so that soil systems can absorb and circulate both air and water. Usually done as part of weeding operations, this practice can stimulate beneficial soil organisms, from earthworms to microbes, at the same time that it reduces weed competition.
- If irrigation facilities are available, these should be used but sparingly, keeping the soil from becoming waterlogged and thus hypoxic. A combination of air and water in the soil is critical for plants' growth and health, sustaining both better root systems and a larger soil biota.
- Amending the soil with organic matter, as much as possible, to enhance its fertility and structure

and to support the soil biota. Soil with high organic content can retain and provide water in the root zone on a more continuous basis, reducing crops' need for irrigation water.

- *Reducing reliance on inorganic fertilizers and pesticides*, and to the extent possible, eliminating them. This will minimize environmental and health hazards and avoid adverse impacts on beneficial soil organisms, which are essential for SCI success.

The careful transplanting of young rice seedlings, a key practice for SRI methodology, has been found to have strong beneficial effects on some other crops such as finger millet and mustard but not for all. Direct-seeding in conjunction with the other practices can be part of SCI, reducing labor requirements or with some crops like wheat it is simply more successful. Careful crop establishment is an essential part of agro-ecological management, whether for SRI or SCI.

Road Map for Accelerated Adoption of System of crop intensification in India

Before considering the range of SCI innovations that can contribute to sustainable food and nutrition security with less vulnerability to abiotic and biotic stresses, we give an overview of it that spans its varying manifestations. SCI is an agricultural production strategy that seeks to increase and optimize the benefits that can be derived from making better use of available resources: soil, water, seeds, nutrients, solar radiation, and air. There is always need to consider agricultural options in context, taking full account of the factors and interactions of time and space so that field operations are conducted in a timely way, with land area optimally occupied by crops, and not just by a single crop. SCI principles and practices build upon the productive potentials that derive from plants having larger, more efficient, longer-lived root systems and from their symbiotic relationships with a more abundant, diverse, and active soil biota. It is unfortunate that both roots and soil biota were essentially ignored by the green revolution. Road map one of the best ways to accelerate the SCI as follows:

Establish database repository for India

Currently, there is no structured mechanism for tracking the adoption and maintaining database on system of crop intensification/resource conservation technologies (RCTs) in different crops/cropping systems/ecologies of the region. Quality data on availability of Agricultural machinery/custom-hiring centers, area under combine harvesting machinery, amount of crop residues left in field in different crops and cropping systems, farmers practice for management of these crop residues, etc. is also lacking. ICAR Research Complex for Eastern Region in collaboration with CGIAR Centers, SAUs and other institutions should initiate focused programme on data base creation along with collection and collation of statistical information on land use pattern, area under rice-fallow, Agricultural machineries available, important distributers of machineries including repair and maintenance centers. A systematic study on constraints in adoption of Climate resilient technologies in different crops and ecologies of the region also need to be prepared. An urgent action is therefore needed to map the Agricultural research under all initiatives in India to define recommendation domains considering soil, climate, cropping systems as well as socio-economic conditions of the stakeholders.

Setting-up common learning platform and sites of science-based evidence generation on system of crop intensification

The most important limiting factor in adoption of Crop intensification is lack of synthesized knowledge on locally adapted improved agronomic practices which leads to perceived risks among the farmers who feel that puddling/ intensive tillage is essential for cultivation of crops. In India, large chunk of the farmers are even unaware of the resource conservation technologies which accelerate the system of crop intensification. Some of them even have not heard about the Zero-till seed drill/Happy seeder. There is a need to create mass awareness of the technologies and demonstration of their benefits through creating a common platform of learning and knowledge sharing. All stakeholders need to be involved for creating the awareness and providing opportunities for sharing.

Development of effective and productive supply chain system for Agricultural machinery

India has negligible presence of manufactures dealing with Agricultural machineries. Even for spare parts and repair & maintenance of existing machineries, the stakeholders have to depend on the markets available elsewhere in India, especially Punjab. Even for operating combine harvester, the farmers of eastern India rely on the trained manpower, available in Punjab, Haryana and Western UP. Agricultural Mechanization Development Centers (AMDC) needs to be established in each eastern Indian state, particularly for strengthening the small farm mechanization including rigorous multi stake capacity building. Though Custom-hiring Centers (CHCs) are being established in Indian states, limited repair or maintenance support services and lack of spare parts are major limitations for potential use of CHCs. These issues create tangible barriers to adoption and wider acceptance of the benefits of Agronomic practices. Manufacturers and dealers must be provided the required incentives to stock machines as well as spare parts within the region. Similar to Small Farm Mechanization Mission (SFMM) at the Centre, states of the region should also create SFMM. There is also strong need to establish long-term field experiments for generating science based evidence on key performance indicators in diverse ecologies and cropping systems which can also serves as sites of learning and capacity development of range of stakeholders. The platform can also facilitate organizing inter-state travelling seminars for participatory learning on CA technologies to expose the farmers of eastern India to understand the climate smart agriculture interventions going on especially in Haryana, Punjab and in other states.

Addressing subsidies for CA machinery as incentives to the farmers

The slow pace of adoption of Climate resilient based practices in the India may be due to earlier subsidies which have distorted the market price. High empanelment costs created disincentives for manufacturers to engage more widely in the program. Subsidies have resulted in mal practices, and access has been limited to certain sections of society. The farmers are not financially positioned to purchase ZT drills/Happy seeders, and will access the technology primarily through CHCs. In order to promote on large scale, subsidy/incentives needs to be extended to the farmers. However, subsidy should be released based on ground compliance monitoring and assessment. It is also envisaged that there is a need to incentivize the purchase of happy seeder/turbo seeder/and zero-till seed-cum-fertilizer drill to facilitate *in-situ* management of crop residue and retaining the straw as surface mulching. Refinement is needed in current prototypes of Agricultural machineries (ZT drills, Happy seeders, etc.) in accordance with the farmers' need in eastern India besides cost reduction without compromising the quality of machine. Zero-till multi-crop and multi-utility planters need to be developed and popularized.

Pricing strategies to achieve market demand driven approaches for long-term sustained adoption of Climate resilient practices

It has also been deliberated that subsidy extended on purchase of machineries should be based on quality of the machines. In general, bids for the supply of machines invited are generic in nature. Detailed specifications along with brand/mark need to be mentioned in the bid itself, in order to ensure the supply of quality machines. Similar is the case with spares. National and State GST charges also need to be waved off on Agricultural machineries to reduce price barriers to adoption.

Sustainable crop intensification of rice-fallows with suitable crops and crop establishment techniques

India has 11.695 million ha (Gumma *et al.* 2016) area under rice-fallow due to lack of irrigation, late harvesting of long-duration high yielding rice varieties, moisture stress at the sowing time, water logging and/ or excessive moistures in November/December *etc*. Adoption of resource conservation technologies (RCTs) involving suitable crop varieties would offer opportunities to cultivate at least 50% of rice-fallow area. Pulses such as chickpea, lentil, lathyrus and black gram, and oilseeds such as safflower, mustard and linseed through rotation or relay with rice are the candidate crops for efficient utilization of conserved and scarce resources including soil moisture. Crop establishment of these crops has a potential for sustainable intensification of rice-fallows in India which not only will have economic benefits to farmers but also can help country to achieve self-sufficiency in pulses and oil seeds. A systemic future research on nutrient management, crop/ cultivar combination, and farm mechanization is warranted that may further help to upscale system productivity potential in rice-fallow agro-ecosystem.

Cropping system approach and pest dynamics

Soil biology and pest (including insects, pathogens, nematodes and weeds) dynamics under crop intensification is the subject matter of a thorough investigation due to change in hydrothermal regime of the soil in presence of crop residue cover and non-disturbance of soil. Changes in community structure of microbes, microbial dynamics (beneficial *vs.* pathogenic) and microbial mediated processes need to be studied. Intensive research programmes also need to be initiated on sustainable use of crop residues, use of micro-organisms for faster degradation of crop residues, quantification of crop residues suitable for mulching in different crops and cropping systems, development of climate smart crop varieties, crop diversification, *etc*.

Crop residue management

About 650 million tons of crop residue is generated every year in India (NPMCR, 2014). Large portion of crop residue is burnt 'on-farm' primarily to clean the field for sowing of the next crop. Rice, wheat and sugarcane are prone to crop residue burning. There is need to develop, disseminate and incorporate technological options for sustainable management of crop residues; and to formulate and implement suitable law and legislations/policy measures to curb burning of crop residue. Diversified uses of crop residue for various purposes primarily for *in-situ* recycling and also other purposes *viz.,* animal fodder, power generation, as industrial raw material for production of bioethanol, packing material for fruits and vegetables, and glassware, utilization for paper/board/panel industry, biogas generation/bio char production/straw bale for animal feed/ composting and mushroom cultivation in Public Private Partnership (PPP) mode need to be promoted.

Developing synergies among institutional land-scapes

Keeping in view the fact that large numbers of research for development projects are being implemented by the CGIAR Centers including donors besides ICAR & SAUs, and state Governments, effective coordination between NARS and CGIAR Centers at regional level would greatly help in accelerated adoption through bringing more synergies and complementarily and bridging knowledge gaps. Therefore, there is a need to develop a mechanism for regular meetings and interactions at the regional level in different locations involving CGIAR partners, SAUs, ICAR institutions, State Govt. functionaries and other stakeholders. While strengthening the research platforms as sites of learning as well as new scientific insights and evidence generations, the on-farm research-cum-demonstration with farmers' participation involving KVKs is the key for its upscaling/out scaling and promotion on large areas. Duplication in research across the institutions/ organization also needs to be avoided.

Capacity building of stakeholders

Multistake capacity building of stakeholders is essentially required. Training programs to address the skill-gap could be based on existing arrangements elsewhere (e.g. NABARD, Skills Council, Agri-clinics *etc*.). A frequent demonstration of machines (ZT seed drills/Happy seeder/ Tractors/ Laser land levelers etc.) also needs to be arranged in order to increase awareness among stakeholders. Therefore, different training modules targeted to diverse stakeholders need to be developed. Based on the strengths on various aspects, key institutions should be identified to lead and facilitate the capacity development programs in areas of their expertise in different geographies. Different agricultural universities and institutions in the region should introduce a course as a part of course curriculum and also more students and young researchers should be trained through mainstreaming in the programmes like Rural Agricultural Work Experience (RAWE) and practical crop production (PCP) course at under-graduate level and increased post-graduate research.

Development of weather forecasting system and risk mitigation strategies

Weather is quite uncertain and impacts significantly agriculture and community. Therefore, establishment of a network of robust forecasting system and risk mitigation strategies (cold/heat tolerant cultivars, short duration alternative crops, post frost management) and analysis of extreme climatic variability (cold waves and frost/ heat stress) in hill farming is a must. Greater emphasis should be laid on precise information delivery system for climate change induced extreme weather variability for mitigating the risks. Also there is a need to strengthen the data generation system and develop database of climate, markets and other related aspects to support decision making for mitigating weather related market risks.

Promotion of conservation agriculture based sustainable intensification

Traditionally, agriculture is closely linked with forestry and based on biomass recycling. As such the nutrient requirement of the crop is met out either by the decomposition of leaf litter in improved organic matter content in soil. Also systematic information on intensive tillage mediated biomass incorporation v/s no-till/reduced till mediated biomass mulching and their effects on soil erosion, soil moisture retention, temperature buffering, yield, income, etc. is not available. There is a great role for Conservation Agriculture to play in sustainable intensification of crop production. However, in depth studies are required on conservation agriculture in low input and agriculture production systems for enhancing the service functions of hill agro-ecosystems.

Develop post-harvest management and value addition hubs

Since the region is bestowed with rich horticultural diversity, post-harvest technologies, particularly primary processing of perishable commodities in the cluster area of production of niche crops viz. pineapple, jackfruit, high value fruits and vegetables etc. is need of the hour besides infrastructure development for value addition and marketing. Large scale accreditation/certification of mother blocks is also required in order to ensure the supply of quality planting materials.

Promote agri-entrepreneurship and agri-startups to empower youth in agriculture

The region has high potential to harness the power of agricultural bio resources and also to motivate and attract rural youth. Concerted efforts to be made to promote agri-entrepreneurship through capacity building and training through agri-business incubators and such other mechanisms to enable agri-startups and improve employability in agriculture.

Conclusion

A high-chemical and high irrigation-based agriculture while giving short-term returns, damages soilhealth, eco-balance, and agricultural sustainability in the long run. Thus, there is an urgent need to build soil health systematically and maintain it. It is important to increase the productivity and resilience of land resources. System of crop intensification is one of those practices which aim to improve the productivity, sustainability, food security, and resilience to climate change by altering the traditional practices of crop, soil, water and nutrient management. Principles of the system of crop intensification can be applied in various crops such as rice, wheat, sugarcane, and mustard. System of crop intensification practices enable the crop to grow and develop potentially which provides enhanced production in a sustainable and eco-friendly manner. Therefore, classical crop cultivation practices need to overhaul by adopting the system of crop intensification for more profitable and sustainable agriculture.

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A Foreseeable and Desirable Future for the System of Rice Intensification

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Abstract

After some 40 years since when Fr. Henri de Laulanié synthesized the System of Rice Intensification (SRI) methodology, and after more than two decades of experts and practitioners working intensively to disseminate SRI around the world, the time is ripe for a general reflection on what has been done, and especially on how to move forward with the upscaling of SRI methods. This short paper builds on the work carried out by SRI-2030 which, despite being a very young initiative, thanks to the support of the experienced SRI-Rice group from Cornell University, has connected with SRI experts from multiple countries and with various stakeholders of the rice sector.

As the international community recognizes the importance of more sustainable and eco-friendly rice production in terms of food security, less water consumption, and adaptation to and mitigation of climate change, concerted actions should be taken to boost the uptake of SRI, an agroecological practice that tackles all these issues and also improves farmers' livelihoods. However, the diversity within the rice sector and the various context-related barriers to its optimization require diversified strategies. The challenges facing us are global, and a coordinated, collaborative approach is needed. SRI-2030 was established to be a facilitator for the support of synergies among stakeholders in the rice sector with the aim of boosting the upscaling of SRI methods up to 50 million hectares by 2030, to slow the pace of global warming and improve people's well-being.

Keywords: SRI, 2030, Sustainability, Eco-friendly, Collaborative Research, Stakeholders

Introduction

Rice is the staple food for about half of the world's population and employs around 1 billion people, mostly smallholder farmers. However, to do this the rice sector uses 40% of the world's irrigation water and releases 10% of global methane emissions. Given the growing world population, the increased scarcity of water, climate change and the sensitivity of rice to climate stress, the sector must evolve. And it must be quick in making changes because according to current trends, global production of rice is predicted to fall by 15% by 2050, while the world population climbs toward 10 billion (ESG, 2019).

The System of Rice Intensification (SRI) methodology addresses food and nutritional security by enhancing crop yields, water use efficiency, farmers' livelihood (by reducing costs while increasing the outputs), and climate prognosis (by cutting methane emissions). It was selected and recommended by Project Drawdown (Hawken, 2017) as a currently-available and proven technology for reaching net-zero greenhouse gas emissions by 2050. With extensive worldwide research (SRI-Rice, 2022), SRI is well placed to be implemented as a low-cost, high-return course of action for abating global warming and climate change.

SRI principles, appropriately adapted to the ecological and contextual conditions, have been validated 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). Due to SRI having been pragmatically assembled and mainly promoted at the grassroot level through a bottom-up approach, with the active participation of farmers, its theory has followed the practice.

SRI has been framed since the very beginning, not as a technology or a commodity whose exchange is mediated by money, but as an 'open system,' based on a set of principles aimed to improve the outputs and sustainability of rice production by using available resources more effectively (Prasad, 2020; Beumer *et al.,* 2022). The dissemination of SRI has been promoted through an open-source approach, and non-proprietary knowledge is shared to allow free access to farmers, researchers, and NGOs to new opportunities (Prasad, 2020).

Since SRI does not rely on external inputs or depend on herbicides or 'miracle' seeds to improve productivity, farmers all around the globe were encouraged to experiment and adapt the practices to their own needs and constraints (Prasad, 2020). SRI farmers have developed their own methods for growing SRI rice, adapting their practices based on its four SRI principles to their own context. Although this is beneficial to farmers who have learned to adapt the practices to suit their agroecological zones, this means that SRI results cannot be generalised or compared easily.

Moreover, this process by-passed commercial interests which therefore did not drive and dominate this agricultural innovation (Prasad, 2020). That the diffusion of SRI did not rely on market mechanisms and forces and came from outside the formal scientific establishment, little support was garnered from established research institutions (Prasad, 2020; Beumer *et al.,* 2022). The lack of support from recognized and respected agricultural institutions in the first phase of SRI dissemination slowed down the process of diffusion as this was left in the hands of few researchers, civil society organisations, and farmers.

Even so, SRI methods have still expanded to reach at least an estimated 10 million farmers on around 7 million hectares (Prasad, 2020). Today, SRI is widely accepted and recognized by the scientific community as a valid set of principles, but its 'open system' and 'open source' features can still cause friction if looked at through the lens of the Green Revolution framework.

As the biggest investment needed to upscale SRI methods is an investment in knowledge, this agroecological approach to rice production represents an opportunity for everyone involved in the rice sector. SRI requires farmers, researchers, the private sector, and policymakers to think outside of their boxes and to find the best way to adapt a fairly simple set of sound, scientifically-proved agronomic principles to their own context of application. The cross-cutting nature of SRI, touching upon a number of global challenges, makes it an attractive component for global initiatives that aim to ensure a livable future for humanity. Moreover, the decades of research and development of SRI methods provide an extensive knowledge base and the current low rate of application makes today a favorable time for investing energy and resources in the upscaling of SRI methods.

Methods

This paper is not based on empirical research, but rather summarizes insights from the work of SRI-2030, and it outlines strategy, hopes and perspectives for the upscaling of SRI methods. The rationale of the paper assumes that SRI methods are an important part of the solution to the many challenges of the rice sector, and that the implementation and promotion is still at the very initial phase. The multiple discussions with stakeholders consulted by SRI-2030 in the past months have offered food for thought and different views that were helpful in drafting this work. However, the opinion of the various stakeholders consulted may differ on how some of the issues are to be approached, on where emphasis for solutions should be put, and on the conclusions drawn. Therefore, even though the paper reflects and summarizes views and ideas of various rice sector stakeholders, responsibility for the paper's content lies entirely with SRI-2030.

Results

Identified challenges and potential approaches

Training and awareness

A lack of training and awareness are, in many cases, the two greatest constraints limiting SRI adoption (Laksana and Damayanti, 2013; Mwidege and Katambara, 2020). The SRI-Rice team from Cornell University visited about 45 countries between 1997 and 2004 and helped establish local networks of SRI experts and practitioners. However, the diffusion of SRI methods has had little direct, in-person promotion, and has been mostly 'remote'. The transfer of knowledge has been almost entirely through 'hard copy' and 'soft copy' transmission, aided by the internet.

SRI methods have been disseminated mostly through civil-society organizations or government-NGO partnerships. Generally, conventional extension services are accustomed with a top-down approach which doesn't fit the participatory processes needed for a well-suited adaptation of SRI principles. Government-NGO partnerships have been proven useful for extension services to successfully upscale SRI, especially when committed local SRI experts have been able to instruct extension service's staff.

For getting an acceleration of SRI use, the most beneficial driver for spreading awareness and skills training would be the systemic promotion of SRI by governments at a state and national level (Barrett *et al.,* 2021; Mwidege and Katambara, 2020), accompanied by effective provision of training from well-trained and well-motivated extension services agencies developing farmers' understanding and application of skills (Laksana and Damayanti, 2013). There is some evidence that access to extension services positively impacts the likelihood of adoption of SRI (Bello *et al.,* 2022).

Farmer field schools (FFS) have been effective mechanisms for SRI farmer training with the knowledge and skills required to practice SRI and water conservation (Kabir and Uphoff, 2007). This methodology increases farmer-to-farmer transfer of knowledge. In the Myanmar case reported by Kabir and Uphoff, there was a five-fold multiplier effect. More contextual research would allow farmers to make adaptations and evaluations of SRI methods and come up with effective practices for their ecosystems. Participatory management by farmers, extension organisations, and research organisations will further increase suitability of practices, and thus increase yields and reduce inputs required.

Integration of SRI with other agroecological practices

A further opportunity to better understand the potential of SRI and expand its implementation is the quantification of the impact on yield and carbon footprint achievable when SRI is combined with other agroecological practices. According to Singh *et al.,* (2021), agroecological practices are mostly analysed in an isolated way, and it is only in the past few years that researchers started focusing on the combination of multiple agroecological 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 (ibid). Some studies have been conducted on the combination of SRI and CA (Kassam and Brammer, 2016). As both SRI and CA systems focus on improving ecosystem services, and particularly promoting healthy soils, their combination is considered to further support root development and consequently enhance the cropping systems' performances (ibid). Some other studies have focused on the opportunity to practise intercropping in rice farming under SRI management, resulting in further water savings, increased yield and net income for farmers (Shah *et al.,* 2021). More can be done to integrate agroforestry practices into rice systems by planting trees on fields' borders or even in the fields in large-scale systems. The utilization of biochar and the inoculation of beneficial microbes in combination with SRI methods should be pursued and the reliance on synthetic inputs should be lowered or avoided, as is being pursued in India through Natural Farming programs. The combination of SRI and other agroecological practices deserves further promotion and evaluations across various agro-climatic conditions to better understand the environmental, economic, and social implications (Kassam and Brammer, 2016).

Government Investment and Promotion

The general lack of support from state and national governments has been a major constriction to SRI adoption in several countries. As previously mentioned, the open-source approach and non-proprietary knowledge-sharing that has characterized the dissemination of SRI methods did not rely on market mechanisms and happened outside the formal scientific establishment, therefore compromised the participation of the private sector in spreading SRI. The lack of private sector investment and the fact that other institutions are missing in action reduced governments' support of SRI dissemination.

However, thanks to years of research and field demonstrations confirming the effectiveness of SRI methods in sustainably intensifying rice production, some local and national governments have embraced SRI methods and actively supported their dissemination. Some state governments in India are notable examples of the benefits that can be gained when SRI is accepted by a government. The states of Bihar and Tripura have catapulted SRI adoption through promotion of SRI practices. The number of farmers practising SRI in Bihar rose from less than 1000 in 2005, to over 160,000 by 2007 due to active political support (Verma, 2013).

Therefore, government support has been shown to enable faster dissemination of SRI practices. Also, centralized programs for the upscaling of SRI methods should be better able to integrate cross-cutting research of SRI with newer technologies, such as rice varieties, genetics, mechanisation, or e-agriculture systems, as conducted by leading research institutions therefore helping to move SRI into mainstream appeal. As of today, 10 countries have officially included SRI methods in their Nationally Determined Contributions (NDCs) for reducing methane emissions as a strategy for mitigation of and/or adaptation to climate change. However, intensive advocacy work is still needed as none of the major rice-producing countries have yet included SRI in their NDCs.

Access to Appropriate Equipment

Equipment is an important investment opportunity as the use of machinery rapidly decreases the time and labour required for transplanting and weeding, so it can increase productivity, and also decrease drudgery. Multiple types of weeders and seeders have been developed to suit different environmental and social contexts. However, the quality of the equipment is not always appropriate, and the price is often a barrier for rural farmers. It has been recommended that farmers invest together for purchasing appropriate mechanization for their SRI activities (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 for mechanical weeders and other inputs.

Alternatively, many villages have or can mobilize service providers who possess one or more pieces of equipment and rent to small-scale farmers when and as needed, thus the cost of machinery per farmer is reduced. Otherwise, farmer groups can buy their own machinery and share it in turn. As demand for equipment increases, there is an opportunity for job creation as an equipment supplier, or as a service provider. Opportunities for equipment development can be increased with computer-assisted design (CAD) visualisations, open-source file-sharing of ideas, and crowd-sourcing of designs. For example, the US 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). Since in some areas of the world, rice is cultivated also by large-scale farmers, there is an opportunity to develop appropriate machinery to implement SRI methods on a larger scale and with fully-mechanized operations.

The private sector is the main stakeholder for the development of SRI equipment, but governments and public institutions should create the best conditions for the market to flourish and contribute to the upscale of SRI methods as they ultimately benefit the whole population.

Marketing Channels

Uncertified SRI rice rarely receives a higher price at market than conventionally grown rice, even when grown organically. However, certifications are a high-cost expenditure for smallholder farmers. Support from the government for certification and specialized marketing channels could ease this cost or by subsidising organic fertilisers rather than only inorganic fertilisers as is now the case. This expenditure can be considered as part of a country's NDC, as reducing applications of inorganic nitrogen will reduce nitrous oxide emissions (Skinner *et al.,* 2014), while also increasing carbon sequestration through improved soil health (Ghosh *et al.,* 2012). Furthermore, there are no channels in the international market for the sale of SRI rice to large corporations within countries that import a large quantity of rice, such as the US and Saudi Arabia, which are under pressure to achieve NDCs and reduce GHG emissions.

There should be international market channels with the function of conserving rice biodiversity, enhancing soil quality, and reducing water usage, where SRI certification would justify a higher price, especially if the higher nutritional quality of SRI rice were documented. Alternatively, Tamil Nadu has a Department of Agricultural Marketing that helps farmers to sell agricultural produce through a statal facilitation platform. The Uzhavar Sandhai Scheme was established in 1999 to increase accessibility to market by reducing market costs and supporting farmers who sell their produce directly to consumers to make more income from their production (Agriculture and Farmers Welfare Department, 2021).

Carbon Credits

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 system is, among other considerations, an effective way to improve the ability of soil to sequester carbon as these rhizosphere microorganisms are efficient in converting the CO^2 present in the atmosphere into biomass carbon (Xu *et al.,* 2017).

The adoption of SRI principles also enhances enzyme activities in the rhizosphere, as reported by Rajkishore (2013), which improves carbon sequestration in rice fields (Rajkishore *et al.,* 2015). Watkins *et al.,* (2009) have proposed that carbon credits can boost the adoption of no-till systems for rice farming, which also promotes carbon sequestration, and the same concept could be valid for SRI.

By avoiding flooded conditions, SRI methods drastically reduce methane emissions. However, as far as we know, there are currently no projects rewarding SRI farmers with carbon credits for their contribution in sequestering carbon. Various actors have been working to fill this gap and develop a carbon credit marketplace for rice farmers who sequester carbon and mitigate methane emissions. This could therefore be an opportune time for investments and research on ways and means to enhance the adoption of SRI practices by making it possible through the involvement of SRI farmers in carbon credits schemes.

Conclusion

The global nature of the challenges faced and created by the rice sector requires systemic changes, and we should not be satisfied with small or medium-scale implementation of SRI methods. To meet the challenges of halting and reversing climate change, reducing water consumption, and combating hunger and poverty, there should be policies that are supportive and conducive for farmers, researchers, the private sector, and the civil society as well as government agencies to seriously upscale SRI and introduce innovations in the rice sector.

Appropriate measures should be taken to direct farmers toward the adoption of practices that benefit themselves, the environment, and the whole society. Research that contributes to sustainable intensification of rice production should be supported, and the private sector should be encouraged through economic incentives to back up the transition to a more agroecological rice production. Policies should also incentivise the marketing of quality rice by supporting better prices for more environmentally-friendly rice.

Fortunately, the building-blocks for such reorientation are here. Carbon credits are becoming more and more of an effective method to remunerate environment-friendly activities, and the rice sector should be included in these arrangements as it has a huge potential. Technologies for monitoring GHG emissions and C sequestration from satellites are becoming more and more sophisticated every year. Large players in the private sector and food retailing are realizing the impossibility of continuing with 'business as usual' and are starting to adapt (Sustainable Market Initiative, 2022).

International organizations and donor agencies are supporting national states with grants for the implementation of sustainable agriculture. Official documents for national governments to undertake responsibility for reducing GHG emissions have been signed and are being implemented through Nationally-Determined Contributions (NDCs) (Hong *et al.,* 2021). The world is waiting for more States to join and play their parts in addressing today's and future challenges. India does not mention rice in its NDCs and states that no targets will be made as they do not want to be bound to sector-specific mitigation actions. Being India the second largest emitter of GHGs from the rice sector, an official target for the mitigation of methane from rice paddies would encourage the transition toward a more sustainable rice sector.

SRI-2030, together with SRI-Rice, will play roles in facilitating this transition, helping the multiple actors and stakeholders from all the sectors involved to better communicate and collaborate. But there is little time remaining to reverse our presently disastrous course, for dealing with climate change, water scarcity, hunger and poverty, and the threat of food insecurity. We need a sense of urgency, at all levels of government and society, to undertake actions and policies that will uptake and upscale SRI methods and their extrapolation to other crops through SCI to have a prosperous and sustainable future for people and the environment.

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Transitioning to Sustainability: Managing Institutional Change in SRI

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Transition to sustainable food systems is imperative with climate change and extreme weather patterns increasing the vulnerability of agriculture. In India, Green Revolution credited with helping India's food security, is now seen to have resulted in significant negative externalities that include biodiversity loss due to monocultures, and a systemic lock-in where continued use of agrochemical inputs has not only increased the ecological footprint of agriculture but comes at significant costs to the Indian government with the fossil fuel-based fertilizer import and subsidy bill reaching a record USD 27.2 billion in 2022-23.

The need to go beyond productivity and populist frames and transform agricultural systems towards sustainability has been highlighted by a network of scholars working on agrarian studies in India (Kumar et. al, 2020). Despite a plethora of emerging alternatives under the broad rubric of agroecology, sustainable transitions in Indian agriculture, we suggest, is caught between institutional inertia and lock-ins (Vanloqueren and Baret 2009) of its vast agricultural establishment. No national occupational group in the world contains more poor people, than India's agricultural sector. Moving beyond the post-independence pangs of production deficit, India today is a leader in agricultural commodities in the world in vegetables, buffalo meat, rice, wheat, and sugarcane. While crop yields have increased over time, farm incomes have stagnated or declined. Agriculture's contribution to GDP in India has fallen to around 14%, yet 50% of the workforce continues to partially rely on agriculture for their livelihoods. Rising input costs and stagnating output prices coupled with low yields make for low returns. Rural households in several Indian states experience negative growth in real net incomes. Productivity growth in field crops appears to have stagnated owing to a combination of poor soils, water constraints and unbalanced fertilizer use. The current crisis in Indian agriculture is often attributed to a historical policy that privileged self-sufficiency over sustainability (Kumar *et al.,* 2020).

Any discussion on farming and agriculture in India is incomplete without reference to the longstanding agricultural crisis and distress of farmers. The number of farmer suicides in India during 1995-2012 was more than 300,000 (Nagaraj *et al.,* 2014). High dependence on external inputs—seeds, fertilizer, and irrigation water, coupled with increased indebtedness—has meant that Indian farmers are experiencing a loss of agency, "agricultural individualization," and "knowledge dissonance" (Vasavi 2012), and deskilling (Stone 2007). The Indian farmer is vulnerable to game-changing trends that include increased costs, declining and fluctuating commodity prices, and high variability and unpredictability of weather (Prasad 2016).

This talk would focus on how this transition has occurred in the System of Rice Intensification (SRI) in India. It draws upon earlier research on the innovation history of SRI, the reluctance of the scientific establishment in building on the growing research on SRI in India despite the absence of any coordinated research program (Prasad, 2020), the need for building on the creative dissent of scientists who have dared to envision an alternative future, the importance of networks and innovation spaces in promoting alternative visions and the need to learn from alternate scaling models beyond the department of agriculture, such as the rural livelihood missions and the critical importance of building on farmers knowledge and their adaptive capacities in upscaling SRI (Prasad 2006, 2014, 2016, 2019, 2020). The paper argues that there is significant potential for overcoming technological lock-ins in policy if there is greater attention paid to institutional innovation and change.

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Policy Needs for Sustainable Crop Management for Achieving Net Zero Emissions

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With increasing concerns on the sustainability of the modern agriculture practices, alternative approaches to crop production are emerging based on the principle of agroecology. These approaches aim to achieve higher output with less use of water, energy, nutrients and capital. Sustainable Crop Intensification (SCI) is one such approach practised by small holders in India and few other developing countries largely due to the efforts of NGOs. Success stories of small farmers adopting such practices and achieving higher yields economic gains are well documented both from India and other developing countries. In India, we see some Government Support to these approaches in terms of policy and financial incentives in states like Bihar. Related with this approach are Conservation Agriculture(CA), Agroforestry, Integrated Farming systems, IPM etc which are also supported and researched by main stream scientific community.

While conceptually, these practices are considered nature friendly, less capital, energy intensive and climate resilient, in practice farmers face many difficulties and even Governments find it difficult to upscale them to larger areas. Some of these constraints are technological and others are policy related. The major weakness is the lack of adequate and continued research support for SCI. Since it is more knowledge and skill intensive rather than input driven, continuous training and capacity building of farmers are required to sustain and increase the adoption. There are other issues related to high labour dependency, water management, handling machinery and tools etc which need to be overcome.

In addition to being less resource demanding and nature friendly, SCI is claimed to help in climate resilience. Crops grown under SCI can adapt to adverse climatic events in a better way due to improved root system, and more importantly, they emit less greenhouse gasses. There are many reports of reduced methane emissions with aerobic rice, AWD, SRI but the data on N20 are conflicting. Very little work is done on emissions from other crops like sugarcane, wheat, maize, mustard, pulses and vegetables where SCI is promoted. India has committed for Net Zero Emissions by 2070 at the Paris agreement. Though agriculture is not part of this commitment, India cannot achieve net zero without reducing emissions from Agriculture. There is an urgent need to generate data on emission reductions linked to SCI in all these crops both directly due to improved water and nutrient management and indirectly due to reduced energy use and recycling of crop residues to have a clear understanding of the contribution of SCI towards emission reduction in Agriculture sector.

The Current policy frame work in the country has evolved to promote input intensive agriculture. Subsidies on fertilizers, free power and water in many states counter the very objective of resource use efficiency. The efforts to promote eco region specific cropping systems has also not succeeded so far. Rainfed Agriculture which covers 50% of the net sown area has not received adequate attention while planning and resource allocation. The most cited constraints in adoption of SCI are high labour requirement, more drudgery, lack of appropriate machinery for certain specific operations and operational difficulties in water, nutrient and weed management. The yield advantages are not established in all the crops despite increase in labour costs. There is an urgent need to revisit the existing policy and incentive structure in agriculture. Some suggested steps to promote SCI include;

1. Not all areas and crops may be suitable to adopt SCI. As a first step we need to identify and map areas and crops, where SCI can be promoted based on climate, soils, water management systems and the results from on station and on farm experiments. This needs to be done by the states with guidelines from the centre.
2. Include some of the high labour intensive operations in the MGNREGS shelf of works even if they are done on individual farmers' fields. It can be restricted to small and marginal farmers to begin with. The list

of operations can be finalized through a national consultation.

3. Promote small farm mechanization appropriate for SCI, custom hiring centres through FPOs and reduce dependence on large machinery which need more fuel and cause more emissions

4. Support research on agro ecology and regenerative agriculture both in Public and private institutions. Institute a mechanism to learn from the field experiences of the Non-Government Organizations(NGOs)

5. Continued emphasis on capacity building and training of farmers. Dedicated budget line to be provided in each state for farmers training and exposure visits to successful farmers' fields practicing SCI and research stations/KVKs.

6. Carbon finance projects are just picking up in India with few successful projects already approved in the areas of water shed management, agroforestry, natural/organic farming, conservation agriculture etc. Government of India to come out with a policy on carbon markets in agriculture with in the country and payment for ecosystem services

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Evolving Seed System for System of Crop Intensification: Policy Needs

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Abstract

System of Crop Intensification (SCI) evolved as an extension of applying the principles of System of Rice Intensification (SRI) to other crops, aims at improving agronomic performance while conserving and enriching the natural resources. It is largely presumed to be crop and variety neutral. Crop performance is a function of genotype and environment. Ideal plant type of released varieties in several crops is conceptualized, developed and evaluated in monocropping system and not tested for SCI needs. Success of any crop improvement program depends on setting up of priorities based on community needs and consumer preferences. There are few examples of demonstrating release of farmer varieties through participatory varietal selection (PVS) and participatory plant breeding (PPB). Specific plant type suitable and breeding approaches for SCI are briefly discussed. An attempt is also made to address the need for linking SCI with identification of suitable genotype, ensuring access to quality seed supported by an appropriate seed system in place and to highlight the policy needs in the context. An alternative seed system for the varieties identified for SCI is proposed.

Keywords: Crop intensification, seed system, traditional varieties, crop improvement and Seed Systems policy

Introduction

Crop improvement, is an age old dynamic evolutionary process of utilizing genetic diversity based on communities' needs and preferences. The conventional breeding procedures aim at developing improved varieties or hybrids or transgenics targeting mostly high yield or quality. Such developed varieties are linked to institutionalised seed system. Strategies largely follow top down approach. Farmer participatory approach is a recent development but is still not practiced at scale. Green revolution in India succeeded in meeting the historical need to achieve food security. Crop improvement process in Green Revolution was focused on exploitation of genetic potential in response to inputs (seed, water, fertilisers, pesticides etc.). Over time inputs were indiscriminately used leading to soil, water, climate and biodiversity emergencies. Exploitation of genetic potential reached its limits with available strategies and productivity stagnation is of common experience in several crops.

In view of global focus on agroecological farming, there is also a need to relook at varietal performance in the context of nature-based package of practices; called agro-ecological, regenerative, organic or natural farming. There are evidences that under such nature based farming practices, traditional varieties outperform formally notified varieties. SCI has potential to enhance yield of selected crops with positive benefits to ecology and environment. Significant evidence is also accumulated on the success of SCI in selected crops.

However, the effort of exploring the genetic potential of crop varieties that respond to SCI needs to be focused with appropriate policy support. Location specific, highly domesticated landraces which co-evolved over time with the eco-system may have heritable traits suitable for SCI but need to be validated. In-situ conservation and evaluation followed by varietal development and identification of such traditional varieties is the need of the hour. In order to make the quality seed of selected varieties accessible to farmers an effective alternative seed system is required.

The system of crop intensification (SCI) which emerged from the experiences of System of Rice Intensification (SRI) provides a modified strategy for "sustainable intensification" to meet the global food security. SCI is successful in a wide range of crops like rice, finger millet, wheat, sugarcane, tef, mustard, soya bean, kidney bean and several vegetables (Abraham *et al.,* 2014). As per Abraham *et al.,* 2014, in SCI, agronomic management relies on early transplanting, wider spacing or reducing crop density, soil enrichment with organic matter and better water management. The emphasis is on allowing each plant more room to grow both above and below ground. The success of any crop improvement program does not rely on genotype (G) or environment (E) alone but on good combination of G x E. In SCI, effect of E prevails over G and identification of heritable and stable traits over modified agronomic management is the key step. A re-orientation of varietal development in the context of changing climatic scenario and SCI is essential.

The present centralised system of varietal evaluation and release is restricted to improved varieties which are highly homozygous and homogenous and are often vulnerable to biotic and abiotic stresses. In the context of changing climatic scenario and rampant nutritional insecurity, landraces or traditional varieties which co-evolved over time within the eco-system gained importance. The scope of present seed system catering to the needs of formal sector can be further widened to fit into the emerging seed needs of SCI. The present paper is an attempt to highlight policy needs for an alternative seed system.

Crop Improvement and SCI

Crop improvement activities over the decades have been tuned to reorient the objectives and meet the global challenges of food security. Sustainability, nutrition, climate and pest resilience are gaining importance as breeding objectives in the recent past. The System of Crop Intensification (SCI) aims to achieve higher output with less expenditure on land, labor, capital and water by making modifications in crop management practices (SRI-2016). Four principles of crop management practices broadly included to (i) establish healthy plants both early and carefully, taking care to conserve and nurture their inherent potential for root growth and associated shoot growth (ii) reduce plant populations significantly, giving each plant more room to grow both above and below ground (iii) enrich the soil with decomposed organic matter, as much as possible, also keeping the soil well-aerated to support the better growth of roots and of beneficial soil biota and (iv) apply water in ways that favor plant-root and soil-microbial growth, avoiding hypoxic soil conditions that adversely affect both roots and aerobic soil organisms (SRI, 2016).

SCI does not rely only on smart crop varieties that yield with inputs; but, need robust and sustainable genotypes that can efficiently utilize early establishment, wider spacing, better water and nutrient management. Any additional growth, both above and below ground, need to be carefully exploited with minimum loss due to pests and diseases. Among the major crop management practices of SCI, reducing plant populations and enriching the soil with decomposed organic matter with better soil and root management are applicable to even direct seeded rainfed crops.

SCI and relation to plant types

Plant architecture or plant type concept until now has been framed for solo cropping with crop wise optimum plant population. Most modern high yielding varieties, bred specifically for monoculture, may not be suitable for diverse cropping systems (Bourke *et al.,* 2021). Plant type needs of high density adaptation such as short stems, few tillers and erect leaves are different from low density adaptation needs such as high tillering and prostrate leaf stature (Donald, 1968). High yielding cultivars at high density lose their advantage at low density (Reynolds *et al.,* 1994). Performance of genotypes at low density is mostly linked to the plasticity of traits especially tillering and size of upper leaves in comparison to the normal density. Further, in rainfed situations, cropping systems needs are different from irrigated mono cropping approaches. Intercropping, mixed cropping and poly-cropping approaches are often required not only to harness the natural resources efficiently but also to cater to the nutrition and livelihood needs of small holder rainfed farmers.

Selection of best performing genotypes in pure stands relies on a two-dimensional approach where in competition between plants for soil (land) and light (plant height) is considered. In SCI approach, additional dimension of crop competition for both shoot and root growth are added. Present breeding approaches largely ignore the benefits of positive inter- and intra-specific interactions between crops or genotypes and ignored the traits modified with companion crops (Bourke *et al.,* 2021).

Several studies established the merit of crop intensification by mixing species or genotypes in a range of possible spatial and temporal arrangements, over monoculture in terms of efficient nutrient uptake and biocontrol (Boudreau, 2013, Li *et al.,* 2014, Brooker *et al.,* 2015). This may be due to the complimentary uptake of either water or nutrients, when the root systems are spatially or temporally separated

(Henry *et al.,* 2010; Postma and Lynch, 2012) or light capture and light use efficiency due to differences in shoot architecture and photosynthetic efficiency (Stomph *et al.,* 2020, Yu *et al.,* 2015). Efficiency of crop intensification is also measured in terms of reduction in occurrence of weeds due to their early suppression, low incidence of pests and diseases due to host dilution, allelopathy, microclimate, physical barrier effect due to combination of multiple crops (Ampt *et al.,* 2019).

Plant traits which are beneficial in a specific cropping pattern may not be suitable in another pattern due to three types of plant to plant interactions (i) Competition (ii) Complementarity and (ii) facilitation leave behind positive intercrop performance (Li *et al.,* 2013, Li *et al.,* 2014). Ecological perspective coins the process as "niche differentiation" where species evolved to avoid each other's specific niches or direct competition (Meilhac *et al.,* 2020) through a specific trait called plasticity. It is the ability of a plant to morphologically adapt its phenotype to a particular environment. In SCI models, plants tend to be more plastic compared to normal cropping, as they face different micro climate both above and below ground coupled with vigorous root and shoot growth. Plasticity of traits involved in competition like root growth, leaf size, leaf angle or orientation, petiole length, stem growth may be further enhanced through breeding efforts.

In a field experiment, five commercial winter wheat cultivars possessing unique architectures were grown under narrow (NI, 17.5 cm) or wide intercrop rows (WI, 35 cm) at the same population density (170 seeds/m^2) in France. Phenotyping included traits related to development (leaf emergence, tillering), morphology (dimensions of organs, leaf area index) and the geometry (ground cover, leaf angle, organ spreading and orientation). WI led to lower number of tillers compared to NI and later compensated by lower tiller mortality. Genotypic differences were also observed while understanding plant responses to spatial heterogeneity in addition to novel information to simulate light capture in plant 3 D models (Abichou *et al.,* 2019). There is huge diversity available among the traditional varieties for a variety of crop intensification systems and cropping system needs. Authors therefore propose that policy based efforts be directed to study and select among the local traditional varieties along with the traditional knowledge as priority for SCI.

Functional-Structural Plant (FSP) Modelling

Traditionalcropmodellingconceptsrestrictthecombinations of species phenotypes for crop design optimisation due to limited parameters for phenotyping the species and altering the plant arrangements. In FSP models, plant development, growth and architecture are simulated in 3D over time and governed by effects of competition for light, water and nutrients (Bourke *et al.,* 2021). The FSP model is mainly developed to record plant development traits like leaf size and angle, stem length, root branching and thus ideally suited to explore the interaction between plant traits, arrangement and performance in tomato monocrop, wheat-pea mixtures, root traits in single bean plants (Bourke *et al.,* 2021). Further details of both above and below ground processes in FSP help in arriving at a combination of species phenotype and plant arrangement.

Breeding approaches for SCI

Ideotype breeding approach led to higher genetic gain for grain yield in rice than under selection for yield alone (Peng *et al.,* 2008). Ideotype breeding approach is a strategy to improve complex traits by changing simpler traits that are positively correlated with them and avoid unfavorable genetic correlations which offset the merits of traits related to ideotype (Breseghello, 2013). After the success story of semi dwarf rice, model plant type designed as a hypothetical ideotype or new plant type with few tillers, long panicle with >200 grains and lodging resistant thick stems however failed to outyield the best checks. In SCI, ideotype need to include a range of positive interaction effects that optimize collective performance. Brooker *et al.,* 2021 gave a detailed description of favorable interaction effects which is specific to context, crop and experiment conducted. In-silico ideotypes may also provide novel insights if traits (yet-unidentified) with significant agronomic impact are predicted (Louran *et al.,* 2020).

Conservation and evaluation of existing genetic resources is mostly confined to yield, yield components, biotic and abiotic stresses in many crops. SCI involves a complex interaction of G x E and it is crucial to identify heritable traits with additive genetic effects over a period of time. Several stable plant traits that contribute to SCI, need to be carefully identified. Genetic correlations between heritable traits under SCI need to be thoroughly studied to achieve further crop improvement.

In rice, tiller and panicle number are the key determinants of plant architecture even under SCI conditions. Genetic basis of tiller dynamics was revealed by genome-wide association studies using gene sequencing and SNP data set of Korean rice accessions (Zhao *et al.,* 2020). Genes involved in developmental phase transitions, along with genes modulating tiller development suggested rice tillering pattern at different growth stages (Zhao *et al.,* 2020). Such studies need to be initiated in crops that are highly successful under SCI system particularly finger millet that is proved double its yield in response to SCI (Srijit Mishra, 2020).

There are immense possibilities of exploring breeding approaches to develop genotypes that are suited to SCI. However, it is expected that screening the location specific and cropping system based traditional varieties may enhance the value of SCI and reap the benefits.

Seed Systems

A seed system is a set of activities related to seed production, access and use by farmers contributing to crop improvement. Standard formal seed production system aims at providing quality seed access to the farmer through a process monitored and regulated under the provisions of a national act.

Seed systems are often categorized into three types: formal, semi-formal, and informal. Formal seed production system in India with its standard seed production mechanism meets about 60 to 65% of seed needs while the remaining needs of farming community are met through an informal or semi-formal seed sector. Quality seed alone contribute 15-20% depending on the crop and there is a scope to further increase up to 45% with efficient management of other inputs.

Seed system components

A seed system includes a series of crop improvement activities contributing to variety development and seed production with an ultimate goal to cater to the needs of farmers. Sustained increase in agriculture production and productivity necessarily requires continuous development of new and improved varieties of crops and efficient system of production and supply of seeds to farmers. A robust institutional framework for seed production both in the public and private sector still is unable to meet the demand for good quality and quantity seed in time and at affordable price.

Farmers rely on farm saved seeds while seed replacement rate is as low as 10 per cent in some states for specific crops. The prescribed norms of Seed Replacement Rate are 33% for self-pollinated crops, 50% for cross-pollinated crops, and 100% for hybrids (seed net portal). It is an established fact that a strong co-relationship exists between seed quality, SRR and seed yield of crops. Seed quality essentially depends on genetic purity of varieties or parental lines maintained in different classes of seed *viz*., nucleus, breeder, foundation, certified and truthfully labelled (TFL) seed. As majority of the self-pollinated crops of cereals, pulses, oilseeds and millets operate through farm saved seeds or traditional varieties, the concept of seed classification is of not much concern.

Alternative Seed System

SCI, an unexplored and dynamic crop system still has scope to contribute to sustainable agriculture through reorientation of seed systems. In the absence of suitable high yielding varieties for SCI model, exploring and exploiting traditional varieties is one good option. A successful example of Odisha Millets Mission (OMM) included collection of 97 finger millet landraces followed by purification by progeny row selection and participatory varietal selection of nine landraces in 28 blocks of seven districts in farmers' fields. The trials were conducted in a RBD with three replications using microbial organic inoculants such as *ghanajeevamruta* and *jeevaamruta*. Among them, four varieties *viz*., Kalia (P), Bati, Bharati and Mami were higher yielding (>40%) over the state check, Arjun (1098 kg/ha) and Kalua (1218 kg/ha) (Mohanty *et al.,* 2022). Majority of the farmers in seven districts preferred such high yielding landraces or traditional varieties but seed multiplication and availability need to be addressed.

Existing seed systems support only notified and released/ registered varieties. The need for an alternative seed system led to discussions on increasing the access of quality seed to farmers specific to each eco-geographic region, mainstreaming landraces based on traditional knowledge, protocols for collection through melas, evaluation, release, conservation and seed supply chain. Alternative seed system exclusive to landraces or traditional varieties as a parallel channel is approved by the Government of Odisha. Such a system considers the farmer fields data recorded in crop cutting experiments; evaluation to release is confined to the specific traditional varieties and crop cultivated niches, community needs and preferences recorded and valued by involving the community representatives from selection to release process. There is a need to develop such a seed system for the varieties that are identified or developed for SCI.

Key Policy needs

Alternate seed systems mainly emerged to increase access of farmer preferred, location and culture specific traditional varieties. Efforts to mainstream traditional varieties that are found suitable to SCI need collaborative efforts between institutions and farmer centric organisations. Collection of location specific traditional varieties through conducting '*Melas*' and their conservation needs joint efforts. Expertise available in institutions may help in guiding phenotyping and conducting participatory varietal trials in farmers' fields. Multi-location trials with an emphasis on altered agronomic practices as per SCI or farmers' practices using organic agriculture will help in identifying suitable varieties.

Protocols for location specific identification and release of traditional varieties were initiated similar to OMM approved process may be developed by formulating state level apex committee including representation of State Agriculture Department, ICAR, OUAT, SSTL, NGOs, custodian farmers etc. Committee will consider promising location specific landraces based on the traits of value to the communities with due importance to performance under SCI in addition to food, nutrition, organoleptic traits, climate resilience, pest and disease resilient and income of the farm families. Apex committee may also set up a Sub-committee from time to time to monitor execution, monitoring and conservation of farmers' varieties. This includes a landraces release sub-committee to develop seed standards, certification protocols, scrutinise applications for release of landraces. Though the effort is on mainstreaming the release of landraces on par with CVRC/SVRC and PPV & FRA, it is imperative to keep the SCI varieties developed from traditional varieties in public domain and there would be no exclusive rights to any individual, organisations or community.

Conclusion

SCI, an emerging system of crop cultivation has potential for crop improvement. As of now there are no specific varieties developed for SCI. Plant types and breeding approaches suitable to SCI specific varieties are discussed with scientific basis. A history of crop improvement success stories indicates unilateral investment and importance to genotype alone ignoring the role of crop management interventions is not balanced either to achieve targeted yield and quality or ensuring the ecosystem health. As SCI is still an emerging field, research and public investment need to focus on selection of genotypes that performs well in specific niches in the changed agronomic packages of SCI. Exploring the potential of traditional varieties adapted well in specific ecological niches can be a way forward. Seed systems may be further strengthened to widen the scope of mainstreaming farmer preferred, location specific, highly adaptive traditional varieties.

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System of Crop Intensification – An Experience with SRI Policies and Perspectives

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Abstract

Indian population growth by 2030 is expected to be 1.515 billion surpassing China with the present trend of reduction in arable land created a challenge on the sustainability of food production system. Countries of Asia, Africa and Latin America due to the population pressure and to safeguard the food security have adopted a system of crop intensification among various crops like wheat, finger millet, sugarcane, mustard, soybean and kidney bean. The system of crop intensification along with new technologies could show crop improvement in the growth of yield during the previous decade (2011-12 to 2021-22) in rice-wheat. There is an evident yield gain particularly in SRI cultivation as reported by many researchers. The technologies of SRI advocate intensive use of some inputs combined with organic components making the plant sturdy for better intake of nutrients. Studies on standardization of the techniques for SCI by repeated experimentation are observed as a lacuna by the present study.

The recent alternatives like using less quantum and more efficient use of water recommended by dry seeded rice techniques in compression with SCI techniques were not tested with ground reality. The changes perceived with the policies related to irrigation, procurement, price policy and trade policy are examined in the present study. Additional areas brought into irrigation were always converted into rice fields. Due to area expansion and also by the potential yield gains by SCI, the whole enhanced production will reach the market for want of marketing. This excessive supply of rice reported by the balance sheet of rice which resulted in price crash, price volatility etc. Curbing the unnecessary area expansion under single mono cropping by diversifying with crops like millets, pulses and oilseeds.

The excessive supply also creates a burden on procurement of grain which necessitates additional storage space public and private and payment burden on Central government as well as agencies like FCI. Instead of MSP as a whole a differential payment approach also can be adopted to reach more farmers and cover volumes of production. Moreover, additional supply may create more exports but the question of virtual water trade arises there resulting in a dilemma to expand exports or not. On the other hand, India being a strong exporter of rice can influence the imports of the exporting counties and flare up the food inflation in the world. All the above discussions favor the controlled and balanced production which may be affected through the SCI *i.e.*, achieve the desirable production through reduced area under rice thereby allocating the remaining areas in cultivation of diversified crops. The experiences of rice can be replicated in other crops also.

Introduction

Population policy adopted during the past fifty years from 1970 to 202 resulted in a notable decline in annual rate of population growth in India from 2.2 to 1.0 per cent compared to 1.2 to 0.1 per cent in the US and 2.8 to 0.1 per cent in China. Even this controlled growth could not match with the figures of US and China with an expected population of 1.515 billion, surpassing China 1.416 billion by 2030 creating pressure on increasing productivity per unit area posing a challenge to the existing food production systems (https://www.weforum.org/agenda/2022/08/world-population-countries-india-china-2030).

Per capita arable land in India in 1961 is 0.34 ha which declined to 0.11 ha in 2020 (World Bank, 2020), will be diminishing further by 2030 causing a drastic shrinkage in arable land thrusting on accelerated productivity in all the food crops to augment the need to feed the expected additional population of 0.104 billion.

Productivity of the world's major food crops (rice, maize and wheat) already reached to a stagnation (Deepak *et al.* 2012). Concerns have been expressed two decades ago that rice – wheat system is causing environmental degradation along with stagnation in productivity threatening food security (Agarwal *et al.* 2000). The twin threatening issues were stagnation productivity and increasing population left the policy makers with a challenge of expediting for techniques of more crop per drop and conservation of the natural resources. Due to depleting water resources and soil fertility status, Asia and Africa witnessed crop intensification techniques in the form of System of Rice Intensification (SRI) and extrapolated its experience to other crops like wheat, finger millet, sugarcane, mustard, soybean and kidney bean (Binju *et al.* 2014). During the last two decades the CAGRs for rice yield were estimated to be 1.59 per cent (from 2001-02 to 2010-11) as compared to 1.69 per cent (from 2011-12 to 2021-22). In case of wheat the CAGRs for the above periods were found to be 1.20 and 1.74 per cent for the same periods in India. Part if this varied improvement in growth during second period can be majorly attributed to adoption of crop intensification techniques.

SCI – Gains and Experiences

Asia, Africa and Latin American countries widely adopted System of Crop Intensification (SCI) which promoted more root growth, enhanced soil nutrient intake, optimum plants with less water, fertilizer and seed. SCI in crops like wheat, finger millet, chickpea and maize were tried in different states apart from rice. The package of seed treatment, organic sprays, water management and followed spacing specifications of 25 x 25 cm in rice and 20 X 20 cm in wheat resulted in enhanced yields due to deep root system and better uptake of nutrients enhanced yields.

Probably, due to the practices mentioned above under the system of crop intensification in various crops, there have been yield gains reported by various studies conducted. Among all the crops, rice exhibited higher gain in yields ranging from 50-100 percent and 86 percent reported by two different studies compared to the gains reported for other crops such as wheat, pulses, vegetables, finger millet, chickpea and maize (**Table 1**).

Table 1: Experienced yield gains in India under different studies conducted

Crop/ References	Binju *et al.*	LEISA	Prabhakar *et al.*	Gaurendra *et al.*	Ram *et al.*
	Yield gains due to SCI over conventional method (%)				
Rice	86	-	-	50-100	-
Wheat	72	-	35-67	50	18-67
Pulses	56	-	45	-	50
Oil seeds	50	-	-	-	-
Vegetables	20	-	20	-	-
Finger millet	-	14.7	-	-	60
Chickpea	-	20.3	60	-	-
Maize	-	-	75	-	75
Sugarcane	-	-	40	20-30	80-90

Source: Published articles

It can be inferred that the utilization of resources had been optimum for rice under the system of rice intensification wherein, more experimentation had been done in standardizing the practices to be followed. For other crops the recommended management practices have to be evolved through conducting comparative experiments under conventional and intensified techniques. But, due to the potential gains in yields particularly under rice an amicable balance sheet must be developed by recommending the reduction in rice area under the ground water cultivated scenario, diverting the remaining saved water into other crops in the groups of millets, pulses and oil seeds. The state government should encourage conversion of paddy fields into normal cultivable lands suitable for ID crops. For this, a suitable policy package must be envisaged to promote diversification wherein any subsidies and investment support must be linked with diversification as a pre requisite or mandate.

As per the recent estimates of the *www.agriwatch.com,* 2021 the gap between supply and demand is 32.19 million tones (MT) of excessive supply in India, leads to crash in prices, price volatility and burden of procurement of *kharif* and *rabi* rice.

Irrigation Policy

Last few decades, the accelerated irrigation development has been on priority at macroeconomic level wherein the major, medium and micro irrigation projects were funded by the financial institutions and implemented by various states. Raising the height of existing irrigation dams, desilting of water bodies and construction of lift irrigation projects, were promoted / completed in the southern states such as Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu.

In Telangana with the creation of recent new irrigation facilities (lift irrigation projects-*Kaleshwaram, Palamuru - Rangareddy, Sita Rama and Devadula*) doubled the gross irrigated area from 62.48 lakh acres to 136.86 lakh acres from 2014-15 to 2020-21. This further led to expansion in *kharif* area under rice from 35.37 lakh acres to 104.23 lakh acres during the above said period. It is worth to note that during 2014-15, 56 percent of gross irrigated area was devoted to rice whereas the same was 76 percent in 2020-21. Ensuing discussion not only suggests that rice takes away any additional area created compared to other crops, but also resulted in mono cropping poses a potential threat to crop diversity.

The policy directive should be to encourage other crops in the new areas through proper extension mechanism. This will increase the crop intensity and water use efficiency ensuring crop diversification.

Firm decisions on reduction in area under rice coupled with new systems of crop intensification encompassing various direct seeded rice techniques to sustain the production as it is already in excess as inferred from the earlier discussion is required at present. So, the state and policy makers should consider these facts and protect the farmer from falling in the crisis trap. Due to the accumulation of rice stock in the form of carry forward from past season from the farmer, aggregators, private players and buffer stocks along with the current years enhanced production as a consequence of area expansion, flooding into the market necessitate the unimaginable storage space. So if this is not regularized, there may be persistent price volatility and increased risk to the paddy growing farming community.

Moreover, construction of scientific storage space through Public Private Partnership (PPP) such as godowns in rural areas at the regional marketing centers may need to be doubled in Telangana if the production is not controlled and unregulated. Lest, it would result in more post harvest losses due to exposure of stored grain to the nature's extremities. At present, rural godown capacity in Telangana is 65 lakh tons (*Telangana Today, dated 24.11. 2022*)

Further to reiterate the state directive should be encouraging crop and irrigation intensity on one hand and crop diversification on the other hand rather than area expansion in single crop leading to mono cropping threatening the sustainability of the production resources. As a move towards the sustainability research policy should focus on Natural Resource Management (NRM) and environmental issues such as long run experimentation on the release of green house gas emissions. Such data should be documented, stored using the new data warehousing and cloud computing technologies to standardize the climate smart operational guidelines.

Procurement policy

There are centralized and decentralized procurement systems in vogue, wherein centralized procurement of food grains as central pool is undertaken by the FCI or State government agencies. State will hand over the quantity procured to FCI for storage as per GOI allocations and movement of surplus stocks to other states. For the stocks received by FCI, the cost sheet is issued by GOI. Accordingly, payments are made to the states.

Under the decentralized procurement system, state government procures, stores and distributes as per the GOI allocations to TPDS and other welfare schemes within the state. Excess stock procured by state will be handed over to the FCI for the central pool. Fully DCP mode was adopted in Telangana (2014-15) along with few other states. Ever since Telangana adopted DCP system almost direct procurement from FCI ceased in the state and there is no involvement of private players also.

Therefore, the procurement policy facilitates procurement of food grains on behalf of central government wherein FCI procures paddy for central pool offering MSP which is open during the stipulated procurement period. So, they are operated by government agencies at temporary procurement centers and aggregation points which will become operational in consultation with the state government.

Custom milled rice is operated by the state by procuring under state agencies and FCI. Further resultant rice from CMR (Custom Milled Rice) is delivered to state and FCI. Out of this total rice procured, 70 % is lifted by FCI for central pool.

Table 2: Procurement pattern of rice in India vs. Telangana

Year	Telangana Procurement in Central pool LMT (rice)	Y-O-Y Percent increase in Procurement	Average Buffer stocks opening balance central pool India	Share of Telangana in Buffer stock	Telangana Rice production	Percent of procurement to total production	No of farmers benefitted through procurement Telangana	Common rice procurement incidental (Rs./qt.)	Payment of GoI to the DCP rice from Telangana (Approx.) (In Cr.)
2014-15	36.04	-	182.77	19.71	44.4	81.17	NA	2722.21	9810.84
2015-16	15.79	-56.19	140.70	11.22	30.47	51.82	535007	2824.51	4459.90
2016-17	35.96	127.74	170.52	21.08	51.73	69.51	1088312	2967.45	10670.95
2017-18	36.18	0.61	184.55	19.60	62.62	57.78	1077667	2919.92	10564.27
2018-19	51.9	43.45	207.69	24.98	66.7	77.81	1474828	3194.28	16578.31
2019-20	74.54	43.62	254.09	29.33	74.28	100.35	1988630	3258.14	24286.18
2020-21	95.25	27.78	254.68	37.39	102.17	93.23	2164354	3404.02	32423.29
2021-22	79.77	-16.25	254.98	31.28	103.08	77.39	921448	3302.44	26343.56

Note: LMT=Lakh Metric Tones

Source: Ministry of consumer affairs, Food and Public Distribution, GoI

Increased production leads to increased expected procurement by the state and problem of undertaking storage by FCI which is presently carried out by hired storage spaces from CWC, SWCs, State agencies and Private parties. If the balanced production is not targeted based on the demand for consumption and requirement of minimum buffer norms by adopting suitable crop intensification techniques and reducing area under rice, the present storage capacities held by FCI will not suffice which envisages creation of more storage space involving private participation under private entrepreneurs guarantee scheme as stated earlier.

During the last three years the buffer stock maintained by central pool is 254.98 LMT of which 29, 37 and 31 per cent is the share of Telangana in buffer stock and moreover per cent of procurement to the total production was 100, 93 and 77 per cent during 2019-20, 2020-21 and 2021-22 reveals that no farmer is interested to sell his raw rice in the open market.

It is important to note from the table that the per cent of procurement to total production was as high as 100 per cent in 2019-20 and lower side 51.82 per cent in 2015-16. The state governments increase the pressure on the centre to procure maximum production from the state. The burden of the cost sheets of CMR including the incidental charges went up to the Rs. 32,423 Cr. (2021-22) which may become around Rs. 36,000 crores with 10 per cent increase in procurement operations. This is resulting in underplay of the demand and supply forces in the open market, bringing entire rice cultivation into the purview of MSP under price policy covered do not comply with Laissez faire market economy.

Price Policy – An alternative to MSP

The policy of allowing the operation of market forces in the open market transparently with free flow of information has to be implemented through regulated markets which will facilitate the price discovery. Farmers would receive the open market price. At this juncture an altered price policy may be implemented in lieu of the MSP by paying the differential amount between the open market price and MSP to the farmers, a less financial burden to centre and state thereby bringing more farmers into the umbrella of price policy.

Another strategy is to bridge the gap between demand and supply for which due care has to be taken by evolving a mechanism of publishing the balance sheet of rice along with other crops so that advance planning and price forecast and other market intelligence support can be evolved to advocate and implement production to meet the desired level. Strategically, GoI is giving more importance of declaring high MSP to pulses, oil seeds and millets as shown in Figure 1.

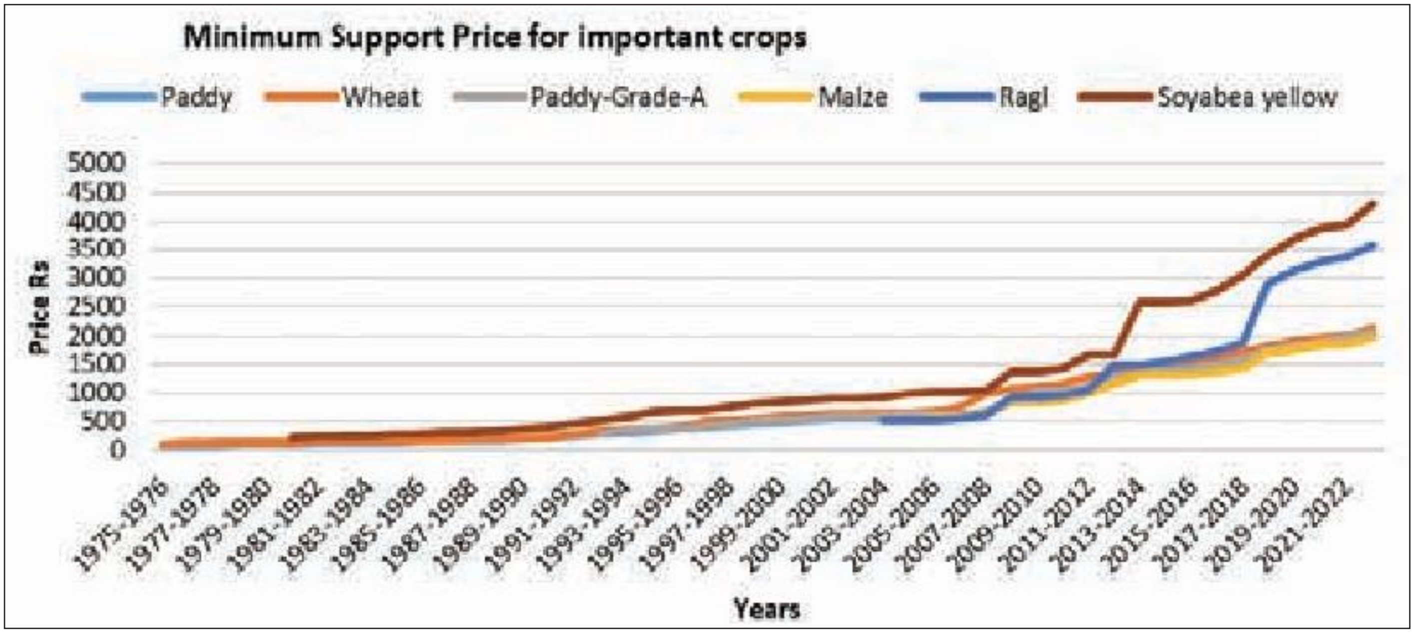

Figure 1: Minimum Support Price of important crops

Source: Directorate of Economics and Statistics, GoI

Table 3: Trade flow of rice in India

Trade flow	Indicator	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Exports	Value (million US $)	2296	4073	6128	8169	7906	6380	5316	7076	7347	6800	7980	9624
	Value Growth Y-O-Y	-4.2	77.4	50.4	33.3	-3.2	-19.2	-16.6	33.1	3.8	-7.4	17.3	20.5
Imports	Value (million US $)	0.11	1.18	0.57	1.3	1.6	1.1	0.9	1.6	4.4	11.2	3.3	3.2
	Value Growth Y-O-Y	-29.7	940.9	-51.2	126.1	26.1	-30.8	-17.1	75.0	168.5	153.6	-70.4	-2.4

Source: https://trendeconomy.com/data/h2/India/1006

India exports broken rice, basmati rice, non basmati, rice in husk, husked brown rice, semi milled and wholly milled rice to different courtiers. Broken rice produced in India is mainly used for poultry and cattle feed. Recently, export duty of 20 per cent is imposed on rice in husk, husked rice, semi milled or wholly milled rice, which might lower the prices of rice. Also ban on export of broken rice which is used in poultry feed industry was imposed due to increase in grain exports which is in line with the sustainable development goals of zero hunger. India exports rice to more than 150 countries. Reduction in exports may cause food inflation in other countries. The destinations for rice exports from India are Saudi Arabia, Iran, UAE, Iraq, Kuwait, UK, USA, Yemen, Oman and Canada and for non basmati rice are Benin, Bangladesh, Senegal, South Africa, Liberia, Nepal, Madagascar and Guinea. India imports rice from

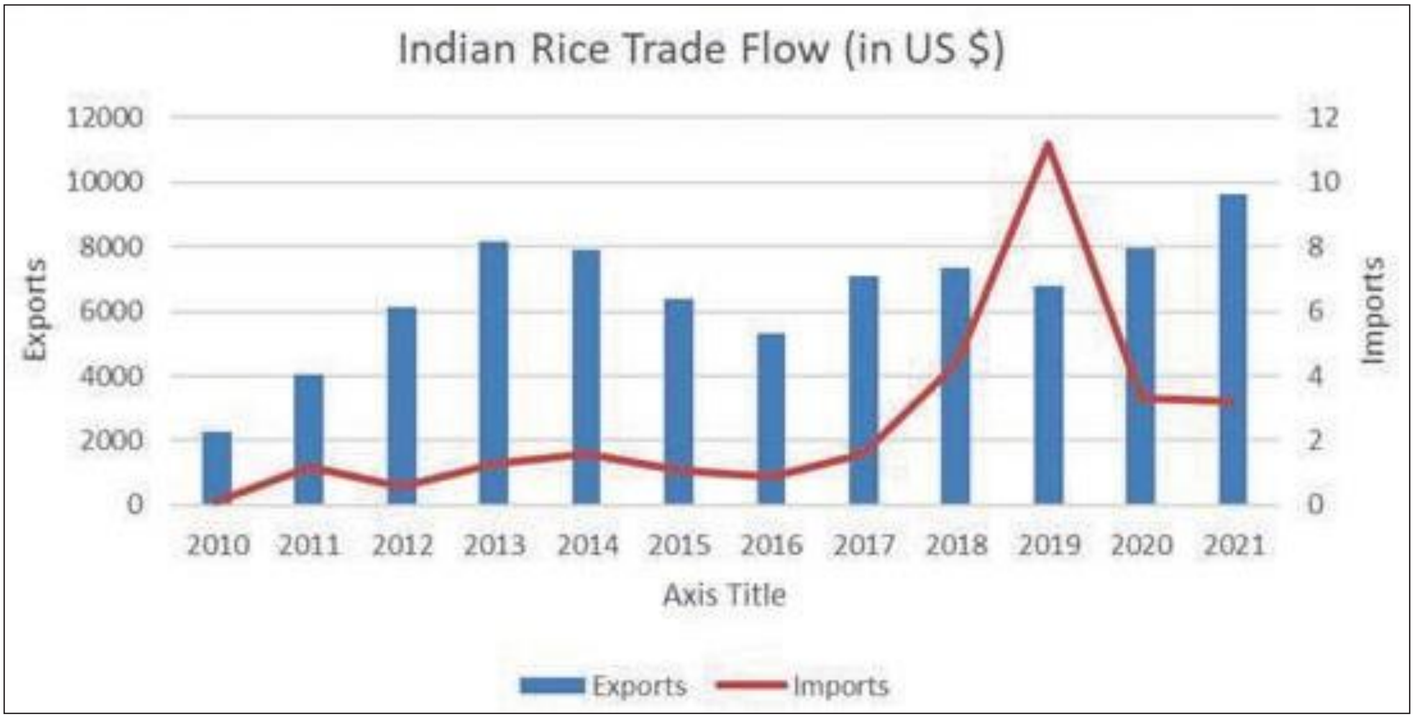

Figure 2: Export and import scenario of rice in India

Thailand, Nepal, Spain, Italy, USA, Russia, Vietnam, Egypt and Oman. Exports in Basmati rice have fallen since last three years due to conversion of basmati acreage into non basmati and due to pesticide residue norms imposed. Nevertheless the Latin American countries opened doors for Indian exports. As discussed earlier, rice exports leads an indirect export of water to other countries.

The phenomenon is called as virtual water trade. The per capita water availability in India is less than a majority of its major importing countries. On the other hand, the export competitors like Thailand and Vietnam better per capita water availability compared to India. In view of all these, wide adoption of water saving techniques like SRI, DSR *etc* are only the possible options.

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Actionable Policy Options for Scaling-Up System of Rice Intensification for Ensuring Higher Productivity, Energy Efficiency and Sustainable Rice Production

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Abstract

Globally, India stands first in rice area and second in rice production. To feed the growing population, rice production has to be increased amid strong competition for limited resources including land. Also, concerns have been raised about yield gaps in rice. The system of rice intensification is one of the strategies to narrow the yield gaps. Rice is the major crop in India, therefore, the identification of an energy-efficient rice cultivation system is important to food security and sustainable intensification (SI). Hence, a comparison was made between conventional and the system of rice intensification (SRI) methods of rice cultivation by conducting two experiments. One field experiment was conducted from 2013 to 2017 at 25 locations across India under the All India Coordinated Rice Improvement Project and another experiment was conducted in 2017 using surveys by collecting data from 262 randomly selected SRI farmers using a personal interview method in the Telangana state of India. The 5-year experimental data revealed that the SRI method of cultivation produced higher rice grain yield (up to 55%) compared to the conventional transplanting method. Survey data revealed that total costs of rice production reduced by 22.71% under SRI. Break even output under SRI was reduced by 58.1%. Adoption of SRI saved total energy inputs by 4350 MJ/ ha. The energy productivities were 0.16 kg/MJ and 0.21 kg/MJ for conventional and SRI methods, respectively. Therefore, for ensuring higher productivity, net returns, energy efficiency and sustainable rice production it is recommended to adopt an environmentally friendly SRI method of crop establishment in the Telangana region of India. Based on the constraints as perceived by the farmers, policy options for scaling up of SRI are suggested.

Keywords: SRI, Scaling-Up, Sustainable Rice Production, Returns, Energy Efficiency

Introduction

Rice is one of the most important staple food crops in the world, representing about 50 percent of the total dietary caloric intake. At the global level, India stands first in rice area with 44 million hectares and second in rice production with 111.52 million tons (Ministry of Agriculture, 2018). Rice production needs to be increased to meet future food requirements amid strong competition for limited resources. The 'Green Revolution' has provided enough food to meet the country's current demand. However, concerns have been raised about sustainable rice production, yield stagnation, and yield gaps. The gaps between the research station and farmer's fields still exist among various rice-growing regions. The yield gaps indicate that the production levels in rice can be increased by bridging the gaps. There are several strategies to bridge the yield gaps and the System of Rice Intensification (SRI) method of rice cultivation is one of the promising approaches for achieving sustainable rice production and increasing the food security of small-scale producers. Rice cultivation is in crisis the world over and India is no exception, with a shrinking production area, fluctuating annual production, stagnating yields, and escalating input costs. The cost of cultivation of rice has consistently been increasing owing to the escalating costs of seeds, fertilizers, and labor. There is a need to grow more rice but with less water and fewer inputs. SRI originated in Madagascar in the early 1980s and the father of this invention is French Priest Henri de Laulanie. He wanted to find ways to enhance the rice productivity of Madagascan farmers who were obtaining rice yields of less than 2 t/ha (Gujja and Thiyagarajan 2009). SRI can increase farmers' rice yields while using less water and lowering production costs (WWF 2007).

Energy use in agricultural production has become more intensive due to the use of fossil fuel, chemical fertilizers, pesticides, machinery, and electricity to provide substantial increases in food production (Nirmala, 2021). Hence, energy efficiency has been crucial for sustainable development in agriculture systems. Efficient use of input energy resources not only saves fossil fuel resources but also provides financial savings (Singh 2004). However, more intensive use has created some important human health and environmental problems (Yilmaz, Akcaoz, and Ozkan 2005). The energy analysis in rice in general and SRI, in particular, is essential because of the direct link between energy and rice yields, and food supplies. Among the different indicators of crop performance, energy analysis is one of importance. Several studies have been conducted on energy analysis of rice in developed countries (Canakci *et al.,* 2005; Cetin and Vardar 2008; Hatirli, Ozkan, and Fert 2005; Jianbo 2006; Kuesters and Lammel 1999; Ozkan, Kurklu, and Akcaoz 2004a; Pishgar-Komleh, Safeedpari, and Rafiee 2011; Tuyet *et al.,* 2017). Energy use and energy efficiency analyses could help in comparing energy use at sectoral and operational levels in rice production. Adoption of SRI can reduce energy use, GHG emissions, and global warming potential (GWP) in rice-growing areas of India. Further, for a cleaner environment, a detailed study of energy efficiency of this technology may add to the suitability for adoption among farmers. Therefore, economically and environmentally sustainable rice establishment methods are needed to replace the conventional methods of rice cultivation in India. Such a method of cultivation must be based on the knowledge of grain yield under different climatic conditions, economics, and energy analysis.

Despite the dispute within the academic community, SRI has been disseminated to farmers in more than 40 countries, most in South and Southeast Asia. Although the exact area of adoption has not been officially reported, there is an estimate that SRI has been adopted on 750,000 ha in India, and 17,000 ha in Indonesia (Uphoff and Kassam 2008). A compilation of results from 11 surveys in 8 countries, including 16,000 SRI farmers, has shown, on average, a 47% yield increase, 40% water savings, 23% lower production costs, and 68% increase in farmer income, compared to conventional rice cultivation (Africare 2010; Sato and Uphoff 2007).

Rice is the major crop in India, therefore, the identification of an energy-efficient rice cultivation system is important to food security and sustainable intensification (SI). Hence, a 5-year study was undertaken at ICAR-IIRR (i) to find a better rice crop establishment method for India by comparing SRI and conventional transplanting methods in terms of grain yield, (ii) to confirm/validate the best crop establishment method through surveys using a personal interview method, and (iii) to provide a detailed study to revalidate a better rice establishment method for higher yield, net returns, energy efficient rice production systems for India. The study was undertaken in the Telangana State of India during 2017-18. A multistage sampling procedure was adopted in getting primary data from farmers.

Economics

Nursery seedlings required for one hecatre under SRI used 5 kg/ha seed as against 75 kg/ha for the conventional method. Significant seed saving can promote seed multiplication rates, purity of seed (single seedling planting), and faster availability and spread of released varieties. It was observed that there was a reduction in costs of all inputs except FYM. The amount spent on FYM was a little high in the case of SRI as compared to the conventional method as more quantities of FYM are recommended for application in the SRI. The amount spent on harvesting was high in SRI, which could be due to more grain yield, which required more time using a hired combine harvester. The results of the study revealed that the total cost of production was US $1084.73 and US$883.92 for the conventional and the SRI methods, respectively, indicating that the adoption of SRI resulted in a reduction in total costs by 22.71%. The Gross returns were US$ 1108.55 and US$ 1295.74, respectively, for conventional and SRI methods (**Table 1**). Higher Gross returns in SRI could be attributed to higher yield (5700 kg/ha) in SRI in comparison with the conventional method of rice production (4880 kg/ha). Higher BCR indicates more profitability with SRI over the conventional method.

Table 1. Comparative economics of rice production under SRI and transplanted methods

Particulars	Conventional method	SRI
Yield (kg/ha)	4880	5700
Gross Returns ($/ha)	1108.55	1295.74
Net Returns ($/ha)	23.82	411.82
BCR	1.02	1.46
Break Even Output (kg/ha)	5751	2409

Energy analysis

The energy productivity (the amount of rice produced per MJ of energy consumed) was calculated as 0.16 kg/MJ and 0.21 kg/MJ for conventional (**Table 2**). Specific energy is an index which shows how much energy was used to produce one unit of disposable product. In this study, the specific energy for each method was calculated as 6.37 MJ/kg and 4.69 MJ/kg, respectively. For producing 1 kg of paddy, 6.37 and 4.67 MJ of energy was spent in the conventional method and in SRI, respectively. This means that each kilogram of paddy produced by the SRI method can save approximately 1.7 MJ compared with the conventional method of rice production.

Table 2: Energy indices in rice production

Item	Unit	Conventional method	SRI
Energy	ratio	4.86	6.6
Energy productivity	kg/MJ	0.16	0.21
Specific energy	MJ/kg	6.37	4.69
Net energy	MJ/ha	119945.27	149673.77
Energy intensiveness	MJ/$	28.66	30.25

The energy intensiveness of rice production for conventional and SRI methods of rice production were 28.66 MJ/$ and 30.25 MJ/$, respectively.

Constraints in adoption of SRI, as perceived by sample farmers

The farmers opined that the skill in transplanting young seedlings was the major constraint in adopting System of Rice Intensification method, followed by difficulty in using conoweeder and nursery management (**Table 3**). Non-availability of organic manure in adequate quantity and unwillingness of labour to do line sowing were the other constraints, as perceived by the selected farmers

Table 3 Constraints perceived by the farmers in SRI method

Sl. No.	Constraint	Mean Score	Garrette Rank
1.	Skill in transplanting young seedlings	73.4	I
2.	Difficulty in using conoweeder	61.6	II
3.	Nursery management	43.3	III
4.	Non-availability of organic manure	41.8	IV
5.	Unwillingness of labour to do line sowing	26.6	V

Policy Options for scaling-up SRI

Although SRI is a proven technology to conserve resources and achieve higher yields, the adoption rate of this technology is slow in India due to the constraints mentioned above. The following suggestions are made for scaling-up SRI in India:

- Policy incentives by the Government play a crucial role in the adoption of any technology. For example, the rice farmers of Tamil Nadu have adopted SRI due to the incentives provided to them. For the promotion of water saving technologies like Direct Seeded Rice (DSR), several state Governments like Karnataka, Andhra Pradesh and Telangana rendered support in the form of cash incentives or subsidies on drum seeder. A similar strategy of providing support may be followed for scaling-up SRI.
- From the various results stated above, it can be concluded that SRI method of rice cultivation has a yield advantage of around 22%. Since the benefit-cost ratio in the SRI method is comparatively more than that of the conventional transplanting method of rice cultivation, it can be inferred that SRI is an economically viable technology and more profitable than the conventional method. Hence, efforts should be made to promote SRI in suitable areas.
- SRI may not suit all the rice growing areas and hence suitable areas may be identified. SRI-suitable areas may be mapped and made accessible to rice farmers.
- SRI is a skill-based technology and hence there is a need to focus on imparting training on SRI to farmers through various extension agencies, in order to double farmer income.
- One of the major constraints in the adoption of SRI was drudgery in using weeder, hence, low cost, user friendly weeders and markers have to be made available to the farmers. The designs of the weeder should be diversified and be made amenable to local production. For large scale adoption of SRI, there is a need for convergence of different organizations working on SRI.
- It is highly imperative to train farm women in different aspects of SRI technology to build their knowledge and skills to ensure widespread adoption of SRI. There is immense scope of harnessing the potential of training of Women's Self-Help Groups (SHG) members to form a SRI task force which could be easily achieved through providing long-term and comprehensive skill based training in the following specific SRI activities.
- Training a cadre of women labourers in every village can help spread SRI and also provide good income for the women.

- Awareness should be generated about SRI through mass media, Krishi Vigyan Kendras, extension departments, etc. SRI offers an opportunity to produce 'Organic Rice', which has significant market potential and paves way for doubling income of the rice farmers.
- Several studies proved that there is a substantial reduction in methane emission in addition, to reductions in the cost of production, higher yields, and saving of irrigation water. Thus, it is imperative to scale-up SRI for reducing water consumption and increasing food production.

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Theme VII

Learning Experiences & Success Stories of SCI; Farmer and Scientist Interaction & Export Potential of Rice and Strengthening FPOs

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The Major Challenges and Scope for Sustainable Agriculture Development in India

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Abstract

Globally the demand for organic farming is increasing and farmers need to adopt novel technologies to resolve the challenges during the practicing of organic farming. Organic agriculture includes sustainability of agricultural production, supporting the rural economy, maintaining ecological and environmental strength within agricultural systems, and also establishing sustainable human health. Improving crop productivity and income of the farmers is to be based on soil health management, pest and disease control, and adapting novel marketing strategies. The utilization of farmyard manure, vermicompost, and biofertilizers in organic farming develops soil health and plant growth that can be benefited by farmers by increasing crop yield and ecosystem health. The application of biopesticide and biocultural agents for controlling pest and diseases on the crop in organic farming will enhance crop yield and also reduces environmental pollution. Organic farmers need to adapt novel marketing strategies to sell their farm produce and to get higher economic benefits. The food produced from sustainable farming increases the health of the human, soil, and environment.

Keywords: Organic Farming, Soil Health, Pest Management, Constraints, Marketing

Introduction

Agriculture can be sustainable and self-reliant only if farmers use locally available resources as inputs eg. Farm wastes, cowdung and other biomass for preserving the soil as a living material. Organic farming can be defined as a production system which largely excludes or avoids the use of fertilizers, pesticides, growth regulators, etc. and relies mainly on organic sources to maintain soil health, supply plant nutrients and minimize insects, weeds and other pests. In other terms, it is a system approach of crop production, observing the rules of the nature, targeted to produce nutritive, healthy and pollution free food, protecting the entire system of the nature, maximizing the use of on-farm resources, minimizing the use of off-farm inputs and avoiding the use of chemical fertilizers and pesticides (National Project on Organic Farming-NPOF).

There are several potential applications are associated with organic farming to climate change mitigation. In particular greenhouse gases (GHG) emissions are reduced by avoidance of mineral fertilizers, lower N2O emissions due to low N input and careful management, Less CO2 emissions due to better soil structure and more plant cover, Highest mitigation potential of organic acids lies in carbon sequestration, The emission reduction potential by avoiding mineral fertilisers is about 20%, compensation potential by C sequestration is about 40-70% of world's current annual GHG emissions (Tuomisto *et al.,* , 2012; Muller et al ., 2017). The worldwide organic farming covers the total Area of 37.2 m. ha. By 1.8 million organic producers and practiced in 162 countries. the major organic cultivating land from Australia (12.02 m. ha.), Argentina (4.4 m ha) and India (1.10 m. ha) 0.6% of the total agricultural area with 5,47,591 organic farmers. The global Market for organic food: 62.9 billion US $, organic food exports increased from 100 m US $ (2008-09) to 157.22 m US $ (2010-11) (World Scenario-2012 survey; Muller *et al.,* , 2017). It is commonly assumed that by 2050, agricultural output will have to further increase by 50% to feed the projected global population of over 9 billion (Alexandratos, N. & Bruinsma, 2012). This challenge is further exacerbated by changing dietary patterns. It is, therefore, crucial to curb the negative environmental impacts of agriculture, while ensuring that the same quantity of food can be delivered. There are many proposals for achieving this goal, such as further increasing efficiency in production and resource use, or adopting holistic approaches such as agroecology and organic production, or reducing consumption of animal products and food wastage (Muller *et al.,* , 2017). Organic agriculture is one concrete, but controversial, suggestion for improving the sustainability of food systems. It refrains from using synthetic fertilizers and pesticides, promotes crop rotations and focuses on soil fertility and closed nutrient cycles (IAASTD-2009; Foley, 2011). The growing health consciousness among the consumer and increasing awareness about organic food has led numerous opportunities for organic producers. Along with opportunities, there also arise various challenges like marketing of organic produce, soil health testing facilitates, availability of biopesticides and biofertilizers are faced by the organic farmers in India.

Organic farming in India

The concept of organic agriculture is not alien to India. In fact, the first scientific approach to organic farming dates back to the Vedas of the later Vedic period, the essence of which is to live in harmony with, rather than exploit, Mother Nature. There is brief mention of several organic inputs in our ancient literatures like Rigveda, Ramayana, Mahabharata, Kautilya Arthasashthra etc. In fact, organic agriculture has its roots in traditional agricultural practices that evolved in countless village's and farming communities over the millennium (Singh *et al.,* , 2019). Therefore, traditionally Indian farmers are practicing organic farming and gradually changed to chemical-based cultivation since 1950's. Chemicals increasingly applied with green revolution and liberal use of chemicals led to health hazards and also Air, water and soil pollution noticed everywhere simultaneously Soil fertility declined in many places. It is definitely true that India had witnessed a tremendous growth in agricultural production in the era of green revolution. Food grain production, which stood at a mere 50 million tons at the time of independence, had increased almost five and half times to 273.38 million tons by the end of 2016–17 (Press Information Bureau, GOI, 2017) from 159.59 million hectares of cultivated area in country (Agriculture Census, 2010–11). The technologies involved during the inception of green revolution supported by policies and further propelled by agrochemicals,

machinery and irrigation were the main driving forces for the enhanced agricultural production and productivity (Roychowdhury *et al.,* , 2013). Despite the fact that the food security of India was definitely addressed by these technologies (Charyulu and Biswas, 2010), an important setback was that the farmers using these technologies were still had to depend upon the purchased inputs. With manufacturing of fertilizers and pesticides as the two major inputs of Green Revolution (GR) technologies, an important point of consideration was the need for fossil fuels and/or expensive energy which are associated with serious environmental and health problems.

In last 50 years we are using heavy amount of fertilizers and pesticides and we already reach on plateau and diminishing low of return start to work (Venkateswarlu *et al.,* , 2008), so we need to apply more input (fertilizer and pesticides) to get small raise in production which cause second generation problem and few of such epitome examples are some regions of Punjab (cancer belt of country) and endosulfan story of cashew plantations area in Kerala. Insecticides and herbicides in ideal condition lethal for target group only, for non-target group and human it is safe but this principle is not followed strictly and indiscriminate use of these chemicals put human life and ecosystem health on verge (Aktar *et al.,* , 2009). All these thing and unsustainability issue associated with modern agriculture force us to look back (Balachandran, 2004) in history to know either we are not doing any mistake by depending on off farm inputs because crop production is a recycle system of nature by putting too much off farm input, we are making it fragile day by day. One of such natural, recyclable and sustainable approach of farming is Organic farming. It is the effective and cost-efficient way to achieve sustainable development in the agriculture sector (IFOAM, 2010). Organic source of nutrient also helps to combat with the problem of multi nutrient deficiency and low organic content in our soil which is affecting productivity of major food crops at farmer field (Singh *et al.,* , 2018).

Organic crops cannot be grown with synthetic fertilizers, synthetic pesticides or sewage sludge. They cannot be genetically engineered or irradiated. Organic animals must eat only organically grown feed and cannot be treated with synthetic hormones or antibiotics. The increasing awareness of the fitness and health benefits of organic foods are fueling the demand for these products across the world. Most developed countries, including the European Union, United States, Canada, Japan, China, Russia, and Australia, require country of origin labeling in order to market food as organic within their borders. Organic food is the fastest growing sector of the American food industry (Alexander *et al., ,* 2015). The government of India is offering strong support and promoting organic farming as it will increase the economic contribution, positive impact on biodiversity, and effective soil management. Organic foods are getting popular in India due to the availability of organic manures in rural areas, the depleted soil and product quality, as well as increased commercialization and competitiveness of the Indian agro-market. Farmers are ready to adapt organic farming based on profitability and concern developed for safe food production and environment protection. National Programme for Organic Production (NPOP) - Launched by Ministry of Commerce, Govt. of India in 2000 for the continuous support and services to the Indian organic farmer. There are several agencies are accredited under NPOP like APEDA (Agrl. and processed food products export development authority), spices board, coffee board tea board, coconut development board and directorate of cashew and cocoa development.

Constraints on organic farming in India

The organic foods have labor intensive demand and farmers do not use pesticides, chemical fertilizers, or drugs. Thus, organic foods normally cost 20%–100% more than conventional foods. Moreover, after all the rigours involved in obtaining labels for organic foods, there is no means for distinguishing between organic and conventional foods unless they are taken into the lab for testing. Organic foods tend to spoil faster than non-organics because they are produced without artificial preservatives or irradiation. Therefore, consumers will not be able to ascertain if the food was produced according to the promised characteristics such as safety and trustworthiness or not. A lot of skepticism is shown by consumers regarding the certification process of organic and non-GMO labels. Besides all these, the major issues faced by organic farmers are soil health management, pest and disease control, and organic product marketing.

Soil health management

Soil health is a term which is widely used within discussions on sustainable agriculture to describe the general condition or quality of the soil resource. Soil management is fundamental to all agricultural systems, yet there is evidence for widespread degradation of agricultural soils in the form of erosion, loss of organic matter, contamination, compaction, increased salinity and other harms (European Commission 2002). This degradation sometimes occurs rapidly and obviously, for example when poor soil management leads to gully erosion. Often degradation is slower and subtler, and may only impact on agricultural production and the wider environment over years. For this reason, research has been directed to devising measures of the health of soil, which could be used to monitor its condition and inform its management so that degradation is avoided (Kibblewhite *et al.,* , 2008).

Agroecological systems such as organic farming and other forms of soil-conserving sustainable agriculture can compete with conventional agriculture and have the potential to maintain food productivity while improving health as well as sustaining soils, waters and ecosystems (Halberg *et al.,* 2015). Agroecological systems are two to four times more energy efficient than conventional agriculture (IPES-Food 2016). They are thus important for the future because of their reduced reliance on fossil fuels for cheap energy and fertilizers and on the novel idea that technology can continue to solve our problems (Weis, 2010). Agroecology, with such emphases on efficient input use and environmental benefits, is also compatible with ideas of sustainable intensification (Lampkin *et al.,* 2015). Organic farming provides sustainable soil quality, crop yield, and ecosystem services, perhaps as a result of soil-aware management (Taylor *et al.,* 2006).

Assessment of soil health across agricultural systems, soil types, and climatic zones presents major scientific and policy challenges. Clearly, no single indicator will encompass all aspects of soil health, nor would it be feasible (or necessary) to measure all possible indicators (Kibblewhite *et al.,* 2008). Soils provide multiple ecosystem services, and as such, soil health management in support of sustainability must consider three points: that enhancing many soil ecosystem services requires multi-functional management; that managing soil to improve one service can have positive (synergistic) or negative effects (trade-offs) on another service; and that soil health management should sustain soil services over the long term (Lehmann *et al.,* 2020).

Management of agricultural practices using new technologies such as testing of soil nutrients is found to be economical and environment friendly in organic farming. In agriculture, encouraging alternative means of soil fertilization rely on organic inputs to improve nutrient supply and conserve field management. Several organic sources are associated to improve soil fertility under organic farming like farm yard manure, compost, vermicompost, coir pith compost, poultry manure, crop residues, green manures, and agro wastes. Biofertilizers, known as microbial inoculants, contain actively living cells of micro-organisms. Efficient nitrogen fixers perform other functions which beneficially affect plant growth and yield. N and P are the main nutrients that can be supplemented by biofertilizers. Rhizobium, Azotobacter, Azospirillum, blue-green algae and Azolla for N, Mycorrhiza, and phosphate solubilizing microorganisms for P are important to many crops. All these natural sources enhance the soil nutrient concentrations, moisture content, and their contribution to plant uptake, and also crop nutrient requirements are to be considered to estimate the quantity of organic sources.

Farmers and stakeholders need to be made aware of the importance of management for the long-term sustainability of soil and food production, and we believe this could be facilitated by improving their connection with the soil. Also, human society as a whole need to become more aware of its connection to the soil and realize the dependence on soil for food, biomass and the functions it provides to maintain the biosphere (FAO and ITPS 2015). It is also very important to increase awareness and understanding of soil security and soil health management in the general public and in agriculture.

Pest and disease control

One way to increase food availability is to improve the management of pests. There are estimated to be around 67 000 different crop pest species—including plant pathogens, weeds, invertebrates, and some vertebrate species—and together they cause about a 40 per cent reduction in the world's crop yield (Oerke *et al.,* 1994). Crop losses caused by pests undermine food security alongside other constraints, such as inclement weather, poor soils, and farmers' limited access to technical knowledge. In contrary to synthetics, biopesticides have emerged as a green tool in the era of sustainable agriculture. These are the most likely alternatives to some of the most problematic chemical pesticides currently in use. Biopesticides offer solutions to concerns such as pest resistance, public health issues and detrimental effects on the surrounding environment. Despite the benefits associated, the overriding challenge for the biopesticide industry is to live up to the promises and expectations of the end-users or the market and public as a whole. It is a well-known fact that as far as environmental perspective is concerned, biopesticides are far better than synthetics, but at the same time, we can't deny that this greener approach is struggling for its place in the established conventional chemical pesticide market (Mishra *et al.,* 2020).

In India, the concept of biocontrol of plant diseases has been in practice for a very long time. The neem tree (*Azadirachta indica* A. Juss) and its derivatives, i.e. leaf extract, oil, and seed cake have been used as fertilizers and also for minimizing the risk of post-harvest loss in stored cereals (Brahmachari 2004). There are evidences where some insects and birds were used in pest eradication and during the 1960s, the concept of integrated pest management (IPM) also emerged with a target of judicious use of pesticides in agriculture. Later, the US National Academy of Sciences also exemplified the term IPM in a broader way, and along with multiple complementary methods to suppress pests, biocontrol was also added (Peshin *et al.,* 2009).

However, in India, a major technological breakthrough in the field of biocontrol happened when chemical insecticides failed to control *Helicoverpa armigera, Spodoptera litura,* and other pests of cotton (Kranthi *et al.,* 2002). It was realized that biocontrol is the only means that can be utilized as a safe, cost-effective, and eco-friendly method to control the widespread resistance of chemical insecticides towards pest insects. Later, biopesticides became a part of IPM which was previously completely based on the use of chemical pesticides. To control pests and diseases in organic farming the farmers need to practice sustainable preventive and controlling methods like selection and cultivation of tolerant crops and crop varieties, cultural control, mechanical control, biological control, use of pheromone traps and biopesticides.

Biological control comprises of the use of plants or botanicals, microbial pesticides, biocontrol by insects, and biorationals (**Table 1**). Botanicals means use of various plant products that been in use for many centuries in India to minimise losses in crops and grain storage. A large database of plant species that possess pest-controlling insecticidal, antifeedant, repellant, attractant and growth-inhibiting properties exists in every village. Plants widely used for botanical pesticides are *Annona* sp, *Azadirachta indica*, *Chrysanthemum* sp., *Cymbopogan* sp., *Nicotiana* sp, *Pongamia* sp, *Vitex* sp., etc. Seeds, leaves, extracts, fruits, kernels, oil and decoctions from botanicals are used to control the pests. Biopesticides are living organisms – or their derived parts – which are used as biocontrol agents to protect crops against insect pests. Seed treatment, seedling root dip, soil application or foliar spray will effectively control fungal diseases and bacterial diseases.

Table 1. Commercially important microbial bio-pesticides and biorationals used in India

Category	Products	Target pest	Major crops
Bacteria	Bacillus thuringiensis Bacillus sphaericus Bacillus subtilis Pseudomonas fluorescens	Lepidoptera Mosquitoes, flies Fungal pathogens Fungal pathogens	Cotton, maize, vegetables, soybean, groundnut, wheat, peas, oilseeds, rice
Viruses	Nuclear Polyhedrosis Virus (NPV) of Helicoverpa armigera, Spodoptera sp. and Chilo infescatellus	American Boll worm,tobacco caterpillar and shoot borer	Cotton, sunflower, tobacco and sugarcane
Fungi	Trichoderma viride Trichoderma harzianum Trichoderma hamatum	Fungal pathogens	Wheat, rice, pulses, vegetables, plantations, spices and sugarcane
	Beauveria bassiana Verticillium lecanii Metarhizium anisopliae Paecilomyces lilacinus Nomuraea rileyi	Insect pests such as bollworms, white flies, root grubs, tea mosquito bugs	Cotton, pulses, oilseeds, plantation crops, spices and vegetables
Biorationals	Pheromone traps Pheromone lures, sticky traps and mating disruptants	Bactocera sp. Chilo sp. Dacus sp. Earias vittella Helicoverpa armigera Leucinodes orbonalis Pectinophora gossypiella Plutella xylostella	Cotton, sugarcane, vegetables, fruit crops

Marketing of organic produces

Marketing and distribution are not efficient because organic food is produced in smaller amounts from the need of world's population that needs to survive. This could lead to starvation in countries that produce enough food today. Along with great opportunities with organic farming, there also arise marketing challenges faced by the organic and conventional farmers in India. The major marketing challenges faced by the farmers, namely, lack of warehousing facility, lack of price information, inadequate demand for crop, costly transportation, market price variations, and lack of government support. There are significant differences in the marketing challenges faced by the conventional and organic farmers across the nation.

Marketing of organic produce is mainly the buying and selling. Rapid transformation in terms of increasing concentration in processing, trading, marketing and retailing is being observed in the agrifood system all over the world. Traditionally the farmers were unaware in advance when, to whom and at what price they are going to sell their produce. This scenario has changed with the greater coordination between farmers, processers, retailers and other players in the supply chain. Now the farmers are producing to the requirements of the market rather than relying on the markets to absorb whatever they produce. The real challenge lies in organising the small and marginal farmers for marketing and linking them to high value agriculture. Thus, group approach is needed for getting benefits from marketing. Small farmers can also benefit from the emerging super markets and value chains if linked effectively. According to the ways in which the farmers link to the buyers, market linkages can be classified into the following categories: 1. Farmer to domestic trader, 2. Farmer to retailer, 3. Linkages through cooperatives, 4. Farmer to agro-processor, 5. Farmer to exporter, 6. Contract farming (**Table 2**).

Table 2. Marketing Linkages for organic agriculture

Type of linkage	Collective activity	Advantages for farmers	Disadvantages for farmers
Direct between farmers and traders	Farmers usually act on individual basis with traders. May work together informally to bulk-up produce to reduce costs and attract larger traders	Trust ensure long term sustainability Formal farmer organisations not usually needed	May need to accept short-term deferred payments Limited access to better markets
Direct between farmers and retailers Linkages through cooperatives	May require formal group structure Farmers may link directly with the cooperatives or through groups	Reliable market at agreed price Inputs, technical assistance etc. may be supplied on credit Crop marketing, packaging, grading and storage and sometimes processing organised by cooperatives Potential for farmers to sell large volumes	Must meet variety, quality and safety specifications Must be able to supply agreed quantities at all times Cooperatives often depend on subsidies and external managerial assistance. Commercial activities can collapse when subsidies and assistance run out
Direct between farmers and agroprocessors	Farmer groups can bulk-up produce for collection by processor Groups can facilitate supply of inputs and provision of technical assistance	May provide secure market at agreed price Inputs, technical assistance, etc. may be supplied on credit Processor often provides transport Potential for farmers to sell larger volumes	There may be an inadequate market for the processed products, thus jeopardizing sustainability Must meet variety, quality and safety specifications Open market price may be higher than that agreed with processor
Farmer to exporter	Often involves grouping of farmers External technical assistance may be required	Potential high returns if quality can be achieved Inputs, technical assistance, etc may be supplied on credit Exporter often provides transport and packaging	Export markets are inherently risky Compliance with standards can be problematic even with technical assistance
Formal large-scale contract farming	Company may prefer to group farmers, formally or informally, for inputs and output marketing and extension	Inputs, technical assistance, etc. may be supplied on credit Crop marketing organized by company	Companies often require external agency (bank) to finance credit provision Frequent mistrust between farmers and companies and their employees Contracted price lower than market price may lead to sales outside of the contract

In the marketing of the final produce, the price that they receive at the farm gate is considerably lower than the retail price. The new institutional innovations in the marketing have been initiated in India in the last decade and some of the cases show that they are far friendlier to the farmers when compared to the traditional marketing forms (**Table 3**). The evolving innovative marketing concepts like direct marketing, co-operative marketing, contract farming etc are however not free of hitches. Proper planning and action of the farmers and the private players capable of engaging in such innovative channels.

Table 3: Marketing strategies for organic agriculture

Marketing Institutions	Features
Rythu Bazaar in Andhra Pradesh	First started in Andhra Pradesh in the direction of empowering the farmers to participate effectively in the open market to get a remunerative price for their produce. To avoid the exploitation of both the farmers and the consumers by the middlemen by creating a positive atmosphere of direct interface between them
Apni Mandi	First started in Punjab in the direction of ensuring direct contact of the producer farmers and consumers and thereby enhancing the distributional efficiency of the marketing system. This system does away with the middlemen. The price spread is considerably low. Working satisfactorily in the case of fruits and vegetables
Farmers markets	Farmers markets initiated in various states to eliminate middlemen and traders from the marketing of vegetables in the farmers markets, and to establish direct contacts between farmers and consumers.
Hardaspar Vegetable Market	Hadaspar vegetable market is a model market for direct marketing of vegetables in Pune city, this is one of the ideal markets in the country for marketing of vegetables. The market has modern weighing machines. Linking farmers to vegetable markets
Shetkari	Shetkari bazaars were established in the Maharashtra state for marketing of fruits and vegetables
Bazar	It will eliminate middlemen, links producers and consumers directly, reduce price spread, and enhance producer share's in consumer rupee. Thus these markets increase the farm income, wellbeing of the farmers
Krushak	Established in the state of Orissa in 2000-01
Bazars	· The purpose is to empower farmer-producer to compete effectively in the open market to get a remunerative price and ensure products at affordable prices to the consumer
Cooperative Marketing Society	The need for cooperative marketing arose due to defects in the private and open marketing system. A cooperative marketing society can eliminate some or all of the intermediaries. Few successful cooperative marketing societies for fruits and vegetables. eg. Maha-grape-cooperative federation marketing, Maharashtra, Cooperative marketing. pomegranate, Co- operatives marketing banana in Jalgaon district, Vegetables co-operatives in Thane District, Milk co-operatives in Maharashtra, HOPCOMS, Bangalore and Gujarat and Co-operative cotton marketing society.
Contract Farming/ Contract Marketing	Essentially is an agreement between farmer-producers and the agribusiness firms to produce certain pre-agreed quantity and quality of the produce a particular price and time. This is an important initiative for reducing transaction costs by establishing farmer-processer linkages. Successful contract farming includes Organic dyes- Marigold farmers and extraction units in Coimbatore, Pepsi Company and farmers of Punjab and Rajasthan for tomato growing
Safal Market	NDDB started a fruits and vegetable unit of SAFAL at Delhi was one of the first fruit and vegetable retail chain. NDDB has set up an alternate system of whole sale markets in Bangalore as a pilot project. This market is a move to introduce a transparent and efficient platform for sale and purchase fruits and vegetables by connecting growers through Grower's associations.

Marketing Institutions	Features
Forward and Future Markets	Forward and Futures markets have been identified as important tools of price stabilization and risk management. Extension of forward and futures markets to all major agro commodities has, therefore, assumed great importance. Commodity futures markets in the country are regulated through Forward Contracts (Regulation) Act, 1952
Commodity Exchanges	Commodity exchanges for futures trading narrows the marketing, storage and processing margins, there by benefiting both growers and consumers. NAFED started National Multi-Commodity Exchange of India Ltd. on 26th November, 2002, for cash crops, food grains, plantations, spices, oilseeds, metals and bullion among others. National Commodity and Derivate Exchange of India Ltd. was established in Dec, 2003 at Mumbai with a similar purpose.
Food retail super markets	Food retail markets in India during 1990s and early 2000 opened up the availability of food products dramatically. They key functions are • Higher standards • Lower prices
Organic Mandi	Being initiated in Haldwani in Uttarakhand by Mandi Samiti

There are many constraints that are responsible for their lower adaptability among organic farmers. To extend the understanding of certain impact factors like differences in microbial applications, selections of specific cultivars suitable for organic and conventional systems, climate change, negotiation on input material and marketing strategies, and also more investigations are needed to drive a complete picture, especially in the context of sustainable agriculture. However, technological challenges and long-term sustainability are the major issues that require immediate consideration. Popularizing and educating farmers on organic agriculture through information services could enhance productivity. More technology services and financial support need to be provided to households to promote the conversion from the traditional production model to sustainable agriculture.

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Rice cum Fish Culture (*Rizi – Pisciculture*) Based Farming Systems – A Way Forward for Organic Rice Production to Enhance Soil and Crop Productivity, Profitability, and Nutritional Security of the Marginal Farmers

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Introduction

Tamil Nadu is one of the most important states for rice production in India because of its favourable soil and climatic conditions. Rice in Tamil Nadu is mainly grown in the Cauvery Delta Zone (CDZ), which lies in the eastern part of the state. The CDZ has a total land area of 1.45 million ha, which is equivalent to 11% of the state area**.** Rice dominates in the cropping systems of Cauvery Delta Zone. It is understandable that with North East monsoon rains pouring at high intensity for short spells coupled with flat slopes and heavy soil, rice is the only ideal crop. Though rice is cultivated predominantly in Cauvery Delta Zone, due to increase in the cost of inputs especially chemical fertilizers, the net return per hectare in rice hardly exceeds Rs. 25,000. It is evident that intensification of mono-culture of rice production system leads to anthropogenic alterations that negatively impact the soil physico-chemical and biochemical indicators resulting in loss of biodiversity and degradation of natural resource base, making farming unsustainable in the long run (Nayak *et al.,* , 2020). The farming constraints in rice growing areas are poor rainfall distribution linked to monsoon based monocropping of rice, dismal economic returns from rice, inadequate or absence of diversification of farm components and exclusive dependence on agrochemical inputs (Kathiresan *et al.,* , 2020). Under such a circumstance, any approaches that would reverse soil degradation, conserve natural resources, improve the soil fertility is need of the hour to stabilize the farm revenue.

Integrated farming systems (IFS) is normally viewed as a sustainable alternative for enhancing livelihood security of small and marginal farmers. However, the successful adoption of IFS is facing challenges of declining land holding size. In the low-lying areas, integration of different enterprises needs proper system, development and validation. The small and marginal farmers may not prefer to invest more for the implementation of IFS. Another major hurdles in adopting IFS are marketing of low volume farm products like egg, chicken, flowers, vegetables and fruits under small farmers' holdings. In CDZ, the farm families never stay in the field where the system will be developed. Hence feeding the animals, birds would be very difficult. Due to the above said reasons, the security of the different components also remains a big challenge. Hence an alternate farming system which integrates an enterprise in the rice field would promote higher farm productivity with minimal risk needs to be evaluated. The rice-fish system was observed to be a profitable technology and that adoption increased household income, labour absorption and better liquidity (Purba *et al.,* , 1998). Main beneficial effects of rice-fish culture were related to environmental sustainability, system biodiversity, farm diversification and household nutrition (Rothius *et al.,* , 1998). Integration of fish in rice fields increased dietary standards in terms of animal protein requirement of the poor rural households (Guttman, 1999). Use of organic manures along with organic pest control in rice was demonstrated as a sustainable approach in rice farming with enhanced crop productivity, improved soil fertility status, increased economic return and reduced agrochemical input (Jayakanth *et al.,* , 2000).

Fertilization of Rice Fields

Increase in the cropping intensity, and higher rates of organic matter decomposition under the existing hot and humid climate, lesser application of organic manure and negligible dependence on green manure practice etc. has led to decline in the crop productivity due to depletion of soil nutrients. Nitrogen (N) is the main limiting nutrient element in paddy fields (Zhu *et al.,* 2018). Thus, a large amount of N fertilizer is needed to meet the demand for rice production (Wang *et al.,* 2017). Excessive applications of chemical N fertilizer increase farmers' input costs, bring about low N use efficiency (Liu *et al.,* 2018), and bring about many environmental problems (He *et al.,* 2018). The use of green manures (GMs) cultivated in agroecosystems is an alternative approach that can be used to solve the problem of excessive N fertilizer application (Zhang *et al.,* 2016) and to improve rice production

Green manuring

Green manuring with nitrogen fixing legume crop can provide a substantial portion of N requirement for rice and also add organic matter (OM) to maintain soil fertility which is essential for sustainable agriculture. Green manuring crops not only transfer nutrients to soil but also can lead to deep root system for nutrient uptake from deeper soil causing absorption of less available nutrients, thereby increasing concentration of plant nutrients in the surface soil (Noordwijk *et al.,* 2015), and reducing the use of fertilizer (especially N). Hence GM can prevent the environmental risks related to $NO3^{-}$ leaching. Well nodulated Sesbania plants can derive up to 90% N from fixation (Pareek *et al.,* 1990) and consequently contribute N in rice cultivation. Hence a viable option is to grow the GM crop and apply it to the soil to reduce the application of synthetic N fertilizer and to improve subsequent crop productivity.

Azolla

Azolla is a free-floating aquatic fern, and naturally available mostly on moist soil, ditches and marshy ponds and widely distributed in tropical India. Nitrogen fixing capabilities of Azolla through the symbiotic cyanobionts (around 1100 kg N/ha /year to the plants) are making plant unique and considered as one of the best bio-fertilizer, feed for livestock and biofuel. Azolla in the rice fields provides substantial amount of nitrogen for rice growth and reduces weed infestations.

Phosphorus, Potassium and Zinc solubilising bacteria

Zinc deficiency in plants leads to retarded shoot growth, chlorosis, reduced leaf size (Alloway, 2004), susceptibility to heat, light and fungal infections, as well as affects grain yield, pollen formation, root development, water uptake and transport. However due to continuous application of Zinc sulphate @ 25 kg/ in the Cauvery delta Zone leads to increase in the total Zinc content. But the available zinc level is very low. Plants can uptake zinc as divalent cation but only a very minor portion of total zinc is present in soil solution as soluble form. Rest of the zinc is in the form of insoluble complexes and minerals. Due to unavailability of zinc in soil, zinc deficiency occurs which is one of the most widespread micronutrient deficiencies. Plant growth promoting rhizobacteria (PGPR) are soil borne bacteria that colonize the rhizosphere, multiply and compete with other bacteria to promote plant growth (Kloepper and Okon, 1994). Various PGPR have found to be effective zinc solubilizers. These bacteria improve the plant growth and development by colonizing the rhizosphere and by solubilizing complex zinc compounds into simpler ones, thus making zinc available to the plants. Hence Zinc solubilizing bacteria can be used to alleviate Zn deficiency in rice cultivation. Similarly, potassium solubilizing bacteria (KSB) can solubilize K-bearing minerals and convert the insoluble K to soluble forms of K available to plant uptake. The KSB are effective in releasing K from inorganic and insoluble pools of total soil K through solubilization (Saha *et al.,* , 2016). Phosphorus-solubilizing bacteria are commonly used plant probiotics that promote plant development by converting insoluble P into soluble P that is easily absorbed and used by roots (Hamid *et al.,* , 2021). Hence PGPR lant growth-promoting rhizobacteria (PGPR) which enhances biological nitrogen fixation (BNF), synthesis of plant hormones, soil nutrient solubilization (as phosphorus [P] and potassium [K] can be used in rice cultivation to avoid chemical fertilizers.

Rice-Fish- Duck-Azolla culture

Rice-fish culture is an innovative farming system in which rice is the primary crop and fish fingerlings are used as a secondary source of income. Farmers' poverty is reduced as a result of rice-fish farming, which improves yield, creates jobs, and increases nutritional consumption, resulting in food security. Farmers who are youthful, have a larger farm size, and stronger infrastructure is able to make higher money, according to the farm-specific characteristics used to explain income. Among the various farming system options in rice ecologies, rice-fish farming having a great potential in eastern India considering its ecology, available resources, food habits, socioeconomic and livelihood conditions of small and marginal farmers (Nayak *et al.,* , 2020). The benefits of Rice-Fish farming are as follows.

1. Increase in organic fertilization by fish excreta and remains of artificial feed.
2. Better tillering of the rice seedlings due to the activity of the fish and duck
3. Reduction in the number of harmful insects, such as paddy stem borers, whose larvae are eaten by fish.
4. Reduction in rat population due to increase in the water level.

5. Increased mineralization of the organic matter and increased aeration of the soil resulting from the puddling of mud by benthic feeders.
6. Control of algae and weeds (by phytophagons fish) which compete with rice for light and nutrients.
7. Reduces the amount of farm input required.
8. Diverse sources of income
9. Provides farmers with a well-balanced, nutritious diet.

In this method of farming technology, ducks and fish in rice field creates symbiotic relationship between rice-fish-duck yielding maximum mutual benefits to all the entities. Ducks and fishes control the harmful insects and weeds, dropping utilized as organic manure and mobilization of nutrients, activities (continuous movement, scooping and churning of soil) aerate the rice ecologies which increases the availability of nutrients (like nitrogen, phosphorous and potash) to the rice crops, enhances biodiversity and reduces the global warming potentials. RFD-IFS technology reduced the cost of cultivation, increases. Fish grown in the paddy fields, will be ideal use of land and would also be an easy source of cheap and fresh animal proteins. Thus, fish culture can greatly contribute to the socio-economic welfare of rural populations of especially developing countries. An added advantage also is that unlike sea fish or other animal proteins, the fish from the local paddy fields would cause no transport problem and would be most fresh and healthy.

The integration of duck, fish and azolla in the rice field creates symbiotic relationship. Rice-fish, duck and azolla provides mutual benefits to all the entities. The ducks and fish bioturbation (rapid movement) and presence of azolla in the rice ecosystem enhances the concentration of dissolve oxygen in water, resulting aerobic conditions, which decreased methanogens bacterial activity and subsequently decreases the GHG emissions. Azolla used as one the feed components for animals reared (fish, duck) in the systems. The integrated system enhances biological diversity leading to augmentation of nutrient mineralization through faster decomposition of organic matters, thereby enhances the release and availability of nutrients to supports better growth and productions. The RFAD-IFS utilizes the maximum ecological niches, increases soil and water nutrient levels and fertility, provides healthy ecosystem services and reduces the GHG emissions, hence, increases the farm productivity and sustainability

Conclusion

Integrating Rice-Fish-Azolla-Duck would not only increase the farm productivity and profitability and also increase the soil fertility which could be a way forward in organic production of rice.

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Leveraging Carbon Finance for Sustaining Livelihoods through AWD

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Introduction

The agricultural sector faces daunting challenges in the wake of the Climate Crisis, amidst increasing global water scarcity, which threatens irrigated crop production. Rice, India's most important crop, uses more water than other crops resulting in land degradation. Therefore, paddy grown by traditional methods is a matter of concern. Alternate Wetting and Drying (AWD), also known as controlled or intermittent irrigation, is a water-saving technology that rice farmers can apply to reduce their irrigation water consumption by 15-20% without compromising on the yield. This session aims to provide an engagement platform for various stakeholders to build knowledge and awareness about the opportunities and benefits that can be realized by implementing result-based financed AWD programs via climate and blended financial instruments.

Methodology

VNV Advisory is a Project Developer of community-based Climate Resilient (Mitigation & Adaptation) Programs in areas of sustainable agriculture, social forestry, mangroves restoration, clean cooking, rural energy access and waste management. Our experience in leveraging Carbon Finance has ensured the empowerment of millions of front lining communities in the South Asian region over the last 16 years. Carbon markets aim to reduce GHG emissions cost-effectively by setting limits on emissions and further enabling the retirement of residual emission units (instruments representing emission reductions). The Voluntary Carbon Market (VCM) is based on voluntary action taken by organizations that certify that their emission reductions have environmental integrity. Flexibility of the Voluntary market– innovations in project finance, monitoring and methodologies that influence regulatory market mechanisms. It has spawned its own standards, registries, and project types beyond the scope of existing compliance market mechanisms. It is critical to ensure, or verify, the emission reductions generated by a carbon project are existent and valid. Herein lies the role of various international standards to ensure the credibility of emission reduction projects. There are many standards that issue offsets through the voluntary carbon market. VNV primarily works with CDM, VERRA, Gold Standard and Plan Vivo. For our Alternate-Wetting-and Drying Programs we use the following methodology:

AMS III AU – CDM Methodology

This methodology outlines the rules and guidelines for the implementation of AWD on low-lying rice fields where irrigation can be controlled. Currently such carbon projects are being implemented in parts of Madhya Pradesh, Maharashtra, Chhattisgarh, and Nepal.

Results

- AWD has been shown to reduce water consumption by 25% and reduce methane emissions up to 50%
- Crop yields are maintained and have not been negatively affected through the introduction of AWD.

Socio-economic Co-benefits of Our Programs

Our programs are designed from the bottom-up, keeping the farmers at the forefront and their empowerment as the focus. Equal representation and participation is encouraged throughout the duration of our programs. Communities are organized and networks are strengthened through the formation of farmer groups. Project staff are recruited locally; project activities and monitoring has created sustainable employment and provided an additional income to members of participating communities. SHG's with a significant number of women have been created to encourage collaborative decision-making, thereby lessening the gender gap in rural communities. Bank accounts have been created for each SHG and Farmer group through which financial incentives are provided to farmers for various activities.

Conclusion

Voluntary Carbon Market (VCM) projects can claim positive and verified contributions towards the UN SDGs, offering an opportunity to identify and address development needs of developing countries, more specifically communities at the front lines of climate change. The value derived from these projects via elements of mitigation, avoidance, and sequestration, particularly through nature-based solutions, isn't restricted solely to financial gains, but the added imperative of social returns such as social networks, gender equality and inclusiveness, affordable and clean energy, and sustainable practices throughout the project. These projects facilitate achieving emission reductions but also earn additional revenue that can be used to support the project activities/communities in perpetuity.

Journal of Rice Research - Authors Guidelines

Scope: **Journal of Rice Research** is a channel for publication of full length papers covering results of original research, invited critical reviews or interpretative articles related to all areas of rice science, rice based crop systems and rice crop management. The journal also publishes short communications, book reviews and letters to the editor.

Articles reporting experimentation or research in any field involving rice or rice based cropping systems will be accepted as original articles while critical reviews are generally invited. Short articles concerned with experimental techniques or observation of unique nature will be accepted as short communication. Letters to the editor concerning previous articles are welcome and are published subject to review and approval by the editorial board. The original authors will be invited to reply to the points raised in these letters for their response which are also published together.

General Requirement:

Submission to the journal must be reports of original research of at least two crop seasons and must not be previously published or simultaneously submitted to any other scientific or technical journal. At least one of the authors (in case of joint authorship) should be member of the Society for Advancement of Rice Research (SARR) and not in arrears of subscription. Authors of invited articles are exempted from this.

Submission of Manuscript:

Manuscripts should be sent by email to the chief editor (jrrchiefeditor@gmail.com/chintalapatipadmavathi68@gmail.com) as an attachment. All the enclosed figures (as ppt/jpg files), graphs (as MS Excel worksheet with original data) and photographs (as jpg or ppt files with high resolution) may be submitted as separate files. Avoid using more than one font. The manuscript should be typed in double spaced times new roman font with margins of at least 2.5 cm. On the first page give the title, a byline with the names of authors, their affiliation and corresponding author's e-mail ID. Abstract should be followed by a list of key words. The usual order of sections to be included after title and abstract pages are: Introduction which includes literature review; materials and methods; results and discussion; conclusion (optional), acknowledgements and references followed by figures and tables.

Title should give a clear idea what the articles is about. It should be brief and informative (12-15 words).

Materials and Methods should include experimental design, treatment details, replications and techniques/ methods employed.

Results and Discussion should be supported by sound scientifically analysed data along with explanatory text with relevant tables and figures.

References should be quoted in author-year notation system only. All the references should be arranged alphabetically by author. All single author entries precede multiple author entries for the same first authors. Use chronological order within entries with identical authorship and add a low case letter a, b, c, etc., to year for same year entries of the same author. References should be presented in the format given below:

Research papers

1. Durvasula V. Seshu**.** 2017. Networking a Pivotal Strategy for Rice Genetic Improvement. *Journal of Rice Research*, 10(1): 1-8.
2. Kemparaju KB, MS Ramesha, K Sruti, AS Hari Prasad, RM Sundaram, P Senguttuvel and P Revathi**.** 2018. Breeding strategy for improvement of rice maintainer lines through composite population for short term diversity. *Journal of Rice Research*, 11(2): 27-30
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Book

Subba Rao LV, Shobha Rani N, Chiranjeevi M, Chaitanya U, Sudharshan I, Suneetha K, Jyothi Badri and Dipal R Choudhary 2013 DUS Characterization of Rice Varieties. Directorate of Rice Research, Rajendranagar, Hyderabad-500 030, AP, India. 524 pp

Figures: Photographs and drawings for graphs and charts should be prepared with good contrast of dark and light. Figure caption should be brief specifying the crop or soil, major variables presented and year. Give careful attention to the width of lines and size, and clarity of type and symbols.

Tables: Tables are used for reporting extensive numerical data in an organized manner and statistically analyzed. They should be self explanatory. Prepare tables with the word-processing tables feature and tabs or graphics boxes should not be used. Table head should be brief but complete and self contained. Define all variables and spell out all the abbreviations. An exponential expression (eg. x 10^3) in the unit's line is often needed to keep length of the data reasonably short, and referenced with an explanatory note. Unless otherwise required, two decimal place values are suggested.

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