System of Rice Intensification

A Synthesis of
Scientific Experiments and Experiences

B.J. Pandian | D. Rajakumar | S. Chellamuthu

TAMIL NADU AGRICULTURAL UNIVERSITY

In collaboration with

National Consortium of SRI

December 2011

SRI in India

Within a span of around 10 years, 250 districts across India have adopted the System of Rice Intensification (SRI). SRI has been adopted and adapted in over three million hectares across various agro-ecological regions of India. With its principles now being applied successfully to wheat, mustard, sugarcane, pulses and millets, SRI is shaping up as a System of Crop Intensification.

SRI today in India is widely debated, within and outside mainstream institutions. It is a work in progress, with every year passing by bringing in new experiences and understanding. The National Food security Mission (NFSM) has exclusive targets in SRI in its rice programme. SRI has become a part of the state policy in Bihar (which declared circa 2011 as the Year of SRI), Andhra Pradesh, Jharkhand and Tripura. Para-statal agencies like BRLPS (Bihar Rural Livelihood Promotion Society), SERP (Society for Elimination of Rural Poverty) in Andhra Pradesh too have been instrumental in spreading SRI within their States. Civil society organizations, research institutions and many resource institutions and programmes have played a very important role in spreading SRI across the country.

Sir Dorabji Tata Trust (SDTT) has initiated the promotion of SRI through many NGO partners in the low HDI states particularly in eastern India. Within a short period of less than three years SDTT has reached out to about one hundred thousand farmers in Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Manipur, Odisha, Uttar Pradesh, and Uttarakhand. NABARD is also extensively engaged countrywide in spreading SRI through their NGO partners primarily in Andhra Pradesh, Assam, Bihar, Chhattisgarh, Jharkhand, Maharashtra, and Karnataka. The Aga Khan Foundation (AKF) works directly and through partners in Gujarat, Andhra Pradesh, Bihar, Uttar Pradesh and Jammu and Kashmir.

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Foreword

It is fitting that this book on the System of Rice Intensification (SRI) in India comes from the Tamil Nadu Agricultural University (TNAU). The TNAU was the first institution in India to take SRI's new ideas seriously enough to test them systematically and correspondingly, Tamil Nadu will probably be the first state in India to reach the milestone of 1 million hectares under SRI management.

An initial evaluation of SRI was undertaken in 2000 at the initiative of TNAU's then-Director of the Centre for Soil and Crop Management Studies, Dr. T. M. Thiyagarajan, Since then, TNAU researchers have gained a greater understanding of both the theoretical concepts of SRI and how it can be used in local conditions. TNAU staff have helped both the State Government, and the World Bank, through its Tamil Nadu Irrigated Agriculture Modernization and Water Bodies Restoration and Management (TN-IAMWARM) Project, which aims to promote the use of the new practices across the state. Dr. B. J. Pandian and other staff at TNAU have promoted SRI ideas and techniques in order to spread word of productive and, eco-friendly opportunities, which will benefit Tamil Nadu's farmers and consumers and the state's natural environment. It should be noted that by 2000, some organic farmers in Tamil Nadu had begun to try out SRI methods (Shambu Prasad, 2006). As a result, evaluations of these farmers and the scientists have proceeded in parallel from the outset. However, it should be noted that these farmers did not have institutional backing.

There is a need for organizational infrastructure and staff to facilitate the broad dissemination of new production opportunities in India. In some states such as Himachal Pradesh and Orissa, NGOs have paved the way for the introduction and sustained use of SRI techniques. In other states, such as Tripura, it was the state's extension service that provided effective leadership to the farmers: under the leadership of Dr. Baharul Majumdar, the number of farmers using SRI methods grew from 44 in 2002, to 2,50,000 farmers by 2010, merely eight years later. On the other hand, in Tamil Nadu, SRI innovation was established and propagated through university initiatives, amplified by government involvement, and eventually, taken forward through the support provided by donor agencies as well as NGOs. Ultimately, however, it must be remembered that SRI techniques belong to the farmers.

Having followed the spread of SRI knowledge and methods around the world, to over 40 countries in just ten years, I am struck by the great variety of arrangements that have facilitated this paradigm shift for rice production.

- In Vietnam, NGOs and universities have been contributing to the development of SRI practices. However, it was the National Integrated Pest Management (IPM) programme, initiated by the Ministry of Agriculture and Rural Development that gave great momentum to the campaign. In 2007, when the Ministry designated SRI as ‘a technical advance’, there were less than 10,000 farmers using SRI methods. Four years later, this number reached 1 million (Nguyen, 2011).
- In China, once there was evidence that SRI methods raised crop productivity and reduced water requirements, research institutions in Sichuan and Zhejiang provinces teamed up with their respective Provincial Departments of Agriculture (PDAs) to provide leadership to SRI-based innovations.

Researchers from the Sichuan Academy of Agricultural Science have been working with the Sichuan Agricultural University and a private-sector Seed Multiplication Farm (SMF) in order, to assist the PDA in spreading and adapting SRI opportunities. PDA records show that, while only 1,133 hectares of agricultural land were using SRI techniques in 2004, by 2010 this area had grown to over 300,000 hectares. The province’s paddy production reached almost 1.5 million tonnes, valued at over 2 billion RMB (over $300 million) (Zheng et al., 2011). An innovation introduced by the SMF in Sichuan which maintains the principle of wide spacing but increases plant density through a ‘triangular’ method of seedling placement has added to the productivity of the original SRI methods (Yuan, 2002; Zheng et al., 2004). Some SAAS researchers working with the farmers in this province have developed a “raised-bed/no-till version” of SRI with plastic mulch to suppress weeds and conserve soil moisture, leading to increased yield at a reduced cost. This technique works better in drought years than in years with normal rainfall.

Similar expansion has been witnessed in the Zhejiang province, where scientists from the China National Rice Research Institute in Hangzhou have teamed up with the PDA in that province.

Some of the early work done at TNAU had clearly demonstrated the benefits of using **soil-aerating methods of weed control.** Initially, these benefits were attributed to the effect of green manure and of returning weed biomass to the soil rather than removing by hand. One important consequence of using cono-weeders or rotating hoes to control weeds while actively aerating the top horizon of paddy soil is the promotion of aerobic soil organisms in the soil biota. Helpful organisms can accomplish important tasks such as nutrient cycling and uptake, building up nutrient reserves in the soil (referred to as ‘immobilisation,’ thereby implying a negative effect of microbial activity), nitrogen fixation, phosphorus solubilisation, protection against pathogens and induced systemic resistance.

For the farmers, ceasing to flood paddy fields may not seem like a very attractive prospect in terms of the ***costs*** of mechanical weeding instead of the use of standing water to curb the growth of weeds. But the ***agronomic and financial benefits*** of mechanical weed control are numerous: it leads to an increase in the yield by 1-3 tonnes per hectare and reduces the costs of purchasing and utilising fertilizers on the field. Once this becomes clear, most farmers will be able to recognise that mechanical weeding is not just a cost, but an investment.

Farmers will become even more favourably disposed towards mechanical weeding if weeder implements can be motorized and designed to cultivate multiple rows at a time. This will greatly reduce the labour requirements and costs of mechanical weeding. Various prototypes of motorised weeders have been developed in recent years. Designing and making available weeders that are not too heavy or expensive, durable and effective should be prioritized in order to further spread SRI opportunities. There is also a need for labour-saving methods for crop establishment to replace mechanical transplanting. A "broadcasting-and-thinning" strategy to the same effect was evaluated at the TNAU by Ramasamy et al. (2006). Their book reveals through empirical research what is often reported anecdotally and demonstrates that SRI methods can actually ***reduce*** the labour requirements for paddy production rather than increase it, a negative stereotype associated with SRI that has inhibited its acceptance. Once it is understood that SRI adoption can save labour costs, SRI methods will prevail, particularly because these methods lead to higher yield, save water and are less vulnerable to climatic and other stresses.

There is no magic in SRI. The combination of recommended SRI practices creates a more favourable growing environment — particularly beneath the soil — for rice plants. Some of these practices are modifications to the plant-population density made when the plants are seedlings. In addition there is an emphasis laid on maintaining the mostly aerobic condition of soil so that air actively circulates within the soil system and in creating a more abundant and diverse microbial population in the soil by providing more organic matter to it. All these strategies enable rice plants to express their genetic potential to a greater extent. These practices help more productive phenotypes to emerge from available genotypes (Thakur et al., 2010). These practices, which are beneficial for rice plants, are also proving beneficial for the growth of other crops, such as sugarcane, wheat, ragi, mustard and even some legumes and vegetables (http://sri.ciifad.cornell.edu/aboutsri/othercrops/index.html).

This book should be regarded as an interim report, rather than as the final word on the matter. Many new and worthwhile research topics have emerged from experiences with SRI and its derivations: System of Wheat Intensification (SWI), Sustainable Sugarcane Initiative (SSI), Specialty Minerals Inc. (SMI), etc. This should make the SRI strategies worthwhile for agriculturalists. SRI strategies are also likely to make it easier and less expensive than previously thought to meet food needs in an environment constrained by climate change. Additionally, farmers should be able to gain more output from available resources. These facts should influence policy-makers in the government.

It is anticipated that prices will fall with higher production. This will benefit all consumers, but particularly poor households who currently spend most of their meagre income on food. If farmers can produce more food at a lower cost, their net income will still increase. Greater resources will be available for poor sections of society to meet needs other than food. Farmers who have been primarily engaged only in rice production will be free to move into more diversified production; this will enhance their earnings as well as their nutrition and should give them a more stable, year-round income stream. Smallholders in Cambodia are already starting to utilize the productivity gains with SRI to diversify their farming systems (Lim, 2007).

Although the adoption of SRI techniques is probably going to be disruptive for some, particularly for rice traders and input suppliers, the total benefits, starting with much greater food security, should far outweigh these disruptions. Farmers themselves will probably become more experimental and entrepreneurial as a result of their engagement with SRI. SRI does not offer "package" technology to be adopted by farmers, as was the case during the Green Revolution. SRI in its core conception involves **adaptation** rather than adoption, and farmers are expected to become more innovative. Rather than presenting SRI as something to be accepted in totality, farmers, once they have understood the basic principles of SRI-recommended-practices are challenged and expected to rethink their conventional wisdom and to experiment with and to evaluate alternatives. They must know and understand the reasons for justifying key SRI recommendations. However, they will remain free to make their own decisions about how intensively and productively they use their own resources.

In 1990, the originator of SRI, Fr. Henri de Laulanie, SJ, and a number of his Malagasy colleagues established an NGO to promote SRI in Madagascar called ***Association Tefy Saina.*** These Malagasy words do not mean 'grow more rice' but 'improve the mind.' Ultimately, SRI is about human development, not just agricultural production. If this innovation is understood and propagated with its original spirit and intent as its concepts and methods are adapted for crops, there should be a rather broad-based uplifting of the rural sector in Tamil Nadu and elsewhere.

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Norman Uphoff

Professor of Government and International Agriculture, and Senior Advisor to the SRI International Network and Resources Center (SRI-Rice)

Cornell International Institute for Food, Agriculture and Development (CIIFAD), Ithaca, New York, USA

Preface

The System of Rice Intensification (SRI) has drawn attention in the recent past owing to the fact that it addresses the current need to decrease the use of inputs such as water and labour along with the current need to protect the environment and offer food security. The concept of SRI may not be new to everyone. SRI originated in Madagascar before spreading worldwide. It is well known that trends in rice cultivation have been changing over the years. Researchers and farmers are developing new strategies to meet new obstacles, particularly with the global scarcity of resources such as water and labour. This awareness and attempts at development have led to many systems of rice cultivation, apart from region-specific and season-specific traditional rice systems, including Integrated Crop and Resource Management (ICRM), Transformed Rice Cultivation (TRC), Aerobic Rice and Furrow Irrigated Raised Bed (FIRB) System.

It is significant that SRI does not deal with any one issue. Rather, it is an integrated management technology that harmonises natural synergistic management practices for better crop performance. The increase in grain yield led to a gain in momentum for SRI practices in farmers' fields. However, it is regrettable that the technology has been employed in the fields before proper scientific validation and appropriate endorsement by the researchers could occur. This has led to a gap in knowledge about SRI techniques. Illusions and unauthenticated results which have spread among the farmers have made them quite unclear about the technology. While it is clear that, since its inception, research had led to ample scientific evidence, nothing has been brought to the limelight. Therefore, the need was felt to write this book on SRI practices, in order to meet the above-mentioned concerns.

A clear picture of the real situation has been painted with the challenging initiatives taken up and the vast experiences gained in the World Bank aided TN-IAMWARM Project to disseminate SRI strategies. This project has brought to light the practical issues related to the SRI management practices. It is therefore our privilege to bring out this book on SRI, in order to serve as a trove of information to bridge the gaps in the knowledge about SRI principles and practices, and also to disclose the science behind it. This book is meant to serve as an informative guide for researchers, students, policy-makers, extension personnel and academicians. The contents have been arranged to focus on SRI since its inception, the initiatives taken, the technology, the principles and practices, SRI's strengths and the opportunities it offers as well as its constraints and possible measures to overcome them and the experiences of the TN-IAMWARM Project and its implications on policies.

The contents of this book have been drawn mostly from journals and books, towards whose authors we would like to express our gratitude. We, with gracious and utmost admiration, register our indebtedness to Dr. Norman Uphoff, Professor of Government and International Agriculture, New York, USA, for his unceasing efforts to sketch out the manuscript and his valuable suggestions. We also record our deep sense of gratitude to Dr. B.C. Barah, Member of the Core Group, National Consortium of SRI (NCS) for his exceptional guidance and assistance while preparing and publishing this book. I am grateful to Mr. Ravindra, Wassan, Prof. C. Shambhu Prasad, XIMB and Mr. D. Narendranath, PRADAN from the National Consortium who provided valuable guidance in bringing out this publication. I also express my sincere thanks to Mr. Rahul Kumar and Ms. Bhawna Khatri of PRADAN for their support in the printing and publication of this book. We also record our sincere thanks to the Aga Khan Foundation for supporting PRADAN under its EU-financed SCALE programme for making available the resources for publishing this book. We express our unbound appreciation to the Project Director, TN-IAMWARM, for his persistent encouragement and the keen interest he showed in our project during the course of its preparation. We are also greatly indebted to the Vice Chancellor, Tamil Nadu Agricultural University, Coimbatore, for his sustained support and consent during the course of preparation. Our sincere thanks are also due to the scientists in charge and field staff of the TN-IAMWARM project.

— The Authors

Executive Summary

In order to understand the science of SRI, relevant research on SRI principles and practices reported in India has been documented. This book also appraises the potentials, limitations and possible practical difficulties that arise in practicing the technology and also discusses measures that can be taken to increase the scale of SRI.

It has been well established that the synergy between the practices — *viz.*, optimum plant population, transplanting single young seedlings (12-14 days), wider square planting (25x25cm), mechanical weeding from 10 days after transplanting up to 40 days at 7-10 days interval, keeping the soil moist but not inundated, Leaf Colour Chart (LCC)-based nutrient management and the use of organic manure — has helped produce more healthy and productive plant phenotypes and subsequently led to higher returns. However, the success of SRI depends on the farmers' understanding and skill levels.

The regular rice-growing seasons of India, *viz.*, autumn, winter and summer, are well suited for SRI and it is evident that irrespective of the variety of rice, increases in yield are more possible with SRI as opposed to conventional system of rice cultivation. Persuading farmers to cultivate hybrids and high-yielding varieties of rice, as well as making seeds available to the farmers, will be an important task in disseminating SRI.

Seedlings can be obtained from any of the nurseries, raised according to the availability and suitability of resources, irrigation facilities and soil type. However, care must be taken not to damage the roots while pulling out the seedlings. Many farmers are still afraid of handling and transplanting a single, young and fragile seedling. To provide a buffer wherever high mortality of seedlings is expected due to factors such as salinity, excess water seepage, poor levelling and trampling by birds, two seedlings could be transplanted instead of one.

Another concern is higher grain yield from the same area. Wide spacing beyond the optimum (25x25 cm) does not give higher grain yield on an area basis. In order to achieve this, a combination of technologies including square planting along with mechanical weeding starting from 10 DAT (Days After Transplantation), must be ensured. The main purpose of square transplanting is to be able to use the mechanical weeder in both directions. Labourers used to conventional planting may find square planting to be cumbersome. However, any apprehensions should be laid to rest by the fact that labourers will have to plant only 25 per cent as many seedlings as before.

Most farmers still believe that a higher quantity of water applied to the rice fields will lead to greater rice yield. This untrue belief needs to be eradicated from farmers' minds. Experimentations related to SRI have indicated that despite a significantly lower use of water, there is a higher yield from the rice crops. Thus, where canal irrigation is practiced, infrastructural facilities have to be developed in order to deliver only the required amount of water to the field and drain excess water.

Benefits from SRI are obtained only by the use of weeders. It has been perceived that weeding with the help of a rotary weeder, also known as a cono weeder, is a critical component of SRI which can neither be avoided nor be compromised on. The first weeding by 10 DAT is crucial. There is therefore a strong need to develop a motorised weeder to ease the weeding process and making it less expensive for the SRI farmers.

SRI makes use of the naturally-available organic manures as inputs. This allows farmers to use organic manures available on the farm at a low cost, and thus be able to meet a significant portion of the crop's nutrient demand and to improve soil fertility. When combined with inorganic fertilisers, this can lead to higher yields and profits, particularly on poor lowland soils.

Despite the many significant benefits of SRI, the spread thereof across the country is dwindling. In Tamil Nadu, the TN-IAMWARM (Tamil Nadu Irrigated Agriculture Modernization and Water Bodies Restoration and Management) Project really served as a channel for scaling up the technology and creating awareness through Information, Education and Communication (IEC) activities. An analysis of the overall performance of SRI in the project area revealed that a majority of beneficiaries have reaped more than 40-50 per cent increase in the yield by following SRI strategies. Thus, SRI has proved its merit in Tamil Nadu.

The Strengths, Weakness, Opportunities and Constraints (SWOC) of SRI were analyzed as well. The strengths and opportunities include using mechanical weeder, square planting with wider spacing, saving water, increased productivity, increased scope for mechanization and equitable gender participation. The weaknesses and constraints relate to the lack of scientific base among the farmers, the lack of skill in raising mat nurseries, the difficulty of transplanting in squares and the use of mechanical weeders, farmers' apprehensions regarding single seedling transplanting, the non-availability of implements, the inability to provide controlled irrigation and the lack of precise land leveling. The suggested measures of scaling up are field demonstrations, exposure visits, community nurseries, rural artisan training, using mechanical weeders for weeding and row markers for square planting.

There is a need to understand, standardise upon and propagate beneficial interactions between crop varieties, environmental conditions and crop management practices. There continue to be gaps between yields at research stations and in farmers' fields, due mostly to a lack of initiatives, resources and extension-outreach programmes. These yield gaps in rice can be improved effectively by SRI through adopting participatory and holistic approaches with institutional and policy support.

The SRI method of cultivation not only increases rice yield, but also makes use of land and labour more efficient, reduces production costs and increases sustainability. While perusing this compendium, it can be observed that the conclusions drawn for SRI are consistent. It is clear that an increased understanding and acceptance of the components of SRI by the farmers and their participation will be the real success of SRI. There is therefore a need to continually strive to fill in fundamental knowledge gaps through detailed research.

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1. INTRODUCTION

Globally, rice is cultivated on 155.5 million hectares of land. In the last 30 years, there has been an annual growth rate of less than 0.5 per cent. The potential for expanding the area under rice-based systems will remain limited in the context of an unabated population and the likelihood of scarcity of land and water resources for agriculture in the near future. Urbanisation and industrialisation have also worsened the situation. The average annual growth rate of rice yield, which was 3.68 per cent in the early 1980s decreased to 0.74 per cent in the late 1990s (Nguyen and Ferrero, 2006). Although several factors have contributed to the decline of the area under cultivation and productivity, some of them are of more serious concern. Among these are limited returns to agriculture, declining productivity in intensive modern rice production systems due to multifaceted and intricate problems including soil health, biotic and abiotic stresses, an increase in production costs and an increasing public concern for protecting environmental resources.

Rice ecosystems in India are extremely diverse (Singh 2002). India has the largest area under rice cultivation in the world. Of the 44.6 million hectares of harvested rice area in India, about 33 per cent is rainfed lowland, 45 per cent is irrigated, 15 per cent is rainfed upland and 7 per cent is flood-prone. In irrigated areas, such as Punjab, Haryana and Tamil Nadu, rice yields have increased from 55 per cent to 98 per cent in the past two decades. These areas now have rice yields of 5 to 6 tonnes per hectare, primarily because of a higher input use. Rice is cultivated around the year in some parts of the country. The national production of rice is about 95 mega-tonnes per year. However, the national average productivity remains relatively low, at around 3 tonnes per hectare.

Unscientific water management and the imbalanced use of fertilisers has caused a rapid degradation of rice ecosystems. This has put tremendous pressure on rice growers to make rice farming more economically viable and ecologically sustainable. Given these constraints, producing more rice in the future to feed an ever growing population is a great challenge. Therefore, henceforth, farmers, policy-makers and researchers alike need to address these threats to rice productivity.

1.1. Rice-Production Scenario in Tamil Nadu

While the area under rice crop in Tamil Nadu has been stable, production and productivity statistics show great fluctuations. Production has ranged from 50.39 lakh tonnes to 75.32 lakh tones with an annual mean production of 55.3 lakh tones in the last 10 years. With regard to productivity per unit of area, the lowest recorded was in 2003-04 (2,308 kg per hectare) and highest was in 2000-01 (3,541 kg per hectare). Tamil Nadu ranks twelfth in terms of total production but second in terms of productivity all over India. The average rice consumption of urban and rural families in Tamil Nadu per month is 9.49 kg and 8.11 kg respectively.

The increase in population corresponds with an ever-increasing demand for rice which has not yet been met. It is estimated that an additional 7.24 million tonnes of rice is required to meet these growing consumption needs – 4.26 million tonnes for rural Tamil Nadu and 2.98 tonnes for urban consumers. The production pattern of rice in Tamil Nadu thus indicates a huge net gap between demand and supply.

Tamil Nadu has a unique three-season pattern of production, namely, Kar or Kuruvai (June to September), Samba, Thaladi or Pishanam (August to January) and Navarai or Sornavari (December to April). Of the total rice cultivation, 16 per cent occurs in Kuruvai, 75 per cent in Samba, and 9 per cent in Navarai. One of the major production constraints is scarcity of irrigation water. Rice, as the predominant crop in Tamil Nadu, consumes 70 per cent of the water available for agriculture. The gap between water supply and water demand for irrigated crops in Tamil Nadu is projected to reach 21,000 million m^3 by 2025 (Palanisamy and Paramasivam, 2000). This gap has partly been created by the inefficient use of irrigation water in lowland rice cultivation, which leaves farms that do not have access to irrigation water vulnerable to severe water scarcity. Whenever the monsoon fails, lowland rice also faces water scarcity, leading either to crop failure or to farmers being unable to plant their crop. There is, therefore, a need to economise on the usage of irrigation water, even though statistics indicate that rice yields have increased over the years.

1.2. Rationale and Route to System of Rice Intensification (SRI)

Concerns of sustainable irrigated rice ecosystems, severe water crisis, and threat to wetlands: Rice research in India during the last century has resulted in the development of important technologies. Adopting these has helped in keeping the growth of rice production growth ahead of the population growth rate. However, the increasing paucity of water now threatens the sustainability of the irrigated rice ecosystem. Water shortage in many rice-growing areas has therefore prompted the search for production systems that use less water to cultivate rice. Although several strategies are being pursued to save water in irrigated rice ecosystems, water loss still remains extremely high because all these systems involve prolonged periods of flooding the rice fields. To minimise the negative impacts of the overuse and misuse of water and to ensure that precious water resources are used optimally, it is necessary to switch to technologies and productive systems that recognise and adequately address these emerging challenges.

Studies show that modern methods of rice cultivation employ the use of 3,000-5,000 litres of water to produce one kilogram of rice (WWF/ICRISAT, 2007). A significant portion of this water is used only to prepare the land for cultivation. In view of the impending water crisis, recommendations have been made for deficit irrigation so long as it is economically tenable. In some areas where water is scarce, farmers are being encouraged to give up production of water-intensive crops such as sugarcane and wetland rice, keeping in mind the concurrent needs to maximise production while at the same time providing minimum sustainable income above the poverty line. There is therefore an acute need for irrigated rice-based systems with technologies that save water.

Mounting demand for food grain and stagnant rice productivity: The United Nations Food and Agriculture Organisation (UN-FAO) estimates that food demand will rise by 70 per cent globally by 2050, doubling its current demand in developing countries. The projections show that cereal output will need to increase by almost 1 billion tonnes (43 per cent) per year to meet this growing demand. In India, the production of food grains has increased from around 50 million tonnes in the 1950s to about 200 million tonnes by 2000. But this need to grow to around 300 million tonnes by the year 2020. Out of a total cultivatable area of 195 million hectares in the country, the net area under cultivation has remained stagnant for the past two decades, at around 142 million hectares. It is estimated that by 2020 at least 115-120 mega tonnes of milled rice needs to be produced in India to maintain the present level of self-sufficiency.

Existing yield gaps and scope for bridging them: The Expert Consultation on Yield Gap and Productivity Decline in Rice Production convened by the FAO in Rome in 2000 recognised that there is a sizeable yield gap ranging from 10 to 60 per cent between attainable and farm-level yields across many-rice growing countries. Integrated and precision crop management technologies, starting from varieties of higher yield stability, can narrow agronomic yield gaps and at the same time help farmers reduce the waste of resources that arises from poor management of inputs and natural resources. Yield differences among farmers in the same area are frequently observed because of different levels of crop management and environmental variations.

Since India is a large country, problems related to rice production are different in different regions. Therefore, to enhance rice productivity, rice yield gap and yield variability in farmers' fields have to be minimised by identifying specific land and management factors that cause rice yield gaps at the regional and local levels. While no major breakthrough is expected immediately, reduction of the yield gap alone could ensure 60 percent of the required increased annual rice demand by the year 2025 (FAO, 2004).

Dynamic competency of conventional research: Agricultural scientists have at their disposal a wide spectrum of complementary tools, including molecular biology and the social sciences. Still, conventional research methods will continue to be an important source of technology supply for crop improvement and management. These continue to provide a steady stream of significant technologies for enhancing cereal crop productivity in areas of seed, crop and resource management technologies. Choosing technologies that are inclusive and integrative can potentially achieve the goal of sustainable food security for those living below the poverty line in the developing world. Also, any intervention in improving the agricultural productivity should be economically viable, socially acceptable and environment-friendly, and take into account the increased factor productivity of water, nutrients, labour and land by adopting integrated soil and crop management practices.

Pursuing the existing vibrant conventional management technologies: It has been generally conceded that productivity gains that can be achieved from conventional technologies have not yet been fully explored and exploited by the farmers. The yield gap between what is possible and what is actually achieved on farmers' fields is quite large, especially in more marginal environments. The farmers in high-potential environments achieve yields that are at par with experimental station yields, but the majority of Indian rice growers lag far behind by as much as 2 to 3 metric tons per hectare. Farmers rarely have uninterrupted access to modern farming inputs. Additionally, they often lack efficient crop management technologies and knowledge that is crucial for bridging the yield gap. For example, the judicious and conjunctive application of nitrogen fertilisers between seeding to heading, in terms of quantity and timing, will by itself significantly contribute to rice yield while avoiding unnecessary losses of nitrogen, which otherwise increases production costs. Zero-input technologies, viz., selection of suitable varieties of quality seeds, seed treatment, optimum plant population and integrated nutrient management and timely operations such as weeding, fertiliser application and harvest, are not being judiciously practiced.

Spirited blooming of System of Rice Intensification (SRI): Rice cultivation must be regarded as a systems approach consisting of diverse opportunities for the integration of management technologies and land and water resources. The intensified efforts to improve crop, water, land and labour productivity, and subsequently the farmers' income, have resulted in many approaches comprising efficient management practices in wetland rice cultivation. The evolution of System of Rice Intensification (SRI) in India is a clear reflection of the above principles and a holistic agro-ecological crop management technique seeking alternatives to high-input agricultural practices. It is a scientific agricultural management tool that converts the conventional agronomic, principles synergistically into a higher-yield production process by making use of irrigation water based on local soil and climatic conditions in order to achieve maximum water productivity.

Global debates about SRI practices have cast shadows of doubt amongst the rice growers of India. As a result, SRI facts must be duly documented and understood before deriving firm conclusions about its potentials, limitations and credibility as a system. In this compendium, the evidence from by research projects conducted in India has been collected so as to examine the complementary effects of SRI components, including agronomic management methods of improving rice productivity. Efforts here are made not only to appraise the probable utility of SRI but also to acknowledge the possible practical difficulties that may arise from introducing SRI techniques at the field level and from attempts towards scaling up the technology to benefit rice growing communities and provide long-term food security.

2. SYSTEM OF RICE INTENSIFICATION (SRI)

The System of Rice Intensification (SRI) is an innovative method comprising uncomplicated management practices that allow rice-growers to attain higher productivity. Similar to the central principle of sustainable agriculture which seeks to make optimal use of naturally available resources as functional inputs, SRI too works by integrating invigorative processes such as optimum plant population, transplanting single young seedlings, wider square planting, mechanical weeding at 10 DAT (Days After Transplantation), keeping the soil moist but not inundated, using Leaf Colour Chart (LCC)-based nitrogen management schemes, using compost, FYM or green manure to the greatest extent possible and converting all of these resources synergistically to achieve higher yield from the rice crop. The synergy between these practices helps to produce more healthy and productive plant phenotypes and subsequently to obtain higher returns. SRI also minimises the use of high-cost external inputs that are detrimental to the environment. However, the success of SRI depends on knowledge and skills of the farmers and how productively they are able to employ them.

2.1. Dawning and sprouting of SRI

The System of Rice Intensification (SRI) was initially developed in Madagascar in the 1980s by Fr. Henri de Laulanié, in association with a non-governmental organisation called Association Tefy Saina (ATS) and many small farmers. Since then, it has spread to many countries. The emergence of SRI in India was slow as compared to other rice-growing countries. The pioneering steps to introduce SRI in India were taken by scientists of the Tamil Nadu Agricultural University, Coimbatore, and Acharya N.G. Ranga Agricultural University, Hyderabad. State Agricultural Universities (SAUs) in Southern India refined SRI practices to suit local conditions by conducting numerous field experiments. SRI was made known to the Tamil Nadu Agricultural University (TNAU) through an informal e-mail communication from Plant Research International (PRI), Wageningen, in early 2000 when PRI initiated a collaborative research project with TNAU on 'Waterless Rice'. SRI principles were introduced in the experiments conducted during this project. The first on-station experimental evaluation of SRI in India was carried out in Tamil Nadu during 2001-02 at TNAU (Senthilkumar et al., 2008). Consequentially, a package of modified SRI practices evolved and gained momentum after 2000.

Andhra Pradesh, Tripura and Tamil Nadu are leading the adoption and popularisation of SRI in India. Concerted efforts are also being made by the states of Bihar, Jharkhand, Orissa and Chhattisgarh.

2.1.1. On-farm experiments

The experimental site had clayey-loam soil with pH value of 8.3, EC of 0.54 dSm-1 and organic carbon content of 8.2 grams per kilogram of soil. Two experiments were carried out, one during the wet season from September 2001 to January 2002 with rice hybrid CORH 2 and the other during the dry season from February to June 2002 with rice hybrid ADTRH 1. Four management factors were implemented as treatments in a split-plot design with four replicate blocks. The main plot treatments were the planting method and irrigation application with sub-plot treatments of weed and nutrient management (Table 1).

Table 1. Testing of Crop management practices in Tamil Nadu during 2001-02

Management factors	Conventional method	Modified method (SRI)
Experiment 1		
Planting (P)	P1: 24 day old seedlings transplanted from conventional nursery, single seedling hill-1	P2: 14 day old seedlings transplanted from dapog nursery
Irrigation (I)	I1: Irrigation to 5 cm depth one day after disappearance of surface water	I2: Water saving irrigation after crop establishment *i.e.*, irrigating to 2 cm depth after surface crack development up to flowering followed by conventional irrigation during grain filling.
Weed management (W)	W1: Weeds removed by manual weeding (3 times)	W2: Weeds mechanically incorporated with a mechanical weeder in two directions 5 times
Nutrient management (N)	N1: Recommended N (150 kg per hectare), P (26 kg per hectare), K (75 kg per hectare) and Zn (10 kg per hectare) applied in split doses.	N2: Same as conventional plus green manure; Sesbania aculeata (fresh weight 6.25 t per hectare which added 58:6:49 kg of NPK per hectare)

Management factors	Conventional method	Modified method (SRI)
Experiment 2		
Planting (P)	P1: 24 day old seedlings transplanted from conventional nursery, single seedling $hill^{-1}$	P2: Direct seeding 2-3 seeds manually sown but later thinned to a single seedling $hill^{-1}$
Irrigation (I)	I1: Irrigation to 5 cm depth one day after disappearance of surface water	I2: Water saving irrigation after crop establishment i.e., irrigating to 2 cm depth after surface crack development till maturity
Weed management (W)	W1: Pre Emergence application of Butachlor fb manual weeding 2 times	W2: Weeds mechanically incorporated with a mechanical weeder in two directions 5 times
Nutrient management (N)	N1: Recommended N (150 kg per hectare), P (26 kg per hectare), K (75 kg per hectare) and Zn (10 kg per hectare) applied in split doses.	N2: Same as conventional plus green manure; Sesbania aculeata (fresh weight 6.25 t per hectare which added 58:6:49 kg of NPK per hectare)

In experiment 1, the overall grain yields with water saving irrigation (6.4 t per hectare) were similar to yields under conventional irrigation (6.5 t per hectare) while on an average 41 per cent of the irrigation water was saved. Practicing water-saving irrigation from transplanting to flowering, while maintaining a thin layer of standing water during the post-flowering stage, did not lead to a reduction in grain yields, which stood at an average of more than 6 tonnes per hectare with all irrigation treatments.

In the second experiment, water-saving irrigation techniques led to the significant reduction of the yield to 6.2 tonnes per hectare from the 6.5 tonnes per hectare obtained with the use of conventional irrigation. This yield reduction may have been due to the continual use of water-saving irrigation up to maturity. But, it must be noted that 50 percent of the irrigation water was saved at the expense of just 0.3 tonnes per hectare of grain yield.

The highest water productivity was obtained from a combination of conventional planting and water-saving irrigation in both the experiments (0.73 kilograms per cubic meter and 0.87 kilograms per cubic meter, respectively). In this treatment combination, water productivity was increased by 84 and 96 percent, respectively, compared to conventional irrigation. The greater water saving in Experiment 2 was due to the continuation of water-saving irrigation up to maturity.

Table 2. Water productivity and water saving achieved in Experiments 1 and 2

Particulars		Water used (10^3 x m^3 ha-1)			% water saved	Grain yield (tonnes per hectare)	Water productivity (kg grain m^{-3})
		Irrigation	Rainfall	Total			
Experiment 1							
Conventional planting	CI	11.85	3.56	15.41	--	6.1	0.40
	WSI	5.21	3.56	8.77	43	6.4	0.73
Modified planting	CI	13.35	3.56	16.91	--	6.8	0.40
	WSI	6.70	3.56	10.26	39	6.3	0.61
Experiment 2							
Conventional planting	CI	13.41	0.56	13.97	--	6.2	0.44
	WSI	6.21	0.56	6.77	52	5.9	0.87
Modified planting	CI	16.63	0.56	17.19	--	6.8	0.39
	WSI	8.42	0.56	8.98	48	6.4	0.72

CI – Conventional Irrigation; WSI – Water Saving Irrigation

Source: Senthilkumar et al., 2008

2.1.2. Experiments on the farmers' fields

The results of the on-station experiments were encouraging enough for the Government of Tamil Nadu to support Adaptive Research Trials (ARTs) in 2003-04 with 100 farmers each in the two major rice-growing areas of the Thamirabarani and the Cauvery river basins. Each ART was performed in a 1000 meter square area without any replications. Each trial was designed to compare the modified rice cultivation method with the conventional rice production method. One remarkable feature of the results, which are enumerated as follows, was the consistency in the responses: in all the farms, the modified production method gave the same or better yield than the conventional method.

- In the Thamirabarani basin, grain yields in farmers' fields where modified rice cultivation was practiced ranged from 4.2 to 10.7 tonnes per hectare (the mean yield was 7.2 tonnes per hectare). On the other hand, where conventional rice cultivation was practiced, the grain yield ranged from 3.9 to 8.7 tonnes per hectare (the mean yield was 5.7 tonnes per hectare). The overall yield advantage with the modified rice cultivation method was 1.5 tonnes per hectare.
- In the Cauvery river basin, the grain yield where modified rice cultivation was practiced ranged from 4.1 to 7.9 tonnes per hectare (the mean yield was 6.0 tonnes per hectare) and where conventional rice cultivation was practiced, the grain yield ranged from 2.7 to 6.6 tonnes per hectare (the mean yield was 4.6 tonnes per hectare). This gave an overall yield advantage of 1.4 tonnes per hectare for the modified production method.
- In the 36 ARTs of Thamirabarani river basin, on an average, an overall saving in cost of cultivation of about 11 percent was found in areas where modified rice cultivation was tried out. This cost reduction was achieved through savings in terms of labour, seeds, fertilisers for nursery preparation and mechanical weeding.
- The seed requirement for the dapog nursery was 7.5 kilograms per hectare as compared to 60 kilograms per hectare for the conventional nursery.
- No organic or inorganic fertiliser was applied to the dapog nursery, which further reduced the cost of cultivation.
- The dapog nursery did not require ploughing with the tractor as it was based in small areas near farmers' homesteads. The nursery requirements per hectare of cultivated land was 100 square meters. The conventional nursery comprised, on the other hand, an area of 800 square meters per hectare.
- Labour requirements for nursery maintenance were halved from six to three labour days in the dapog nursery.

- The overall cost for the dapog nursery was reduced from Rs 2,115 to Rs 675 per hectare of transplanted rice.
- Mechanical weeding led to a significant reduction of the cost of cultivation. The use of a mechanical weeder halved the labour requirements for weeding.
- Labour costs were calculated based on a wage rate of Rs 41 per labour days for both men and women. Costs were 11 percent less for the modified method.
- Traditionally in Tamil Nadu, hand weeding of rice fields is done by the female labourers, whereas implements are used by the male labourers. The introduction of mechanical weeding led to a shift from the use of women's labour, for weeding by hand, to men's labour for mechanical weeding, in the modified rice cultivation. Taking into account the gender differentiation and the corresponding actual differences in wages – i.e., Rs 81/- per labour day for men and Rs 41/- per labour day for women – the overall cost saving was about five percent (Table 3).
- The cost of transplanting was higher in the areas where modified rice cultivation was practiced because transplantation in neat rows requires more labour. This is because extra care is needed to handle young seedlings and the time taken to transplant seedlings into rows at regular intervals, to facilitate mechanical weeding, was greater.
- The labour requirement for the water-saving irrigation method was less, because the time required for irrigation as well as the frequency of irrigation were both significantly lower in the modified rice cultivation method.
- There was no difference in cost of field preparation, manure and fertiliser application, plant protection and harvesting between the two methods being tested.
- The average gross and net incomes through the sale of grain and straw for the 36 farmers who had adopted all components of modified rice cultivation was Rs 42,930/- and Rs 20,160/-, respectively (average grain yield – eight tonnes per hectare; average straw yield – 11.7 tonnes per hectare). For those who had only used the conventional methods, the average gross and net incomes were Rs 32,580/- and Rs 8,775/- respectively (average grain yield – 6.1 tonnes per hectare; average straw yield – 9.1 tonnes per hectare). The benefit-to-cost ratios for the modified method and the conventional method was 2.2:1.5, modified to conventional.

Table 3. Comparison of inputs and costs (per hectare) used in conventional (C) and modified (M) rice cultivation methods of the on-farm ARTs in Thamirabarani river basin

Particulars	Male labour (labour-day)		Female labour (labour-day)		Total cost including input (seed, fertiliser) (Rs)	
	C	M	C	M	C	M
Nursery preparation	6	3	0.5	5.5	2,115	675
Main field preparation	12	12	-	-	2,025	2,025
Manures and fertilisers	7	7	10	10	7,245	7,245
Transplanting	5	5	55	75	2,430	3,240
Weeding	-	38	80	-	3,240	1,530
Irrigation	7.5	6	-	-	315	225
Plant protection	2	2	2	2	675	675
Harvesting	12.5	12.5	75	75	3,690	3,690
Total	52	85.5	222.5	167.5	21,735	19,305

Source: Senthilkumar et al., 2008

Additionally, the opinions of the farmers about the use of labourers in the modified rice cultivation method were recorded. In both basins, farmers noted that the majority of labourers complained about the modified rice cultivation method (Table 4). Most of the problems were experienced due to the square planting method (90 and 76 percent in Thamirabarani and Cauvery river basins, respectively), followed by the line planting method (86 and 72 percent respectively). Mechanical weeding was considered to be an easier activity by labourers in the Thamirabarani basin (74 percent), but labourers in the Cauvery basin were less satisfied (40 percent) because of the weight of the cono weeders.

Table 4. Farmers' perception on labourers experience on different components of modified rice cultivation compared with conventional rice cultivation in the Thamirabarani and Cauvery river basins

Particulars	Thamirabarani river basin (%)				Cauvery river basin (%)			
	Hard[a]	Normal[b]	Easy[c]	Not adopted[d]	Hard[a]	Normal[b]	Easy[c]	Not adopted[d]
Farmers experience on modified rice cultivation methods								
Main field preparation	6	92	2	0	36	64	0	0
Modified nursery preparation	56	12	30	2	32	28	20	20
Line planting	58	20	22	0	24	52	24	0
Square planting	68	10	20	2	28	48	24	0
Mechanical weeding	12	4	78	6	40	4	56	0
Farmers opinion on labourers experience of modified rice cultivation methods								
Line planting	86	8	6	6	72	20	8	0
Square planting	90	2	2	2	76	16	8	0
Mechanical weeding	14	4	74	74	56	4	40	0
Overall opinion on TRC	86	10	4	4	76	24	0	0

Source: Senthilkumar et al., 2008

[a] Hard: practicing the modified method is more difficult than conventional method

[b] Normal: no difference experienced between the methods

[c] Easy: practicing modified method is easier than the conventional method

[d] Not adopted: that particular modified rice cultivation was not practiced by the farmer

[e] Rotary weeder in case of Thamirabarani basin and Cono weeder in Cauvery basin

Based on these promising results, a package of practices was developed and evaluated as an Adaptive Research Trial (ART). This was implemented in 100 farmers' fields during 2003-04 in the Hanuman Madhi sub-basin with financial support of Rs 25 lakhs from the Government of Tamil Nadu. The grain yields recorded for fields where SRI techniques were used ranged from 4,214 to 10,655 kilograms per hectare (STDEV: 1379). Those fields where conventional cultivation method was practiced recorded 3,887 to 8,730 kilograms per hectare (STDEV: 1108). The mean grain yield was 7,227 kilograms per hectare for cultivation with SRI methods and 5,657 kilograms per hectare under conventional cultivation. This indicated an average yield advantage of 1,570 kilograms per hectare for the SRI methods. Nearly 31 farmers recorded yields of more than eight tonnes per hectare and the maximum yield advantage recorded for SRI was 4,036 kilograms per hectare (70 percent).

2.2. Arriving at the components of SRI

2.2.1. Through Integrated Crop Management (ICM) experiments

There is a need for a thorough understanding of farmers' production environment, problems and potentials. Farmers generally gather individual technologies from different researchers or extension staff. Thereafter, they integrate them experientially, based on their own field evaluations, to maximise yield and profit. In this context, then, Integrated Crop Management (ICM) can be defined as the integrated use of compatible technologies that meet the farmers' needs and improve their productivity and incomes (Balasubramanian et al., 2005). There is an illusion that SRI is a completely novel entity with a lot of complications and a set of complex management practices. Quite to the contrary, SRI is also an ICM technology, which synthesises the use of congruent management practices, which act synergistically and lead to better crop performance. This synthesis of science with practicality and performance has been evaluated and practiced under earlier integrated crop management schemes, such as Integrated Crop and Resource Management (ICRM) and Transformed Rice Cultivation (TRC).

During the 2002-2003 wet season, ICM and Conventional Rice Cultivation (CRC) were evaluated at the Soil and Water Management Research Institute (SWMRI) farms in Thanjavur, Tamil Nadu, and at the Tamil Nadu Rice Research Institute (TNRRI) at Aduthurai (Balasubramanian et al., 2005). The experiment consisted of 13 treatments placed in a randomised block design, with three replications. The 13 treatments were selected combinations of the following:

Crop management factors for ICENTIMETRE	Recommended cultivation practices of CRC
15-20-days old seedlings (4-leaf stage)	25-days old seedlings
Single seedling per hill	Multiple (3-4) seedlings per hill
22.5x22.5 centimetre	15x10 centimetre
Mechanical weeding and soil stirring	Hand weeding
Intermittent irrigation	Continuous flooding

A modified mat nursery (MMN) was raised using a mixture of soil and manure further enriched with powdered diammonium phosphate at 0.5 grams per kilogram of the soil-manure mixture. The seed rate was 8-10 kilograms per 100 square meters of the MMN to transplant in one hectare. A urea solution with a concentration of 0.5 percent was sprayed on the 9th day after sowing in order to enhance seedling growth. Young robust seedlings about 15-16-days-old were transplanted into the ICM plots, while 25-day-old seedlings were planted in the CRC plots, as per traditional cultivation practices. The quantity of irrigation administered in both sets of plots was recorded. All other management practices, including nutrient management, were followed uniformly at the optimal level for all seedlings.

Effect of ICM factors (Table 5)

Combined effect of all five ICM factors

At the TNRRI, the combined effect of all five ICM factors produced the highest grain yield of 7.1 tonnes per hectare, which reflects an increase of 48 percent over that of the full combination of CRC practices. At SWMRI, the grain yield was 6.6 tonnes per hectare, an increase of 35 percent over CRC practices. The increased yield in the ICM treatment was due to more panicles per unit area (35-49 percent over CRC plots) and more filled grains per panicle (23- 44 percent over CRC plots).

Individual effect of ICM factors

The removal of one ICM component at a time resulted in various degrees of yield reduction. The following table reflects research findings:

Component	Yield reduction (%)
Mechanical weeding and soil stirring	18-20
Use of young seedlings	15-17
Planting single seedlings per hill	14
Intermittent irrigation	10

These observations indicate that mechanical weeding and soil stirring together are the most important of the five components, followed by the use of young seedlings, planting of single seedlings per hill and intermittent irrigation, in decreasing order of importance. With the adoption of intermittent irrigation in ICM plots, the amount of water used decreased by 33 percent and grain yield increased by 11-12 percent. Most significantly, it is clear that the removal of two or three ICM factors at a time reduced rice yield drastically (by 1.9 to 2.0 to tonnes per hectare) compared with the yield of full ICM.

Effect of adding ICM factors to CRC

When intermittent irrigation was adopted for CRC, the amount of water used was reduced by 37 percent. There was a positive effect on yield in the clayey soil at TNRRI, with an increase of 0.3 tonnes per hectare. On the other hand, the effect on yield in the sandy-loam soil at SWMRI was negative, with a decrease of 0.4 tonnes per hectare. Different combinations of ICM components could result in significant yield increase on both sites. The above data has clearly demonstrated that by changing all five factors of CRC, it will be possible to raise grain yield of the transplanted rice crop to its optimal level.

Cost-benefit analysis

The cost of raising seedlings in MMN was reduced by 50 percent, while the cost of crop management in the main field was reduced by less than ten percent in ICM. The simultaneous reduction in the cost of cultivation and the increase in grain yield added to farmers' profit. During the on-station trials, the calculated B-to-C ratio was 3:2 for ICM (compared with 1:5 for CRC) at TNRRI and 2:7 for ICM (compared with 1:7 for CRC) at SWMRI.

Table 5. Comparative view on the effect of ICM and CRC on grain yield, yield parameters and the B-to-C ratio; TNRRI and SWMRI farms, Tamil Nadu; 2002-03 wet season

Particulars	TNRRI					SWMRI				
	No. of irrigations	Panicles m^{-2}	Grains $panicle^{-1}$	Grain yield (tonnes per hectare)	B:C ratio	No. of irrigations	Panicles m^{-2}	Grains $panicle^{-1}$	Grain yield (tonnes per hectare)	B:C ratio
YOSCI Full ICM	12	457	130	7.1	3.2	16	424	184	6.6	2.7
NOSCI ICM–YS	12	377	110	5.9	2.6	16	344	162	5.6	1.9
YMSCI ICM–SS	12	390	115	6.1	2.8	16	362	167	5.7	2.3
YOSHI ICM-SStir	12	365	105	5.7	1.8	16	336	147	5.4	2.2
YOSCF ICM-IntIrri	18	412	118	6.4	2.9	21	396	178	5.9	2.4
YORHI ICM-SqP and SStir	12	332	97	5.2	1.6	16	290	139	4.6	1.9
YMRHI ICM-SS, SqP and SStir	12	337	97	5.2	1.7	16	299	144	4.7	1.9
NMSCI CRC w/SqP + SS-tir + IntIrri	12	369	106	5.8	2.6	16	332	160	5.4	1.9
NOSHI CRC w/SS + SqP + IntIrri	12	359	105	5.7	1.8	16	336	156	5.2	1.8

Parti-culars	TNRRI					SWMRI				
	No. of irrigations	Panicles m^{-2}	Grains $panicle^{-1}$	Grain yield (tonnes per hectare)	B:C ratio	No. of irrigations	Panicles m^{-2}	Grains $panicle^{-1}$	Grain yield (tonnes per hectare)	B:C ratio
NMSHI CRC w/SqP + IntIrri	12	357	103	5.6	1.8	16	328	152	5.0	1.8
NORHI CRC w/SS + IntIrri	12	352	102	5.5	1.7	16	304	148	4.9	1.7
NMRHI CRC w/IntIrri	12	331	96	5.1	1.6	16	280	138	4.5	1.6
NMRHF Full CRC	19	304	90	4.8	1.5	21	312	149	4.9	1.7
LSD (5%)	--	25	6	0.2	n.a	-	21	7	0.1	n.a

Source: Balasubramanian et al., 2005

Y – young seedlings (YS) (15-days old); N – normal age seedlings (25-days old); O – 1 seedling / hill (SS); M – Multiple seedlings (3-4/hill); S – square planting (SqP) (22.5x22.5 centimetre); R – row planting (15x10 centimetre); C – conoweeding + soil stirring (SStir); H – hand weeding; I – intermittent irrigation (IntIrri); F – flooding; “-“n.a. – not statistically analyzed.

These results clearly demonstrate that the combination of all five crop management components - viz., mechanical weeding and soil stirring, single seedling per hill, square planting at 22.5x22.5 centimetre spacing, 15-20 days old seedlings (4-leaf stage) and intermittent irrigation – increased profits in rice farming, decreased the cost of cultivation and increased grain yield.

2.2.2. Through System of Rice Intensification (SRI) experiments

As discussed earlier, parallel experiments on SRI techniques were conducted at the same time as the ICM experiments enumerated above, in order to evaluate the magnitude and significance of various components of SRI on grain yield and the cost of production. Field experiments were conducted at TNAU, Coimbatore, during the wet and dry seasons of 2002 and 2003, respectively, to study the effects of SRI-recommended practices on yield, yield attributes and the water productivity of rice (Vijayakumar et al., 2004). These experiments were conducted in a randomised block design with three replications. The treatments included:

a. use of 21-day old (conventional) and 14-day old (dapog nursery) seedlings;

b. crop geometry at 15x10 centimetre, 20x20 centimetre or 25x25 centimetre;

c. irrigation at a depth of 5.0 centimetre (conventional) and 2.0 centimetre (dapog) when hair line cracks developed;

d. weed control (conventional and SRI weeding); and

e. nitrogen management (recommended and LCC-based N application) during the wet seasons of 2002.

Table 6. Effect of SRI practices on yield, yield attributes and the water productivity of rice in wet season of 2002

Treatments	No. of filled grains panicle $^{-1}$	No. of productive tillers m^{-2}	Grain yield (kilograms per hectare)	Water productivity (kilograms per cubic meter)
T_1 - 21-d seedling + 15x10 centimetre + CI + RN + CW	81.2	437	5,651	0.3214
T_2 - 21-d seedling + 15x10 centimetre + CI + LCC + CW	84.1	439	5,696	0.3239
T_3 - 21-d seedling + 15x10 centimetre + WSI + RN + CW	83.8	429	5,600	0.4298
T_4 - 21-d seedling + 15x10 centimetre + WSI + LCC + CW	81.8	427	5,490	0.4214
T_5 - 14-d seedling + 20x20 centimetre + CI + RN + CW	87.6	403	6,289	0.3919

Treatments	No. of filled grains panicle $^{-1}$	No. of productive tillers m^{-2}	Grain yield (kilograms per hectare)	Water productivity (kilograms per cubic meter)
T_6 - 14-d seedling + 20x20 centimetre + WSI + RN + CW	85.6	403	5,997	0.5217
T_7 - 14-d seedling + 20x20 centimetre + WSI + LLC + CW	86.5	410	6,062	0.5274
T_8 - 14-d seedling + 20x20 centimetre + WSI + RN + SRIW	89.4	416	6,577	0.5722
T_9 - 14-d seedling + 20x20 centimetre + WSI + LCC + SRIW	89.3	420	6,603	0.5744
T_{10} - 14-d seedling + 25x25 centimetre + CI + RN + CW	95.4	398	6,325	0.3941
T_{11} - 14-d seedling + 25x25 centimetre + WSI + RN + CW	92.6	401	6,308	0.5488
T_{12} - 14-d seedling + 25x25 centimetre + WSI + LCC + CW	93.5	392	6,283	0.5466
T_{13} - 14-d seedling + 25x25 centimetre + WSI + RN + SRIW	99.4	411	7,009	0.6097
T_{14} - 14-d seedling + 25x25 centimetre + WSI + LCC + SRIW	92.5	414	6,919	0.6019
SEd	3.4	42	214	0.0176
CD (p=0.05)	7.0	NS	439	0.0359

Source: Vijayakumar et al., 2004

During the dry season of 2003, all the treatments were repeated except for nitrogen management, since there was no response to LCC-based nitrogen in the wet season. The treatments were modified accordingly.

Table 7. Effect of SRI practices on yield, yield attributes and the water productivity of rice in dry season of 2003

Treatments	No. of filled grains panicle $^{-1}$	Sterility percentage	No. of productive tillers m^{-2}	Grain yield (kilograms per hectare)	Water productivity (kilograms per cubic meter)
T_1 - 21-d seedling + 15x10 centimetre + CI + CW	76.2	19.4	437	4,414	0.2725
T_2 - 21-d seedling + 15x10 centimetre + WSI + CW	79.6	24.5	427	4,019	0.3483
T_3 - 14-d seedling + 15x10 centimetre + CI + CW	74.9	29.5	425	4,649	0.3058
T_4 - 14-d seedling + 15x10 centimetre + WSI + CW	80.8	29.4	437	5,140	0.4888
T_5 - 21-d seedling + 20x20 centimetre + CI + CW	75.4	25.2	378	4,637	0.2634
T_6 - 21-d seedling + 20x20 centimetre + CI + CW	76.5	42.2	384	4,817	0.2736
T_7 - 21-d seedling + 20x20 centimetre + WSI + SRIW	81.7	32.5	404	4,855	0.3827
T_8 - 14-d seedling + 20x20 centimetre + CI + CW	83.0	30.4	404	4,459	0.2685
T_9 - 14-d seedling + 20x20 centimetre + CI + SRIW	81.7	26.1	389	5,235	0.3152
T_{10} - 14-d seedling + 20x20 centimetre + WSI + SRIW	80.8	36.7	402	4,911	0.4287
T_{11} - 21-d seedling + 25x25 centimetre + CI + CW	85.5	45.1	370	5,143	0.2921

Treatments	No. of filled grains panicle $^{-1}$	Sterility percentage	No. of productive tillers m^{-2}	Grain yield (kilograms per hectare)	Water productivity (kilograms per cubic meter)
T_{12} - 21-d seedling + 25x25 centimetre + CI + SRIW	90.8	43.5	403	5,369	0.3050
T_{13} - 21-d seedling + 25x25 centimetre + WSI + SRIW	85.8	33.1	382	5,592	0.4408
T_{14} - 14-d seedling + 25x25 centimetre + CI + CW	83.2	39.7	383	5,078	0.3057
T_{15} - 14-d seedling + 25x25 centimetre + CI + SRIW	86.3	26.0	382	5,242	0.3156
T_{16} - 14-d seedling + 25x25 centimetre + WSI + SRIW	91.2	35.7	404	5,655	0.4937
SEd	2.5	4.8	39	158	0.0259
CD (p=0.05)	5.1	9.7	NS	322	0.0533

Source: Vijayakumar et al., 2004

* Conventional Irrigation (CI) – The crop was irrigated to a depth of 5 centimetre one day after the disappearance of ponded water from planting to maturity. Irrigation was stopped ten days prior to harvest.

* Water Saving Irrigation (WSI) – Two centimetre depth of water was given throughout the crop growth period on the development of hairline cracks.

* Conventional Weeding (CW) – The emulsifiable concentrate of butachlor 1.25 kilograms per hectare was applied as a pre-emergence herbicide mixed with sand (50 kilograms per hectare) at 3 DAT with about 2 centimetre of standing water and hand weeding was done twice (20 and 45 DAT)

* SRI Weeding (SRIW) – A total of five mechanical weeding were given at 7-days interval from 12 DAT

* Recommended N (RN) – Recommended dose of N (120) in the form of Urea (46 % N) was applied in four splits: 1/6th at 7 DAT, 1/3rd at 21 DAT, 1/3rd at panicle initiation (PI), 1/6th at first flowering.

* Leaf Colour Chart N management (LCC) – The LCC values were recorded as per the standard procedure (IRRI, 1996) at weekly intervals starting from 14 DAT to flowering. Whenever the LCC values were found to be below the fixed critical level (No. 4), 35 of N ha-1 was applied.

From the data above, it can be inferred that between all the SRI components – viz., 14-day old seedlings, 25x25 centimetre spacing, water saving irrigation and LCC-based nitrogen management (in the wet season only) – SRI weeding was found to record significantly higher yield and yield attributes than other treatment. The grain yield obtained was 7,009 and 5,655 kilograms per hectare with water productivity of 0.610 and 0.494 kilograms per cubic meter of water during wet and dry seasons, respectively.

Several observations can be made based on the above studies:

a. The practice of transplanting younger (14-day-old) and single seedlings per hill led to enhanced tillering and increased grain yield.

b. Increasing problems were observed in terms of weeds, higher level of asynchrony in flowering and maturity, and a potential reduction in yield due to square planting at spacings wider than 25x25 centimetre.

c. The stirring of soil during mechanical weeding is important, because it increases root and shoot growth; consequently, the final grain yield is greater as well (Thiyagarajan et al., 2003).

d. Alternate wetting and drying (AWD) irrigation is especially beneficial for farmers who pump ground water for irrigation because this practice saves energy and pumping costs. It is also projected that this will help to reduce the rate of over-exploitation of ground water for irrigation in rice-growing areas.

Based on these observations, the components of SRI are delineated as follows:

a. Young and robust seedling (12-14 days)

b. Single seedling per hill

c. Square planting with wider spacing (25x25 centimetre)

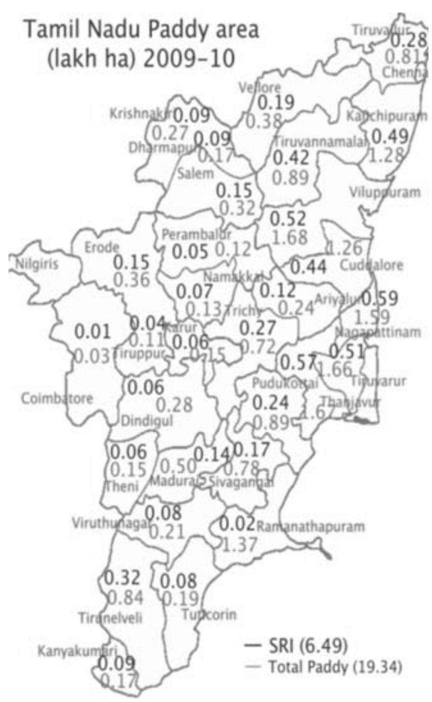
d. Rotary weeding up to 40 days at 7-10 days interval starting from 10 DAT

e. Irrigation at a depth of 2.5 centimetre after the disappearance of ponded water

f. Integrated Nutrient Management and nitrogen management through Leaf Colour Chart (LCC)

Figure 1. Key components of SRI

2.3. Reach of the SRI technology



The Department of Agriculture of the Government of Tamil Nadu has included SRI in all existing and new schemes that focus on increasing food production. These include the Integrated Crop Development Programme (ICDP), the Agricultural Technology Mission Agency (ATMA), the National Agricultural Development Programme (NADP), the National Food Security Mission (NFSM), and the Tamil Nadu Irrigated Agriculture Modernisation and Water Bodies Restoration and Management Project (TN-IAMWARM).

It is estimated that the area under SRI cultivation has been increasing every year. From a coverage of 4.2 lakh hectares in the year 2007-08, it increased to 5.38 lakh hectares in 2008-09 and to 6.49 lakh hectares in 2009-10, against the total area of rice cultivation of 18.20 lakh hectares.

3. SRI MANAGEMENT PRACTICES

In spite of positive initial results, the progression of SRI across the country has been rather constricted. SRI is a new concept in most areas. It depends on the synergy of six important critical management techniques. The success of SRI mainly relies upon the farmers' adherence to all six main principles. While some farmers adopted SRI principles completely, others adopted them only partially, leading to incongruous results from farming community. A lack of awareness among the farmers about the scientific facts behind the components of SRI is, most likely, the cause for this incongruity.

The results of the experiments conducted at TNAU demonstrated that all the components of SRI are equally important. A certain degree of discrepancy is admissible based on existing field conditions, except when it comes to mechanical weeding, which is crucial. Although SRI initially looks like a more labour-intensive process, interactions with practicing farmers as well as scientific evaluations have proved that there is in fact a reduction of labour and labour costs; there is an eight percent reduction of required labour. A strong need has therefore been felt to disseminate not only the technology but also the scientific facts behind all six components, in order to properly promote SRI techniques in the country. The subsequent chapters are collections and discussions of research evidence from across the nation, and should be views as a means of disclosing the science behind this revolutionary technology.

3.1. Season

In India, rice is grown under widely varying climatic conditions; the rice-growing seasons vary in different parts of the country depending upon the variety, temperature, rainfall, soil type, water availability and other climatic conditions. There are three seasons for growing rice in India:

Season	Sowing period	Harvesting period
Kharif	May – June	Sept. – Oct.
Rabi	June – July	Nov. – Dec.
Summer or Spring	Nov. – Dec.	March - April

In the eastern region and in peninsular India, the mean temperature is found to be favourable for rice cultivation throughout the year. As a consequence, there may be as many as three harvests of the rice crop in a year. In the northern and western parts of the country, however, where the winter temperature is fairly low, rice is only grown during the kharif season (May-June) only.

In 2001-2002, two field experiments were conducted at the wetlands of the Agricultural College and Research Institute, Coimbatore, with two hybrids, CORH-2 and ADTRH-1, during the wet and dry seasons, respectively (Thiyagarajan et al., 2002). The soil of the experimental site was a clayey loam, classified taxonomically as *Vertic Ustochrept.* The treatments included modified planting through the use of dapog seedlings in the wet summer season and through direct seeding in the dry winter season; limited irrigation (modified SRI irrigation); weed management aided by in-situ weed-matter incorporation using the cono weeder; the use of green manure along with chemical fertilisers. These can be compared to the conventional methods of transplanting older seedlings, continuous flooding for irrigation, hand weeding and inorganic fertilisation.

The results of the wet season experiment (Table 8) showed that by adopting the modified SRI irrigation practices, 56 percent of the water that would have been used for conventional irrigation was saved. With the use of modified SRI planting, 49.8 percent of water was saved. In both cases, this did not have any significant effect on grain yield. A maximum yield of 7,612 kilograms per hectare was obtained from the modified SRI practices on the CORH-2 hybrid. The mean grain yield for the water-saving treatment (6,352 kilograms per hectare) was at par with the conventional practice (6,461 kilograms per hectare). With the application of green manure and conventional weeding, water-saving irrigation *reduced* the yield when compared to conventional irrigation. This might have been due to the unavailability of irrigation water for the proper decomposition of green manure. In-situ incorporation of weeds in the modified SRI practice significantly increased the yield (6737 kilograms per hectare) when compared to conventional weeding (6076 kilograms per hectare).

During the dry season (2002), on the other hand, modified planting led to the highest grain yield of 6,610 kilograms per hectare as against 6,052 kilograms per hectare observed under conventional planting (Table 9). At the same time, conventional irrigation methods led to significantly higher grain yield of 6,492 kilograms per hectare as against 6,171 kilograms per hectare observed under modified SRI irrigation. Cono weeding has an appreciable impact on the grain yield; due to the use of this mechanical weeder, a higher grain yield of 6,436 kilograms per hectare was observed as against 6,226 kilograms per hectare under conventional weeding. The uses of green manure and other inputs were not significant in influencing the yield of rice.

Table 8. Grain yield (kilograms per hectare) of rice hybrid CORH 2 under conventional and modified SRI methods of cultivation during wet season

Particulars		Conventional planting (P_1)		Modified SRI planting (P_2)		Mean	Mean
		I_1	I_2	I_1	I_2		
Conventional weeding (W_1)	N_1	6151	6199	6841	6268	6365	6076
	N_2	6000	6195	5893	5059	5787	
Modified SRI weeding (W_2)	N_1	6008	6908	6838	6707	6615	6737
	N_2	6343	6343	6349	7612	7126	
Mean		6126	6413	6796	6290	--	
Mean		6269		6543			

Source: Thiyagarajan et al., 2002

I_1 – Conventional irrigation ; I_2 – Modified SRI irrigation

N_1 – Recommended N (175 kilograms per hectare) ; N_2 – Green manure (6.25 tonnes per hectare) + Recommended N

Table 9. Grain yield (kilograms per hectare) of rice hybrid ADTRH 1 under conventional and modified SRI methods of cultivation during dry season

Particulars		Conventional planting (P_1)		Modified SRI planting (P_2)		Mean	Mean
		I_1	I_2	I_1	I_2		
Conventional weeding (W_1)	N_1	6009	5694	6682	6366	6187	6226
	N_2	6261	5809	6600	6391	6265	
Modified SRI weeding (W_2)	N_1	6240	6014	6890	6400	6386	6436
	N_2	6311	6080	6941	6612	6486	
Mean		6205	5899	6778	6442	--	
Mean		6052		6610			

Source: Thiyagarajan et al., 2002

Mean : I_1 – 6492; I2 – 6171; N_1 – 6287; N_2 – 6376 kilograms per hectare
I_1 – Conventional irrigation; I_2 – Modified SRI irrigation
N_1 – Recommended N (175 kilograms per hectare);
N_2 – Green manure (6.25 tonnes per hectare) + Recommended N

SRI is not contradictory to the customary cultivation practices in terms of the growing season: the regular rice-growing seasons of India, autumn, winter and summer, are well suited for SRI. However, there is a need to take care and ensure that an optimal quantity of water is applied for green manure decomposition as well as for the growth of the crop, especially during dry seasons. Green manure has to be grown and incorporated in-situ well ahead of the planting season to ensure that decomposition and mineralisation occurs, enriching the soil before the crop is planted.

3.2. Varieties

Generally, the long-duration varieties of rice perform better with wider spacing, which is the recommended practice under SRI, than the short-duration varieties of rice. Stoop (2005) explained that this is because of the extended crop growth period of long-duration rice varieties. Latif et al. (2005) also reported that long-duration varieties are more suitable for SRI practices, as they led to a higher grain yield. In Tamil Nadu, the long duration variety ADT 47 recorded a higher total number of tillers, productive tillers and number of panicles per square meter; it recorder a higher yield than the hybrid ADTRH 1 under SRI (Sivakumar, 2002). However, only limited studies have been carried out on the comparative performance of different duration varieties under SRI and conventional systems.

During the wet seasons of 2003-2005, an experiment was conducted at Maruteru, on the vertisol soil of the Godavari delta, to evaluate the performance of SRI with six different duration varieties of rice. During this experiment, it was found that the maximum grain yield (7.2 tonnes per hectare), root mass and root volume were recorded with the Swarna variety of rice. All varieties exhibited superior yields with SRI management practices (Raju and Sreenivas, 2008) and, irrespective of varieties, significantly higher values of root weight, root volume and grain yields were noticed in SRI as compared to conventional method (Table 10).

Table 10. Root growth under SRI method during wet seasons (mean of two years)

Treatments	Root volume (ml plant-1)		Root weight (g hill-1)		Grain yield (tonnes per hectare)	
	Conventional	SRI	Conventional	SRI	Conventional	SRI
MTU 1071	12.4	26.2	5.36	11.7	4.34	5.94
Samba Mahsuri	13.5	31.5	6.14	13.5	4.11	5.79
MTU 1032	11.6	23.7	4.73	9.9	3.88	4.80
MTU 2716	10.1	22.8	4.18	9.6	3.58	3.96
Swarna	35.6	85.1	8.90	17.9	5.64	7.24
Indra	12.5	31.9	6.24	15.3	5.26	6.47
CD (p=0.05)	7.8		3.7		0.32	

Source: Raju and Sreenivas, 2008

An experiment was conducted at Department of Rice, TNAU, Coimbatore, during the Rabi season of 2008-09, with the objective of evaluating aromatic hybrids and medium-duration varieties under SRI techniques (Dhana Jeyanthi, 2009). This experiment was laid out in a randomised block design with six aromatic rice varieties (Indrabhog, Bhadshabhog, Mugad Sugandi, Kalanamak, Jeeragasamba and GEB), five hybrids (PSD, PA 6444, Goracnath, KRH 2, CORH 3 and Ajay) and six medium-duration varieties (CO (R) 48, CR 1009, BPT 5204, Paiyur-1, White Ponni and CO (R) 49). The following results were observed:

- Productive tillers per square meter, panicle weight and fertility percentage were higher in the hybrids while a higher panicle length was recorded in aromatic rice varieties. The number of spikelets per panicle was higher in medium-duration varieties. The medium-duration variety, CO (R) 48, recorded the highest grain yield (7.27 tonnes per hectare) followed by the hybrids CORH-3 (6.61 tonnes per hectare), KRH-2 (6.44 tonnes per hectare) and the medium-duration variety White Ponni (6.60 tonnes per hectare). Mugad Sugandhi recorded the highest grain yield among the aromatic rice varieties (5.24 tonnes per hectare).

- It is inferred that Mugad Sugandi, GEB 24 and Jeeragasamba in aromatic rice varieties, KRH-2, CORH-3 and Ajay in rice hybrids, and CO (R) 48, White Ponni and Paiyur-1 in the medium-duration varieties are preferable varieties for rice cultivation under SRI methods, in terms of crop productivity. Notably, the quality parameters that were recorded were found to be higher in aromatic rice varieties.

Another field experiment was conducted at the Deras Research Farm in Bhubaneswar, Orissa, to evaluate comparatively the performance of different rice varieties under SRI and the conventional transplanting system (CTS) (Thakur et al., 2009). Five rice varieties were used for the study: Khandagiri (early duration, 90 days), Lalat (early medium duration, 110 days), Surendra (late medium duration, 130 days), CRHR-7 (late medium duration hybrid, 135 days), and Savitri (long duration, 145 days). It was found that for all five varieties of rice, the percentages of effective tillers were significantly enhanced (by about 15 percent) in areas where SRI practices were used (Table 11). The highest percentages of effective tillers were found in the long-duration variety of rice, Savitri (391 m-2), followed by the hybrid CRHR-7 (341 m-2). The percentage increase was least in the short-duration variety of rice, Khandagiri (285 m-2).

Table 11. Comparison of grain yield, grains per panicle, grain filling percentage and number of panicle of different varieties and hybrids under SRI and conventional transplanting system (CTS)

Varieties and duration (days)	Grain yield (tonnes per hectare)			Total grains panicle^{-1}			Grain filling percent			Panicle number (m^{-2})		
	SRI	CTS	Mean	SRI	CTS	Mean	SRI	CTS	Mean	SRI	CTS	Mean
Khandagiri (90)	4.25	3.18	3.72	130	94	112	82	73	77	285	249	267
Lalat (110)	5.68	4.16	4.92	156	114	135	85	76	80	337	313	325
Surendra (130)	6.25	4.39	5.32	164	132	148	86	77	82	339	315	327
CRHR-7 (135)	6.06	5.37	5.72	163	114	138	84	81	83	341	350	345
Savitri (145)	6.26	5.12	5.69	171	136	154	86	83	85	391	369	380
Mean	5.70	4.45		157	118		84	78		338	319	
	Practice	Variety	PxV	Practice	Variety	PxV	Practice	Variety	PxV	Practice	Variety	PxV
LSD (5%)	0.17	0.16	0.23	4.2	7.2	10.2	1.6	2.3	3.3	3.6	19.5	27.6

Source: Thakur et al., 2009

The experiment led to numerous observations and inferences:

- The accelerated growth rate of rice varieties where SRI strategies were employed was primarily caused by the planting of younger seedlings in optimal growing conditions. This is because these plants are able to complete more phyllochrons before entering their reproductive phase. Longer-duration varieties have a longer vegetative period and thus get more time to produce tillers than the short or medium-duration varieties. This leads to both a higher number of tillers per hill as well as an enhanced production of effective tillers in long-duration varieties of rice.
- It was observed that all the varieties yielded more grains under the SRI methods, with an improvement in the harvest index and a significant enhancement in yield components. The increase in yield under SRI practices, as compared to the conventional methods, was observed more in medium-duration varieties rather than short-duration variety. However, this difference was less for long-duration varieties and least for the hybrids.
- Under SRI management practices, new tillers (shoots that grow from the parent stem) emerged from the culm (main stem) of the crop at a greater angle from the main stem, as compared to the tillers which grew under conventional methods. For all the varieties of rice, the spread of tillers was greater under the SRI methods of cultivation. Tillers in the crops that were conventionally grown also had a lesser angle of inclination from the culm and their spread was correspondingly lower. Significantly, a higher leaf area index was recorded at the flowering stage in all the varieties grown under SRI. Light interception was also significantly higher in SRI plots than in conventional plots for all the varieties due to the angle of inclination of the tillers.
- The shallower planting of young seedlings in SRI practice might be responsible for the emergence of more tillers in at a greater angle from the main stem. Newly-emerged tillers from three deeply inserted seedlings cultivated in the conventional method competed for space, leading to a more compact structure of the hills, with closely bound tillers. On the other hand, the open plant structure of the SRI strategy gave every tiller a greater ability to intercept light. What is particularly unique about the SRI method is that the lowermost leaves could also get sufficient light.

The results of experiments with different duration varieties and hybrids showed that responses to SRI cultivation differed with different genotypes of rice. It is evident that greater increments in yield can be realised under the SRI methods far more than in the conventional systems of production. Thus, it can be stated that under a suitable system of cultivation, the varieties and hybrids exhibit their maximum genotypic potential with superior phenotypic traits. Thus, replacing low-potential, pest- and diseasesusceptible traditional varieties of rice with new high-yielding varieties with promising yield potential must be encouraged actively. One important aspect of disseminating SRI practices will thus be persuading farmers to cultivate hybrids through demonstrations and making seeds easily available to them at lower rates.

3.3. Pre-requisites of SRI

3.3.1. Quality seeds

The most important requisite for the complete realisation of the yield potential of any variety of rice is the quality of the seed sown. Good quality seeds can increase the yield by as much as 20 percent.

Since SRI insists on planting only one seedling per hill, obtaining healthy and robust seedlings from high quality seeds is crucial. Clearly, every seed counts. Better quality seeds can ensure vigorous seedling growth, reliable establishment in the field, a uniform plant population, an accelerated growth rate, resistance against pest and diseases and uniform maturity at harvest. Interestingly, it has been reported that while seed germination may not vary significantly in different methods of cultivation, or with the use of different kinds of manures and fertilisers, seeds produced under the SRI method have shown a significantly higher vigour index value (2314) as compared to what was observed under traditional methods (2050) (Krishna et al., 2008).

3.3.2. Seed rate

Under the SRI methods of cultivation, a single seedling is planted per hill and the hills are more widely spaced. Therefore, the number of seedlings required for the planting unit area is reduced to a great extent. Only 5-7.5 kilograms of seeds are required to plant one hectare, as compared to the 60-80 kilograms that are required in conventional cultivation. This is the first obvious benefit of SRI management practices for the farmer. Based on the number of seedlings required per unit area, and considering 100 percent seed germination, the seed requirements in SRI would be about a tenth of those in the conventionally transplanted rice (CTR). Thus, even in the absence of a yield advantage, SRI is superior to CTR in terms of seed rate and correspondingly, time and labour requirements during transplanting (Sharma and Masand, 2008).

3.3.3. Nursery

The nursery area is reduced from 800 square meters to 100 square meters, with the use of SRI management techniques. Additionally, active maintenance of the nursery is only required for about 14 days. Therefore, the costs of using and maintaining the nursery are reduced considerably.

3.3.3.1. Dapog, mat and pai nurseries

Although raising young seedlings in dapog, mat and pai nurseries is not unheard of amongst researchers, it is not familiar to the farmers. The dapog nursery offers a conducive environment for growing robust seedlings within a fortnight. In an experiment conducted to study the effect of crop establishment techniques and nitrogen levels on the growth and productivity of the rice variety ADT-43 in the wetlands of TNAU, Coimbatore, it was found that the mat nursery techniques recorded significantly higher growth parameters at all growth stages, over the conventional wet nursery.

It was observed that the crops that grew from the seedlings derived from the modified mat nursery displayed enhanced in root length, volume and dry weight. All the physiological parameters – including LAI, crop growth rate, and net assimilation rate – were higher for the 14-day-old seedlings derived from the modified mat nurseries and planted as single seedlings (Prema, 2007). But the use of 14-day-old seedlings led to a significant increase in grain yield irrespective of nursery methods; it did not seem to matter whether the crop was planted in SRI nurseries or in conventional nurseries. The increase in grain yield with the use of 14-day-old seedlings was 7.2 per cent in the SRI nurseries, as opposed to the 21-day-old seedlings in conventional nurseries (Bommayasamy et al., 2010).

It should be noted that the above studies were concerned with transplanting the seedlings at the appropriate stage, and not with testing the benefits of different kinds of nurseries. In conventional nurseries, care must be taken not to damage the roots while pulling out the young juvenile seedlings. It is recommended that soil levels in nurseries be raised for SRI techniques, depending on the availability and suitability of resources, irrigation facilities and soil type. The soil can be raised in nurseries in the following ways:

- Raising on polythene spread sheet
- Raising on ‘garden’ (hand watered) raised beds
- Raising on banana leaf sheaths
- Raising on wooden frames / plastic trays

Groups of farmers can build community nurseries at common places as a means of becoming acquainted with the above mentioned practices of raising the nursery soil as well as with SRI management techniques. This could also considerably reduce considerable labour and maintenance costs in raising the nursery.

3.3.3.2. Method of Nursery Preparation

It is preferable to choose a space in the field that facilitates the distribution of seedlings to the whole field with minimum delay, because the young, tender seedlings may become flaccid even during the process of transplantation. Care must be taken to transplant them all in the shortest possible time.

The following practices are recommended:

- In order to plant the rice crop in an area of one hectare, the nursery needs to occupy about 100 square meters.
- 20 raised beds with dimensions of 1x5 meters must be raised to a height of five centimetres with native soil and with furrows around the beds.
- A plastic/polythene sheet or any locally available material, such as banana leaf sheath, coconut frond or even paper rolls, should be spread on the beds. This prevents seedling roots from running too deep into the soil, leading to damage to the roots when they are pulled from the soil.
- On the sheet, a four centimetre thick seedbed composed of blended soil and FYM (farm-yard manure) in a ratio of 2:1 must be laid. Care must be taken to apply well-decomposed FYM to the nursery bed; otherwise, this can lead to the scorching of the seedlings.
- If the native soil is not so fertile, it needs to be mixed with 95 grams of DAP (diammonium phosphate) per five square meters before being spread on the sheets. Seedlings that do not attain optimal growth in one week's time should be sprayed with a solution of urea, with a concentration of 0.5 percent.
- 7.5 treated and pre-germinated seeds per hectare should be sown, approximately at the rate of 375 grams of seeds per five square meters, not too densely on the seedbed.
- The seeds need to be covered with sand or finely ground FYM and sprayed with water, initially with a rose can. The furrows can be irrigated to soak the beds.
- During bright sunny days, the nursery should be covered with straw or coconut fronds for about two days, so that the seedlings do not get scorched by the sunlight.

3.3.4. Pulling Out the Seedlings

Roots of young seedling are sensitive and therefore require careful handling while they are being pulled out for transplantation. If the roots are injured, seedling and crop mortality in the main field will increase correspondingly. The dapog nursery has added advantages in that it makes it easy to remove seedlings from the nursery bed and to carry them into the main field to assure the quick transplantation of the crops within about 20 minutes. It is desirable to pull the seedlings along with the soil, making sure that the roots remain intact, and plant them immediately. This helps the seedlings to establish themselves in the fields quickly.

3.3.5. Land Preparation and Land Leveling

One of the key determinants of rice yield in the SRI production system is appropriate land preparation. Systematic land preparation is crucial to avoid the risks involved in young seedling establishment and to enable the decomposition of organic material, such as crop residues, green manures and weeds. Unevenness in land level results in uneven crop stands, increased weed population and uneven maturity in crops. This, in turn, will lead to reduction in the grain yield and degrade the quality of the grain. Effective land leveling in SRI could help in ensuring quick crop establishment, synchronised crop maturity, improved water application efficiency and increased water productivity, leading to the more efficient usage of applied nutrients.

The following practices are recommended in this context:

- The main fields and bunds must be cleared of all vegetation and weeds; these can then be mixed with crop residues in the field.
- The field needs to be flooded with water for 2-3 days depending on the type of soil, in order to soften the soil to facilitate tillage and the incorporation of crop residues and weeds.
- The soil should be ploughed to turn, break up and loosen clods and large aggregates to incorporate rice stubbles, green manures, green leaf manures and other plant debris to hasten their decomposition.
- The field should be flooded with a ten centimetre layer of water for 2-3 weeks to kill insect and pests that hide in the weed and crop residues and in the soil. This will also facilitate the thorough decomposition of all plant residues, allowing weed seeds to germinate or rot, and the application of basal organic manures or compost.

- At the end of this period, the field should be ploughed again to turn the soil and mix it with the water, to distribute decomposed organic residues, to remove germinated seeds, to puddle the soil to make perfect leveling easier and to prepare a good bed for transplanting.

3.3.5.1. Laser Land Leveling

The lack of precise land leveling is a major concern in SRI management practices, where fields are often uneven. This can cause trauma to young seedlings when transplanted and causes adverse effects when coupled with the AWD method of irrigation. Traditionally, leveling is done by tractor-drawn levellers or boards or by bullocks using wooden planks. But even after many efforts and heavy investments, deviations of 8-15 centimetres in the field levels have been observed.

In the laser land leveling trials conducted in Bihar, savings in the irrigation costs for different crops were monitored (Jackson, 2009). Laser land leveling saved up to 40 percent of irrigation water. The time taken to irrigate one hectare of land decreased from 28 hours in unlevelled fields to 12-18 hours in laser-levelled fields. This translates into average savings of Rs 900 per hectare.

A crop-wise analysis showed that savings in irrigation costs from laser leveling ranged from Rs 495/- to Rs 1440/- per hectare for the rice crop when compared with the traditional leveling methods. In addition to this, farmers also observed better germination and crop stand after more precise land leveling, leading to higher productivity. Farmers who used the laser land leveller also reported an increase in available area for cultivation by about 2-5 percent. Laser leveling systems are commonly used in Australia, Japan and the United States where operational holdings are larger. Nowadays, laser-guided systems are being used in lesser-developed countries also. However, this type of land leveling encounters some limitations too:

- The high cost of the equipment
- The need for a skilled operator to adjust laser settings and operate the tractor
- Lack of suitability for fields of irregular size and shape.

3.4. Principles of SRI

3.4.1. Young seedlings

The rice ecologies in India can broadly be characterised as dry, semidry and wet. In these systems, crop establishment is predominantly carried out through direct wet seeding or dry seeding and, subsequently, transplanting the seedlings from conventional or dapog nurseries.

Important non-cash inputs for achieving higher productivity are the timely plantation and transplantation of appropriately aged seedlings. The age of the seedling when it is transplanted is an important factor for uniform crop stand, proper establishment of the crop, effective tillering (the development of tillers) and improving the productivity of rice under SRI schemes. The recommended age in conventional practices for transplanting seedlings is calculated by adding one week for every month of the duration of the variety; thus, seedlings should be about 18-22-days-old for short-duration varieties, 25-30-days-old for medium-duration varieties and 35-40-days-old for long-duration varieties of rice. But the age of the seedling at the time of transplantation in practice depends upon the availability of water for the main field, the availability of labour during the season and the timely availability of other inputs and credits; thus, the age of the seedlings when they are transplanted is highly varied.

On the other hand, the transplantation of rice seedlings into puddled fields does occur and is widely practiced as a means of weed control. Transplanting of very young seedlings, 8-10-days-old and never more than 15-days-old, preserves the potential for tillering and rooting, which may be reduced if transplantation occurs after the 4th phyllochron, 15 days after emergence (Uphoff, 2002; Stoop et al., 2002). Transplanting 14-day-old seedlings produces a significantly higher leaf area, higher number of tillers per unit area and better biomass with active tillering (Senthilkumar, 2002). Similarly, planting younger seedlings from the mat nursery with the adoption of mechanical weeding enhances the root volume over seedlings grown on conventionally weeded soil (Nisha, 2002). The use of young seedlings registered higher values of growth attributes, such as plant height, leaf area index, total tillers, dry matter production and crop growth rate, particularly when the crop was managed by hand weeding coupled with the rotary weeder (Ramamoorthy, 2004). Younger seedlings (7-12-days-old) transplanted according to SRI practices produced plants taller than older seedlings (22-28-days-old) transplanted according the conventional cultivation methods by an average of 14.1 centimetres (Sharma and Masand, 2008).

Thiyagarajan (2003) found that younger seedlings and limited irrigation led to significantly higher tiller density of 534 tillers per square meter, while conventionally transplanted seedlings, which were older and irrigated with continuous flooding, led to a tiller density of 503 tillers per square meter. Vijayakumar et al. (2006) reported that yield components and yield were significantly improved when younger seedlings (14-days-old) were transplanted, before the start of the 4^{th} phyllochron.

A similar experiment, conducted to study the effect of crop establishment techniques and nitrogen levels on the growth and productivity of transplanted rice variety ADT-43, in the wetlands of TNAU, Coimbatore, revealed that the crop raised from 14-days-old seedlings drawn from modified mat nurseries and subsequently grown on single seedling per hill registered significantly higher grain and straw yields (Prema, 2007). While investigating the age of seedlings under SRI, Manjunatha et al. (2010) observed that the transplanting of 9-days-old and 12-days-old seedlings gave a significantly higher grain yield (6071 kilograms per hectare and 6018 kilograms per hectare respectively) than transplanting 15-day-old (5792 kilograms per hectare), 18-day-old (5771 kilograms per hectare) and 21-day-old (5721 kilograms per hectare) seedlings. The more vigorous plants with higher tillering capacity produced with seedlings younger than 15-days-old were able to extract more nutrients from the soil. In contradiction to the above results, it has also been reported that SRI and conventional nurseries with 14-day-old seedlings had registered statistically similar yields as that of conventional nurseries with 21-day-old seedlings (Bommayasamy et al., 2010), which is a contention that demands proper review.

3.4.1.1. Facts about the use of young seedlings

Conventional transplanting not only requires more labour and management, but also a longer period for the rice plants to establish themselves in the main field due to the shock the plant suffers from transplantation. SRI insists on the use of younger seedlings. Though reports from Madagascar and experimental evidences from different rice growing regions in India suggest that 8-12-day-old seedlings are better suited for transplantation (Sharma and Masand, 2008; Manjunatha et al. 2010), in Tamil Nadu, 12-14-day-old seedlings are recommended based on the results of preliminary trials and experiments. Apart from these, the practical feasibility of handling young fragile seedlings and the apprehensions of the farmers have also been considered in determining the appropriate age for transplanting the seedlings. For early seedling establishment, seedlings must be healthy; only then can they produce new roots, leaves and tillers quickly. If the nursery bed is prepared with the proper mix of manure and sufficient organic matter, robust seedlings that can be handled with greater ease can be obtained.

One highly distinctive characteristic of SRI that grabs everyone’s attention and demands some explanation is profuse tillering. One of the processes that greatly influences rice yield is tillering. Using low seed density promotes tillering and increases the ratio of Productive Tiller Number (PTN) to Maximum Tiller Number (MTN), a prerequisite for high yields (Ling et al., 2000). At high seeding rates of 120–150 kilograms per hectare, not only did no tillers produce panicles, but also, a considerable proportion of the main stems (17–50 percent) died due to pronounced competition between individual plants. However, with seeding rates of 45–60 kilograms per hectare, the PTN increased to 30–59 percent of MTN (Yan et al., 2010).

To have a clear understanding of the plant processes that govern yield formation, proper knowledge of rice phenology, related particularly to tillering, is essential:

- *Phyllochron* is the period of time between the emergence of one *phytomer* (a set of tiller, leaf and root, essential organs which emerge above the soil and below the soil from the base of the plant) and emergence of next phytomer. Phyllochron length reflects the speed at which the rice plants' "biological clock" is operating (Khanal, 2005).
- In germinating rice, a *prophyll* (rudimentary leaf) emerges from the *coleoptile* (the pointed protective sheath covering the emerging shoot) followed by the emergence of the first leaf above the prophyll. A typical rice leaf consists of a sheath, a blade, a *ligule* (strap) and *auricles* (protrusion at the base of the leaf).
- The emergence of the rice leaf is an important aspect of the establishment of the crop, because the leaf is the source of carbohydrates for the plant and the plant's associated physiological phases are positively correlated with photosynthesis and yield.
- The transformation of *auxillary* buds into tillers and the subsequent formation of productive panicles largely depends on the nodal position of the tillers and on the developmental stage of the plant (Jaffuel and Dauzat, 2005).
- Tillers are branches that emerge from the leaf axils at the nodes of the main stem or tiller stems. Tillers growing from the main stem are called primary tillers. These may generate secondary tillers at their base, which can in turn generate tertiary tillers if the plant is still in a phase of vegetative growth.
- Tillers are produced in a synchronous manner. Although initially they remain attached to the plant, at later stages they become independent because they produce their own roots. Different varieties and races of rice differ in their tillering abilities. It has been recognised that the productive tillers in the rice crops are usually primary tillers and rarely secondary or tertiary tillers (Ling et al., 2000), although this may be due to the degeneration of roots under conditions of continuous flooding.

According to Laulanie, if transplantation occurred after the fourth phyllochron (about 15 days), the first primary tiller (and its secondary or tertiary tillers) will not emerge. Similarly, if transplantation is further delayed by the length of another phyllochron, the second primary tiller and all its descendants are also forgone. Uphoff, on the other hand, suggests that when conventional practices (older seedlings, crowding and flooding of plants, etc.,) are used, the length of phyllochron periods increases and fewer phyllochrons are completed before panicle initiation. Katayama (1951) observed that the appearance of tillers on the main stem of rice is synchronous with the appearance of leaves. He demonstrated that, for rice, three phyllochrons separate the appearance of a culm from the appearance of the first tiller and one phyllochron separates the appearance of two successive tillers on a culm. Thus, the appearance of the fourth leaf on the main stem coincides with the appearance of the first leaf on the first tiller.

It has been frequently demonstrated through experiments that young rice seedlings, before the beginning of their fourth phyllochron of growth (less than 15 days), have the potential for producing a large number of tillers and roots simultaneously. Tiller production in rice happens at regular intervals. Depending on variety, climate, soil and other factors, one phyllochron may be last for 5-8 days (the length of time depends on how favourable or unfavourable the growing conditions are). This means that one or more phytomers will be produced from the planted seedling during a period of 5-8 days.

The length of the phyllochron can be as short as four days under ideal growing conditions – warm (but not excessively so) instead of cold, with sunlight instead of shade, with wider spaces between plants rather than crowded rows, with soil that is loose and friable rather than compact, with an abundant supply of soil nutrients rather than nutrient deficiency, with sufficient oxygen rather than hypoxic (lacking oxygen) soil and with sufficient moisture but not so much that the plant suffocates for lack of oxygen. In this case, the plant can complete many cycles of growth before its vegetative stage comes to an end and turns into the reproductive (grain-forming and grain-filling) stage. With poor conditions, on the other hand – i.e., cold, shade, crowding, compacted soil, nutrient constraints, hypoxia and drought – the periods could as long as ten days, and only a few cycles of growth (four or five phyllochrons) will be completed before growth stops and reproduction begins.

Therefore, under favorable growing conditions, the number of tillers can increase exponentially, with each phyllochron producing a number of phytomers equal to the previous two phyllochrons, in a pattern that matches the Fibonacci series, with an exponential power of about 0.65. After three phyllochrons there will be three leaves in the planted seedling (approximately 15 days after transplanting). After this, from each bud in the stem, an increasing number of tillers will be produced during every phyllochron. On the other hand, if, for any reason, a tiller is not produced from a bud, it will not produce at any time afterwards.

Thus, shallow planting of young seedlings with native soil particles clinging to the root intact not only avoids transplanting shock but also aids in the quick establishment of the crop. It further preserves the potential for profuse tillering and stronger and deeper root growth that is otherwise lost when seedlings become older.

3.4.1.2. Facilitating the tillering process

By the time that 27-day-old seedlings are planted, six phyllochrons would already have been completed. The narrow space and competition for resources between seedlings in the nursery would hamper the growth of tillers. Only six tillers would be produced from the main stem by the time these seedlings are planted. Moreover, when aged seedlings are transplanted, they would suffer from a transplanting shock that would last for up to two weeks. Reducing the period of the transplanting shock also helps in making sure that more tillers are produced. Additionally, this provides an advantage of about to the crop, which encourages early maturity, about seven days before maturity would have been attained otherwise (Shekhar et al., 2009). Apart from this, when the seedlings are transplanted under the SRI methods, 10-20 days before seedlings transplanted in the conventional method, they get a longer period for tillering.

3.4.2. Single seedling

It is observed that the transplanting of a single seedling per hill in a square pattern with wider spacing extends the “edge effect” to the whole field. Generally, the open canopy formation that SRI practices adopt (Thakur et al., 2010) allows the crop greater coverage of the ground area and gives it the ability to intercept more light. While in conventional cultivation methods, it is typically recommended that 2-3 seedlings be planted per hill, in reality, 4-6 seedlings, and sometimes even more, are planted. Having multiple seedlings in a hill is actually counterproductive as it inhibits the growth of the roots.

Field studies undertaken to evaluate SRI in comparison to the traditional system of rice cultivation in Himachal Pradesh affirmed that transplanting one seedling per hill in a square pattern while maintaining 30 centimetres between them as per the SRI techniques significantly lowered the seed requirement, when compared with the conventional practice of transplanting three seedlings per hill while maintaining about 15 centimetres between them (Sharma and Masand, 2008).

Similar field experiments were carried out in 2003-05 at the Agricultural College and Research Institute, Killikulam, Tamil Nadu, located at 8º 46´ N latitude and 77º 42´ E longitude at an altitude of 40 meters above mean sea level. The purpose of these experiments was to perfect the techniques of establishing crops within SRI

(Bommayasamy et al., 2010). The sandy-clay soil possessed medium quantities organic carbon (0.58 % per hectare), nitrogen (270.6 kilogram per hectare), phosphorus (18.7 kilogram per hectare) and potassium (224.0 kilogram per hectare). Different types of nurseries and differently aged seedling were tested in the main plot, while three different plant geometries were tested sub-plots. Additionally, tests were conducted to deduce the optimal number of seedlings per hill in sub-plots, whether single seedlings were to be planted or two at a time, with three replications. The number of seedlings per hill failed to exert any significant influence on the yield. In fact, additional yield was recorded in double seedling plantations over single seedling plantations, at 100 kilogram and 200 kilogram per hectare during 2003-04 and 2004-05, respectively. This could perhaps be attributed to the little influence of this factor on Crop Growth Rate (CGR), nutrient uptake and, consequently, the yield parameters and yield. But the number of seedlings per hill had a significant influence on LTR. It was observed that LTR was significantly lower in double seedlings per hill (45.56) when compared with single seedling per hill (47.05).

The fear for handling and transplanting single, young and fragile seedling still exists among many farmers. This relates to many practical issues including seedling mortality, destruction of the crops by birds and the high wind during the planting season that can drown the seedlings in mud. One example of such issues is crop cultivation in the Aliyar sub-basin, where field-to-field irrigation (by the cascade system) is being practiced using the PAP-canal (Parambikulam Aliyar Project) as the main source of irrigation. Therefore, alternate wetting and drying system of irrigation is not possible here, and the field is flooded for a long time. Under such conditions, it is difficult to maintain a thin film of water (2.5 centimetre depth) in the field and, often, the single seedling drowns and dies. Birds pose a greater problem for the farmers, destroying the crop by trampling the seedlings.

Maintaining the population of the crop is thus a problem to begin with. Additionally, the transplanting of a single seedling requires thorough land levelling, without which the seedlings planted in depressions would die. The field experiments led to the conclusions that while usually, in SRI, only one seedling has to be planted per hill, wherever there exists a problem of mortality of seedlings (due to salinity, excess water seepage, poor levelling and trampling by birds), two seedlings can be transplanted to one hill.

3.4.3. Optimum spacing

For rice production to be prosperous and to improve the growth variables responsible for high yield, timely transplantation and the administration of appropriate vegetative growth throughout, with suitable transplanting densities for optimum tillering, are essential. Best possible plant spacing with the optimum seedling rate per hill could in itself guarantee higher productivity through rational growth and utilization of resources. Many studies have assessed the phenotypical impacts of SRI along with physiological changes that can be induced in the same genotype by simply employing proper crop geometry while planting and transplanting.

In with the context of the above, field experiments were conducted to evaluate SRI in comparison with the traditional system of rice cultivation in a high rainfall zone in Himachal Pradesh (Sharma and Masand, 2008). The experiment compared three factors in eight treatment combinations, replicated thrice in a randomized complete block design. The three factors were the age of rice seedlings when transplanted (7-12-days-old in SRI vs. 22-28-days-old in conventional transplanted rice, henceforth known as CTR), plant-hill spacing (15x15 centimetre vs. 30 x30 centimetre for both SRI and CRF) and the water regime (continuous flooding – CF – vs. intermittent flooding – IF). The findings of the field experiments are detailed below:

- While effective tillers per hill increased from 10 to 25, effective tillers per square meter decreased significantly from 413 to 277 with the increase in plant-hill spacing. On the other hand, 30x30 centimetre spacing produced higher grains per panicle (79) and more 1000-grain weight (21.67 grams) than the 15x15 centimetre spacing (70 grains per panicle and 20.42 grams of 1000-grain weight).
- Grain yield was statistically identical in all treatments under intermittent flooding (3.24 to 4.05 tonnes per hectare), except for CTR-30 (30x30 centimetre) which had the lowest grain yield of 2.84 tonnes per hectare. Numerically, SRI-15 (15x15 centimetre) under CF and SRI-30 (30x30 centimetre) under CF produced 20 and 13 per cent higher grain yield, respectively, as compared to CTR-15 (15x15 centimetre) under CF (Table 12).
- Apart from the above, it was observed that less time was required for transplanting rice seedlings at 30x30 centimetre spacing than at 15x15 centimetre spacing, which was an obvious conclusion, as the number of hills per square meter in the former was a fourth of the latter (11.1 vs. 44.4 respectively). This lowered the labour requirements for transplanting rice seedlings at 30x30 centimetre spacing. SRI at 30x30 centimetre spacing required about a fourth of labour per hectare (222 man-days per hectare) as compared to CTR at15x15 spacing (833 man-days per hectare). On the other hand, transplanting younger seedlings required careful handling and thus consumed 9-11 per cent more time than transplanting older seedlings.

Table 12. Effects of age of seedlings, plant-hill spacing, and water regime on plant height, effective tillers and grains per panicle, 1000 grain weight, and grain yield (pooled mean of 2002-04)

Treatments	Plant height (centimetre)	Effective tillers square meter	Grains per panicle	1000-grain weight (g)	Grain yield t per hectare
With continuous flooding (CF)					
SRI-15	116.6	421	74	20.70	4.05
CTR-15	100.4	385	69	20.39	3.37
SRI-30	116.5	282	84	22.29	3.80
CTR-30	103.9	263	77	21.03	2.84
With intermittent flooding (IF)					
SRI-15	115.2	427	70	20.50	3.98
CTR-15	102.3	419	68	20.07	3.24
SRI-30	117.8	292	81	22.20	3.59
CTR-30	103.0	270	74	21.15	2.83
LSD (5 %)	10.9	38	10	0.82	0.92
LSD (1 %)	15.1	53	14	1.14	1.27

Source: Sharma and Masand, 2008

Another field study was carried out during the rainy seasons of 2005 and 2006 on the sandy clay loam at the Deras Research Farm, Mendhasal, in the Khurda district of Orissa. The purpose of this study was to evaluate the performance of three different duration rice varieties with different spacing under SRI methods of cultivation as compared with conventional methods. The three different varieties of rice were Khandagiri (short duration, 100 days), Surendra (medium duration, 125 days) and Savitri (long duration, 150 days) (Thakur et al., 2009). The results are as follows:

- In terms of grain yield with the given soil and climatic conditions, the optimum spacing under SRI in short and medium duration varieties was 20x20 centimetre and, for the long duration variety, 25x25 centimetre . At the spacing of 20x20 centimetre, short and medium varieties gave 46.8 and 41.9 per cent more yield as compared to conventional methods.

Table 13. Effect of plant spacing and yield attributes under SRI and conventional method of rice cultivation

Varieties and spacing	Tillers square meter	Panicles square meter	Panicle length (cm)	Yield (t per hectare)	% increase in yield over CT
Khandagiri (short duration)					
SRI – 30x30 cm	203c	190c	22.2a	2.97c	-1.65
SRI – 25x25 cm	217c	206c	21.8a	3.42b	13.1
SRI – 20x20 cm	313b	291b	20.7ab	4.44a	46.8
SRI – 15x15 cm	333b	308b	16.7bc	3.01c	-0.39
SRI – 10x10 cm	369a	351a	15.2c	2.88c	-4.80
Conventional method	335b	313b	16.2c	3.02c	--
Surendra (medium duration)					
SRI – 30x30 cm	216d	198d	22.3a	2.94d	-33.48
SRI – 25x25 cm	270c	245c	22.0a	4.26bc	-3.58
SRI – 20x20 cm	365b	352b	21.2a	6.27a	41.89
SRI – 15x15 cm	383a	365b	18.8ab	4.21bc	-4.71
SRI – 10x10 cm	398a	381a	15.7b	4.16c	-5.84
Conventional method	392a	363ab	18.2ab	4.42b	-
Savitri (long duration)					
SRI – 30x30 cm	207d	201d	23.8a	3.86c	-19.79
SRI – 25x25 cm	368c	346c	21.8ab	6.31a	31.16
SRI – 20x20 cm	399b	389b	20.0b	6.06a	26.03
SRI – 15x15 cm	420a	394b	18.5bc	4.40d	-8.53
SRI – 10x10 cm	433a	416a	16.3c	4.23d	-12.10
Conventional method	416ab	382b	18.2bc	4.81c	--

Source: Thakur et al., 2009

- There was a 31.2 per cent increase in grain yield for the long-duration variety of rice cultivated under with SRI techniques with a spacing of 25x25 centimetres as compared to the conventional system with the same spacing.
- In spite of higher number of panicles at narrow spacing (10x10 centimetre), the yield was lower for all three varieties of rice cultivated under SRI (4.8 per cent in short duration, 5.8 per cent in medium duration and 12.1 per cent in long duration varieties) than when cultivated in the conventional system. This was mainly because of thinner tillers, shorter panicles and lesser number of grains per panicle. This happened mainly due to greater competition for nutrients, space and air between the plants due to the narrower spacing. This relationship between tillering and yield in rice has been studied by many authors, and most have reported that increased tillering is generally accompanied by a decreased number of grains per panicle. This was reiterated in this study (Table 13).

As mentioned above, field experiments were carried out from 2003-05 to optimize the establishment techniques of SRI at the Agricultural College and Research Institute, Killikulam, Tamil Nadu, (Bommayasamy et al., 2010). The treatments consisted of the types of nursery and the age of seedlings in the main plots, three different plant geometries in sub-plots and the number of seedlings per hill (single or double) in the sub-sub-plots, replicated thrice. The results of the experiments are as follows:

- Closer spacing (20x20 centimetre) led to a higher number of productive tillers square meter (491), but the number of filled grains per panicle was lower (116.7). Even so, the over grain yield was higher (8.0 tonnes per hectare). This indicated that with increase in spacing, the productive tillers square meter decreased while filled grains per panicle increased.
- Crops cultivated with gaps of 20x20 centimetre led to the highest higher grain yield, followed by those cultivated with gaps of 25x25 centimetre. 30x30 centimetre spacing actually led to 11 per cent reduction in the grain yield (Table 14).

Table 14. Influence of age and number of seedlings, nursery type and spacing on LTR, panicles square meter, filled grains per panicle, and grain yield of rice

Particulars	LTR at flowering		Panicles square meter		Filled grains per panicle		Grain yield (tonnes per hectare)	
	2003-04	2004-05	2003-04	2004-05	2003-04	2004-05	2003-04	2004-05
Types of nursery and age of seedling (days)								
SRI and 14 days	46.85	45.91	437	431	126.8	121.8	7.6	8.6
Conventional and 14 days	49.56	44.61	449	449	118.5	129.1	7.8	8.8
Conventional and 21 days	44.83	45.23	424	436	129.0	127.9	7.3	8.7
SEm	0.52	0.78	5	6	1.5	1.5	0.1	0.2
CD (p=0.05)	1.81	NS	18	NS	5.2	NS	0.5	NS
Spacing								
20x20 centimetre	39.69	41.99	489	493	115.1	118.2	7.8	9.3
25x25 centimetre	49.67	45.26	419	433	125.2	126.9	7.4	8.5
30x30 centimetre	52.73	48.49	378	390	132.4	133.7	7.0	8.4
SEm	0.36	0.47	4	4	0.9	1.2	0.1	0.1
CD (p=0.05)	1.07	1.43	10	13	2.8	3.7	0.3	0.3
Number of seedlings per hill								
Single	48.06	46.03	428	436	123.4	125.5	7.4	8.6
Double	46.66	44.46	430	441	125.1	127.1	7.5	8.8
SEm	0.33	0.44	2.8	3.5	0.8	1.0	0.1	0.1
CD (p=0.05)	0.94	1.30	NS	NS	NS	NS	NS	NS

Source: Bommayasamy et al., 2010

Another study was conducted to examine how plant geometry affects root development, canopy structure and light interception, plant growth and, consequently, the yield under SRI and recommended management practices (RMP) (Thakur et al., 2010):

- Spacing of 20x20 centimetres is optimal; grain yield decreased both with decreasing and with increasing the gaps between the plants. No significant differences in grain yield were recorded when crops were planted 25x25 centimetres and 15x15 centimetres apart under both SRI and conventional management practices.
- SRI panicles had significantly greater number of filled grains than conventional panicles. Closely-spaced hills had significantly lower grain fillings than widely-spaced hills. There was no significant difference in grain fillings between 25x25 centimetre-spaced and 20x20 centimetre-spaced hills. Grain weight was also greater with SRI practices than with conventional methods (Table 15).
- During the maturity stage, hills with wider spacing had larger root dry weight, produced greater xylem exudates and transported these towards the shoot at faster rates. In individual hills than with closely-spaced plants, these features contributed to the maintenance of higher chlorophyll levels, enhanced rates of fluorescence and photosynthesis and more favorable yield attributes and grain yield. Moreover, these parameters further improved under SRI practices, apart from the enhanced percentage of effective tillers, and showed substantial and positive impacts on grain yield (17 per cent) as compared with RMP.
- Both set of practices gave their highest grain yield with 20x20 centimetre spacing; however, SRI practiced led to 40 per cent more grain yield than RMP. At this spacing, canopies also had the highest LAI and light interception during the flowering stage. The lowest yield was recorded at 30x30 centimetre-spacing under both practices, despite improved hill performance, which was a consequence of smaller plant population (11 plants per square meter) (Table 16).

Table 15. Grain yield, number of panicles, and grain filling percentage at different spacing under SRI and RMP

Spacing	Grain yield (g square meter)			Panicles square meter			Grain filling percentage		
	SRI	RMP	Mean	SRI	RMP	Mean	SRI	RMP	Mean
30x30 centimetre	295	247	271	250	197	223	87.9	82.7	85.3
25x25 centimetre	426	398	412	287	235	261	85.1	80.0	82.6
20x20 centimetre	627	448	538	339	278	308	84.0	78.4	81.2
15x15 centimetre	422	403	413	365	280	322	71.8	70.4	71.1
10x10 centimetre	388	343	366	427	367	397	68.5	63.1	65.8
Mean	432	368		333	271		79.5	74.9	
	Practice	Spacing	PxS	Practice	Spacing	PxS	Practice	Spacing	PxS
LSD (5%)	18.5	19.4	27.5	24.8	29.2	Ns	2.7	3.3	ns

Source: Thakur et al., 2010

Table 16. Canopy angle, root dry weight, and xylem exudation rate at different spacing under SRI and RMP during early ripening stage

Particulars	Canopy angle (º)			Root dry weight (grams per square meter)			Exudate amount (grams per square meter)			Rate per square meter (grams square per meter)		
	SRI	RMP	Mean	SRI	RMP	Mean	SRI	RMP	Mean	SRI	RMP	Mean
30x30 centime-tre	44.6	36.5	40.6	207	165	186	139	91.6	115	5.8	3.8	4.8
25x25 centime-tre	37.2	32.1	34.6	257	190	224	158	102	130	6.6	4.3	5.4
20x20 centime-tre	32.0	23.8	27.9	324	242	283	183	124	154	7.6	5.2	6.4
15x15 centime-tre	25.1	19.1	22.1	443	280	362	180	107	144	7.5	4.5	6.0
10x10 centime-tre	21.1	16.8	18.9	683	465	574	200	138	169	8.3	5.7	7.0
Mean	32.0	25.7		383	269		172	113		7.2	4.7	
	Practice	Spacint	PxV	Practice	Variety	PxV	Practice	Variety	PxV	Practice	Variety	PxV
LSD (5%)	2.1	3.4	ns	59	87	123	13.4	8.5	12.0	0.56	0.35	0.50

Source: Thakur et al., 2010

In conclusion, wide spacing beyond the optimum plant density does not give higher grain yield on a per unit area basis. For achieving this, a combination of technologies, including square planting with optimum plant population and mechanical weeding starting from 10 DAT, must be worked out. Numerous factors, such as spacing, temperature, light, nutrient supply and cultural practices, also affect tillering. Thus, wider spacing and square planting is best when used with an understanding of the natural resources and environment.

3.4.3.1. Square transplanting

In SRI, square transplanting with 25x25 centimetre spacing is recommended. This can be achieved through several means. One commonly-practiced method is to use either coconut fibre rope or nylon rope to mark out the line along which planting is to occur. Small sticks or coloured cloth strips are stuck into the soil to mark 25 centimetres, where the crops are to be planted. These spaces can be marked with paint or insulation tape as well. The rope has to be held tightly at either end, and subsequently moved after every 25 centimetre row is planted. Markings can also be made on bamboo sticks or aluminium pipes. Farmers have found many other ways of doing this.

One tool that has become very useful for SRI practiced is a roller marker made of iron rods. When the roller is rolled over the levelled main field, impressions are formed on the soil. The intersecting points indicate the spot where the seedlings are to be planted. Conditions for the use of the roller marker include that the field should be levelled well and the soil and climatic conditions should be such that the marks do not disappear quickly due to excessive moisture. If the field is drained the day before, the soil conditions will be moist enough to pull the marker.

SRI methods state that single seedlings have to be transplanted at the intersecting point. It appears that the labour requirement for transplantation in SRI will be higher than the requirement under conventional methods. But a recent analysis in the TN-IAMWARM project showed that farmers engaged 45-75 labourers for conventional planting compared with 22-48 labourers for SRI planting, the respective averages being 60 and 35. Therefore, there is a 58 per cent reduction in the use of labour under SRI.

The main purpose of square transplanting is to be able to use the mechanical weeder in both directions. The primary benefits of SRI are experienced only when the weeder is used. Labourers who are accustomed to conventional planting may find square planting cumbersome. But this discomfort should be outweighed by the fact that they have to plant only 25 per cent as many.

3.4.3.2. Use of markers for square transplanting

- Based on reports about its efficiency, the 6-row marker is most appropriate for SRI. Enough working space should be provided in between six rows in order to facilitate easier planting. This will also aid in the smooth progression of intercultural operations.
- Markers can operate best if the field possesses optimum moisture conditions. Otherwise the impressions may not be persistent. The field must be drained completely before markers are operated on them; otherwise the entire operation would be in vain.

3.4.4. Irrigation after the disappearance of ponded water

Water has a greater role in the production of rice than in the production of any other crop. It has been universally acknowledged that rice has been associated with fields of standing water in various agro-ecological systems. Unlike many other crops, rice makes the most out of water in numerous ways. This can have effects that are beneficial as well as non-beneficial; evapotranspiration, seepage and percolation are some of these effects. There is therefore a need for specific water management practices such as land preparation. While scientific advancements in agriculture have culminated in paradigm shifts in various areas, including water management, nutrient management, plant protection, precision farming and value addition, motivating farmers to employ scientific water management techniques, especially in rice, is still an obstacle.

A study was conducted to work out the water productivity levels in the seven predominant agro-climatic regions of Tamil Nadu during the three seasons of rice production, namely, samba, kuruvai, and navarai. In this study, it was found that throughout the state, the kuruvai season (June to September) registered the highest average water productivity rate of 0.48 kilograms per cubic meter evapotranspiration), followed by navarai (December to April) at the rate of 0.44 kilograms per cubic meter and samba (August to December) at the rate of 0.41 kilograms per cubic meter. Erode District recorded the maximum rice water productivity of 0.65 kilograms per cubic meter, followed by Salem District (0.54 kilograms per cubic meter) and Namakkal District (0.53 kilograms per cubic meter).

Out of the seven agro-climatic zones of Tamil Nadu, the North Western Zone registered higher levels of water productivity ranging from 0.52 to 0.62 kilograms per cubic meter. The maximum water productivity was recorded in high altitude zones, where, however, the crop was only grown during one season (Ramesh et al., 2009).

Table 17. Spatial and temporal variations in water productivity of rice in Tamil Nadu

Agro-climatic zones	Water productivity (kilogram per cubic meter evapotranspiration)		
	Kuruvai	Samba	Navarai
North Eastern Zone	0.44	0.48	0.47
North Western Zone	0.62	0.59	0.52
Western Zone	0.58	0.49	0.41
Cauvery Delta Zone	0.42	0.33	0.39
Southern Zone	0.41	0.35	0.39
High Rainfall Zone	0.47	0.58	-
High Altitude Zone	0.47	-	-

Source: Ramesh et al., 2009

Water utilization at the field level is always expensive and exhaustive for the rice crop. It ranges from 900 millimetre to 2250 millimetre per season, as opposed to cereals, which use 400-600 millimetre of water per season. Cultivated rice is an annual crop, which evolved from a semi-aquatic ancestor. Thus, to ensure good yield, most farmers tend to inundate their fields completely. The general consensus is that higher the amount of water delivered to the rice fields, the better the rice yield. However, this fallacy needs to be eradicated from farmers' mindset. There is a need for awareness that the controlled and judicious usage of water does not lead to losses.

Moreover, as there is a high level of competition for water due to rapid industrialisation, it is becoming increasingly crucial for farmers to find efficient and scientific ways of water utilisation to sustain their cultivation of rice. During the last decades, various new techniques of rice production have been experimented in national and international rice research institutes. All these techniques tend to keep in check the flow of water at the field level either partially or completely. These new techniques also counteract the old conception of rice as an aquatic crop.

3.4.4.1. Alternate Wetting and Drying (AWD) Irrigation

SRI management practices recommend the alternate wetting and drying (AWD) system of irrigation. This provides the rice plant with the conditions necessary for optimal yield. When combined with transplanting of single young seedlings and mechanical weeding technologies, this leads to an unparalleled yield advantage.

AWD is a water-saving technology that lowland rice farmers are practicing to reduce their use of water. In AWD, irrigation water is applied to flood the field for a specific number of days after the disappearance of ponded water. The field is allowed to be dry for a few days between water applications; the field is kept either completely flooded or just moist. The number of days of non-flooded soil in AWD between irrigations can vary from one day to more than ten days depending on soil and climatic conditions.

In Tamil Nadu, water management for rice under SRI is prescribed based on the findings of field experiments. Up to the panicle initiation stage, it is recommended to irrigate the field to a depth of 2.5 centimetres after the ponded water has disappeared and hairline cracks develop on the soil. At the hairline crack stage, the soil is not completely dry but a little moist. Shallow irrigation of this sort can save water up to 40 per cent without any yield loss. Irrigation intervals vary with soil texture; fine textured clayey soil with higher field capacity needs irrigation at longer intervals while coarse textured light soils with lower water holding capacity requires irrigation more frequently (Thiyagarajan et al., 2003).

One important point that farmers should remember is that rice does not require flooded water or standing water; it is enough simply to keep the soil moist. Farmers using ground water will certainly make use of strategies for saving water, time and electricity under SRI irrigation methods. The amount of water saved under SRI techniques will be enough to bring more areas under cultivation.

The field experiments indicated that the adoption of SRI irrigation practices led to the saving of irrigation water, even under conventional planting methods, without any significant reduction in grain yield (Thiyagarajan, 2002). Total water consumption varied depending on the duration of the variety of rice and the method of irrigation adopted. Accordingly, under conventional irrigation (irrigating to a depth of five centimetre one day after disappearance of surface water), CORH 2, a medium-duration rice hybrid, consumed 15,143 cubic meters per hectare in 108 days of main field duration; thus, the water requirement was 142.2 cubic meters per hectare per day. The short-duration rice hybrid ADTRH 1, which requires 91 days of main field duration, consumed 13,966 cubic meters per hectare of water (153.5 cubic meters per hectare per day) under conventional irrigation methods. The higher per-day consumption for ADTRH 1 was because this hybrid was cultivated during the dry season. Water-saving irrigation (irrigating to a depth of 2.5 centimetres after hairline cracks developed on the soil) led to a significantly lower consumption of 87.7 cubic meters per hectare per day in the wet season (CORH 2) and 79.5 cubic meters per hectare per day in the dry season (ADTRH 1). This variation is due to the fact that the water-saving irrigation method was continued until maturity during the wet season, whereas, during the dry season, this method was used up to the flowering stage, after which conventional irrigation was employed (Senthilkumar, 2002).

Field experiments were conducted at Maruteru on the vertisols of the Godavari delta, during the wet seasons of 2003-2005, to evaluate the performance of SRI methods concerning various aspects of nutrient management, soil water regime, varieties and weed management (Raju and Sreenivas, 2008). The trial on soil water regimes was carried out during the dry season 2003-04 with five treatments laid out in randomized block patterns with four replications. The experimental bunds were covered with polythene sheet to arrest horizontal seepage and the water used was measured with a ‘V’ notch. Continuous flooding (at a depth of five centimetres) of the rice field registered the highest water requirement (1,482 millimetre). This was 40 per cent more than the requirements of the SRI method of cultivation or AWD (883 millimetre) (Table 18). 600 millimetres of irrigation water per hectare was saved in SRI, which was at par with irrigating six days after disappearance of water (6 DADW). Intermittent flooding at intervals of eight days recorded the lowest water requirement (725 millimetre) but with a drastic decline in grain yield. Maximum water use efficiency (8.19 kilogram per millimetre per hectare) was observed with SRI methods and the lowest value was obtained with continuous flooding.

In an experiment conducted at the Agricultural Research Station, Siruguppa, Raichur, during the kharif season of 2005, studies were undertaken to analyze the influence of the age of seedlings under three methods of establishment and five ages of seedlings, it was found that the water requirement was 47 per cent higher in the conventional method of planting (124.96 centimetres) when compared with SRI methods (84.96 centimetres). AWD brought down the water requirement by 32 per cent (Manjunatha et al., 2010). Water use efficiency was higher in the modified SRI methods (74.66 kilogram per hectare per centimetre), followed by the recommended SRI method (73.13 kilogram per hectare per centimetre). These were significantly superior to the normal SRI method (40.85 kilogram per hectare per centimetre) (Table 19).

Table 18. Performance of various soil water regimes in SRI method

Treatments	Grain yield (t per hectare)	Days to panicle emergence	Water requirement (millimetre per hectare)	Water use efficiency (kilogram per hectare per millimetre)	Productivity per day (kilogram)
Continuous saturation (SRI)	7.23	110	883	8.19	65
Continuous flooding (5 centimetre depth)	5.63	102	1,482	3.79	55
Intermittent flooding (5 centimetre) 4 DADW	6.34	104	1,025	6.18	61
Intermittent flooding (5 centimetre) 6 DADW	5.42	104	814	6.65	52
Intermittent flooding (5 centimetre) 8 DADW	4.52	106	725	6.23	43
CD (p=0.05)	0.81	2.1	-	-	-

Source: Raju and Sreenivas, 2008

* DADW - days alternate drying and wetting

Table 19. Water requirement and water use efficiency as influenced by age of seedling and methods of establishment

Treatments	Water requirement (centimetre)						Water use efficiency (kilogram per hectare per centimetre)					
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
M_1	125.0	125.0	125.0	125.0	125.0	125.0	42.6	42.6	40.0	39.3	39.2	40.9
M_2	85.0	85.0	85.0	85.0	85.0	85.0	75.1	74.3	72.4	72.3	71.6	73.1
CUBIC METERS	85.0	85.0	85.0	85.0	85.0	85.0	75.8	75.5	73.3	73.7	75.0	74.7
Mean	98.3	98.3	98.3	98.3	98.3		64.7	64.2	61.9	61.8		
									Sem		CD at 5 %	
Main (METER)									0.30		1.2	
Sub (S)									0.53		1.6	

Source: Manjunatha et al., 2010

M1:	Normal method (Application of RDF through inorganic with FYM @ 10 tonnes per hectare and transplanting at 20x10 centimetre spacing)	S1:	9 days old seedlings
M2:	Recommended SRI (application of RDN through organics and transplanting at 25x25 centimetre spacing)	S2:	12 days old seedlings
CUBIC METERS:	Modified SRI (Application of RDF through inorganic with FYM @ 10 tonnes per hectare and transplanting at 25x25 centimetre spacing)	S3:	15 days old seedlings
RDF:	Recommended dose of fertilizers	S4:	18 days old seedlings
RDN:	Recommended dose of nitrogen	S5:	21 days old seedlings

Studies on water productivity under SRI methods were undertaken as a part of the World Bank-aided TN-IAMWARM project from 2007 to 2010. Irrigation studies conducted at Varaghanadhi sub-basin (Villupuram District, Tamil Nadu) in 2007-08 revealed that the irrigation water required for conventional methods of rice cultivation was 9204 cubic meters per hectare (18 irrigations), as opposed to the 4306 cubic meters per hectare (13 irrigations) required under SRI. Thus, there was a saving of about 41 per cent (Table 20) under SRI methods. Apart from the economy of water usage, the AWD method of irrigation had a positive influence on yield and water productivity (TN-IAMWARM, 2008).

Table 20. Water requirement studies in SRI at Varaghanadhi sub-basin during 200708

Parameters	Conventional	SRI
Number of irrigations	18	13
Irrigation water (cubic meters per hectare)	9,204	4,306
Rainfall (millimetre)	281	281
Total water used (cubic meters per hectare)	12,014	7,116
Percentage of water saving	-	40.8
Grain yield (kilogram per hectare)	5,120	7,528
Water productivity (kilogram per cubic meter)	0.426	1.058

Source: TN-IAMWARM, 2008

Similar studies were conducted at Therkar (Madurai) and Pennaiyar (Krishnagiri district) sub-basins during 2008-09, and revealed that 28-44 per cent of irrigation water was saved (an average of 856 millimetres) under the SRI water management schemes (as against 1400 millimetres in conventional practice). The water productivity worked out to be 7.37 and 3.08 kilogram per hectare per millimetre under SRI and conventional methods, respectively. SRI methods led to 139 per cent higher productivity (TN-IAMWARM, 2009).

During 2010-11, experiments were conducted in four locations – Karumaniar sub-basin (Tirunelveli district, L1), Sevalaperiar sub-basin (Virudhunagar district, L2), Ongur sub-basin (Chengalpattu district, L3) and Nallavur sub-basin (Villuppuram district, L4) to compare the efficiency of SRI irrigation methods with conventional irrigation methods (CI). The comparisons are shown on the next page.

Table 21. Water requirement studies in SRI at Karumaniar, Sevalaperiar, Ongur and Nallavur sub-basins during 2009-10

Parameters	L1		L2		L3		L4		Average	
	SRI	CI	SRI	CI	SRI	CI	SRI	CI	SRI	CI
No. of irrigations	20	19	19	18	14	20	11	17	16	19
Water used (millimetre)	923	1,252	973	1223	827	1148	818	1098	885	1180
Productive tillers per hill	31.3	9.6	48	31	36	13	39	14	39	17
Productive tillers square meter	470	350	612	505	720	580	780	704	646	535
Grain yield (kilogram per hectare)	5810	4450	5982	5032	7046	5965	6784	5689	6406	5284
Water productivity (liter per kilogram)	1588	2813	1626	2430	1174	1924	1205	1930	1398	2274

Source: TN-IAMWARM, 2009

The data clearly indicates that less water was required under SRI (885 millimetre) as compared to conventional methods (1180 millimetre). SRI registered a higher grain yield of 6406 kilogram per hectare and WUE (Water Use Efficiency) of 7.31 kilogram per hectare per millimetre, as compared to conventional methods with grain yield of 5284 kilogram per hectare and WUE of 4.51 kilogram per hectare per millimetre. Water productivity in SRI was found to be 1398 liters per kilogram as against the 2274 liters per kilogram under conventional irrigation (Pandian, 2011).

Contrary to the above studies, Sharma and Masand (2008) reported in their field experiments conducted in Himachal Pradesh during the years 2002, 2003 and 2004, that total water use was higher in SRI by 559, 634 and 380 millimetre, respectively, than in conventional transplanted rice (CTR).

This could be attributed to the fact that younger seedlings were transplanted about 2-3 weeks earlier than in CTR in the month of June before the onset of monsoons. Delay in transplanting under SRI methods in this part of the state is not suitable, because the reproductive phase coincides with low temperatures, leading to increased sterility and low yield. Additionally, the atmospheric evaporation during this period is at its peak. Consequently, the SRI plots had to be irrigated almost daily to keep them saturated. In 2002, 2003 and 2004, SRI plots received about 440, 440 and 80 millimetres of additional water respectively before the seedlings were conventionally transplanted. After the monsoons set in, the rains were almost continuous during the period of study, and irrigation was required infrequently. In some parts of Himachal Pradesh, thus, where low temperatures are not a problem, transplanting of seedlings with the onset of monsoon rains may decrease the total water use under SRI.

It is evident from the above discussions that in SRI, there is significant saving in irrigation water in addition to higher water productivity and higher yield or immaterial yield loss. But, as discussed in the earlier chapters, water management – i.e., maintaining a thin film of water to a depth of 2.5 centimetre after the development of hairline cracks – is a problem in areas where the canal system of irrigation is practiced. In such cases, irrigation infrastructural facilities have to be channelized to deliver only the required quantum of water to the field as well as to drain excess water. Further, efforts must be taken to ensure that the optimum quantity of water is applied for the decomposition of green manure as well as for the crop itself, especially during dry seasons.

3.4.5. Mechanical weeding

Effective and efficient weed management practices are crucial for increasing productivity, given that the soil conditions that are favourable for rice seeds are good for the growth of weeds as well. Controlled flooding is a traditional method of weed control in rice cultivation, which ensures that transplanted rice seedlings get a ‘‘head start’’ over the weeds. Although weeds will not germinate readily under flooded conditions, it is not wise to deluge water just for the purpose of drowning them out, especially in the dry season, as water is a valuable and expensive input for rice production.

In SRI, weeds are seen as a more severe constraint than in the conventional production systems. Young single seedling transplantation, wider spacing, AWD irrigation conditions, etc. are conducive for the germination and growth of weeds, which are highly competitive as plants. Therefore, SRI can only be successful if it is accompanied by effective weed management practices. The use of cono weeders or mechanical weeders is recommended in SRI practices. This has multiple benefits for crop development and yield enhancement and also offers greater scope for effective, efficient weed management.

It has been observed that the combination of mechanical weeding and soil stirring is important for removing weeds. Weeds can reduce rice yield by 18-20 per cent (Balasubramanian et al., 2005). It was been reported, in studies carried out at Aduthurai and Thanjavur, that the use of a cono weeder and associated soil disturbances significantly increases grain yield (by 1363 and 1220 kilogram per hectare, or 24 and 22 per cent, respectively) (Table 22) when compared to the conventional weeding methods (Rajendran et al., 2005). The increase in grain yield might be. In addition to weed suppression, due improved soil aeration and profuse tillering that resulted from soil stirring by cono weeder operations.

Table 22. Individual and combined effects of crop management components on grain yield in Aduthurai and Thanjavur during the wet season 2002.

Components	Treatment	TRRI, Aduthurai		SWMRI, Thanjavur	
		Grain yield* (kilogram per hectare)	Increase over conventional (%)	Grain yield* (kilogram per hectare)	Increase over conventional (%)
Mechanical weeding	YOSCI	7,061 (1,363)	24	6,583 (1,220)	22
	YOSHI	5,698	-	5,363	-
Young seedlings	YOSCI	7,061 (1,187)	20	6,583 (1,026)	16
	NOSCI		-	5,557	-
Intermittent irrigation	YOSCI	7,061 (663)	10	6,583 (704)	12
	YOSCF		-	5,879	-
Synergistic effect	YOSCI	7,061	48	6,583 (1,220)	35
	NMRHF	4,745	-	4,849	-
CD (P=0.05)		163	-	121	-

Source: Rajendran et al., 2005

When SRI was introduced, two types of weeders were recommended - the cono weeder and the rotary weeder. A cono weeder weighs about 7.5 kilograms and can be operated only by male labourers. A rotary weeder is lighter (about two kilograms) and can be operated by female labourers also. Which type of weeder is most suitable is site-specific, depending upon soil conditions and the mindset of the labourers. It has been recommended that a thin layer of water be maintained while using the weeder to facilitate its easier operation. It is very important to remove the left-out weeds near the rice plants by hand; the use of the weeders for these crops can lead to huge yield loss. Apart from weeding, the benefits of mechanical weeders are as follows:

- Weed biomass is incorporated in the soil, adding organic carbon.
- The nutrients taken up by the weeds are returned to the soil.
- The churning up of the soil activates the microbial, physical and chemical dynamics.
- The churning up of the soil makes the plants produce new roots which aids in root activity.
- If other practices remain the same, the use of weeder can enhance crop growth and yield.
- If the use of fertilizers precedes weeder operations, fertilizers are incorporated into the soil and the loss of nutrients by leeching is reduced.
- Cost of weeding is reduced.

From these evidences, it can be concluded that weeding with the help of the mechanical weeders is a critical component of SRI that can neither be avoided nor be compromised on. Mechanical weeding up to 40 days at 7-10 day-intervals starting from ten days after transplanting (DAT) is advised. The first weeding by 10 DAT is crucial. The weeder should be used in between the rows in both directions. The second weeding is done around 20 DAT, and a third weeding around 35 DAT. In many cases, a third weeding cannot be accomplished due to the coverage of the crop canopy. But, by then, the canopy cover suppresses further weed growth. It would be beneficial to continue active soil aeration, but this is not practically possible.

While all the SRI farmers have reported that the use of the mechanical weeder is beneficial, some of them also encountered considerable difficulties. Although maximum benefit is derived by using the weeder in both directions, some farmers can only use it in one direction due to operational difficulties. Most of these problems are associated with the labourers using the weeder. Small farmers often find family labour to be sufficient for the entire weeding operation.

Nonetheless, most SRI farmers emphasize the desirability of having a motorized weeder, to speed up the process and make it less expensive, while possibly doing a better job of aerating the soil. Attempts to develop a motorized weeder will be a boon to SRI farmers.

3.4.6. Nutrient management through Leaf Colour Chart (LCC)

Nitrogen is considered the most important yield-enhancing nutrient when it comes to the rice crop, which accounts for nearly 40 per cent of the total Fertilizer N consumption in India. However, the efficiency of nitrogen use is very low in rice cultivation as only one-third or even less of the applied Fertilizer N is recovered. Nevertheless, the productivity of modern rice cultivars depends on their responsiveness to soil nitrogen supply. Currently, Fertilizer N recommendations in India are available as “blanket” recommendations with appropriate splits and time of application. Although these recommendations are based on nutritional status determined from soil and crop response studies, they cannot fully match the actual crop needs in all given situations. Hence, they cannot always increase nutrient use efficiency.

To ensure high yields, farmers apply Fertilizer N over and above the blanket recommendations, which, conversely, further lower Fertilizer N recovery efficiency. Use of Fertilizer N above crop requirements and inefficient splitting of N applications are the main reasons for its low usage efficiency in rice. Synchronizing the crop’s need for the fertilizer and the supply of nitrogen from soil or applied Fertilizer N is most likely the best strategy to increase N use efficiency. Thus, the split application of Fertilizer N is going to remain an essential component of N management strategies in rice.

Real-time corrective N management is based on periodic assessment of the plant’s nitrogen status. The application of Fertilizer N is delayed until nitrogen deficiency symptoms start to appear. Thus, the rapid assessment of the leaf nitrogen content, which is closely related to photosynthetic rate and biomass production, is the key for real-time corrective N management.

The only non-destructive tools presently available for in-situ monitoring of the leaf nitrogen status in rice are the chlorophyll meter, known as the SPAD (Soil Plant Analysis Development) meter, and the LCC (Leaf Colour Chart), both of which are simple and quick methods. The chlorophyll meter can provide a quick estimate of the leaf nitrogen status, but it is relatively expensive to use. The LCC, developed through the collaborative efforts of the International Rice Research Institute (IRRI) and agricultural research systems from several countries in Asia, is inexpensive, simple and a user-friendly alternative to monitor the relative greenness of the rice leaf as an indicator of crop’s nitrogen status.

With four or colour panels of different shades of green, the LCC is used as a reference tool and is becoming popular as an inexpensive, easy-to-use tool for estimating leaf nitrogen content and thus managing the use of Fertilizer N in rice. LCC-based, real-time N management can be practiced in rice by monitoring leaf colour at 7-10 day intervals during the growing season. Fertilizer N is applied whenever the leaves are less green than a threshold LCC value, which corresponds to critical leaf nitrogen content.

A field experiment was conducted to study the effect of crop establishment techniques (14-day-old seedlings in modified mat nurseries with single and two seedlings per hill; 21-day-old seedlings in wet nurseries with single and two seedlings per hill) and nitrogen levels (120 kilogram, 150 kilogram, 180 kilogram and LCC-based N management) on the growth and productivity of transplanted rice variety ADT-43 in the wetlands of TNAU, Coimbatore (Prema, 2007). In this experiment, all the yield-contributing characteristics were found to be higher with the crop raised in the modified mat nursery with single seedlings per hill when the crop received N application based on LCC readings. Among the various N levels, LCC-based N application amounting to 120 kilograms per hectare resulted in higher grain yield (6532 kilograms per hectare). It was concluded that the crop establishment from 14-day-old seedlings from modified mat nurseries, planted with one or two seedlings per hill, along with LCC-based N application (120 kilogram per hectare) is a promising treatment combination for realizing higher yields and economic returns.

However, in a different field experiment conducted during the wet season (2002) at TNAU, Coimbatore, to study the effect of SRI-recommended practices on yield attributes and yield and water productivity of rice, it was found that there was no response to LCC-based N management (Vijayakumar et al., 2004).

In general, real-time N management based on applying Fertilizer N whenever the leaf became less green than is ideal resulted in the application of 60 to 120 kilogram of N per hectare where rice yields were equivalent to those obtained with the (substantially higher) “blanket” recommendation. The LCC-based management in SRI also suggests that N application can be reduced with no yield loss by appropriately revising the recommendations regarding the fertilizer based on local conditions. But farmers prefer less frequent monitoring of leaf colour and they are accustomed to applying Fertilizer N at growth stages as per the blanket recommendations. The use of LCC for scheduling N application may not be uniformly applicable to all varieties of rice, which differ in inherent leaf colour, and inn all agro-climatic regions, thereby necessitating some standardization. For the easy adoption of the LCC by farmers, a fixed date-variable-rate strategy may be formulated and standardized to allow the application of N during different growing seasons.

3.4.6.1. Integrated Nutrient Management (INM)

Apart from the components of SRI discussed above, in the yield-enhancing process, SRI makes use of naturally-available organic manures as inputs, which in turn also aid in minimizing the use of fertilizers and thus considerably reducing in the cost of cultivation. Organic carbon is an indicator of native soil fertility. In general, rice-growing soils are poor in organic carbon (around five grams per kilogram). For soil to be a sustainable resource, it needs to be replenished with organic matter continuously. This organic matter can be compost, farmyard manure (FYM) and plant residues. These will maintain or even increase the organic carbon content of the soil. The practice of SRI is not limited to improved Fertilizer N management through LCC. Efforts are being made to provide balanced fertilization through integrated nutrient management (INM). Hence, organic manures are seen as the chief source of organic carbon and other nutrients; these are found to lead to a better response from the crop.

INM is the application of available organic resources, such as cattle manure, poultry manure, vermicompost, green manures, green leaf manures and biofertilisers, while using inorganic fertilizers as supplements in adequate splits to meet the nutrient demand of the crop at different stages of growth. This allows farmers to use organic materials or manure available at the farm at a low cost, thereby meeting a portion of the crop's nutrient demand and improving soil fertility. The use of organic manures available at farms can lead to higher yields and greater profit when combined with inorganic fertilizers, particularly on poor lowland soils.

In a field investigation conducted to ascertain the best nutrient management strategy in SRI, in the temperate conditions of the Kashmir valley, it was found that SRI with NPK (inorganic fertilizers with different proportions of Nitrogen, Phosphorous and Potassium) as well as FYM led to superior plant height, tillers per hill, panicles per square meter and grains per panicle over the recommended N practices and the conventional methods of cultivation. It was, at the same time, statistically at par with SRI with NPK and FYM at a spacing of 20x20 centimetres (Hussain et al., 2009). SRI with NPK recorded the highest benefit to cost (B:C) ratio at 1:42, but, at the same time, the highest net profit of Rs. 55,756 was realized under this combination (Table 23).

Table 23. Fertilizer response due to SRI and conventional method of rice cultivation (2007)

Particulars	Panicles square meter	Yield (q per hectare)	Economics (Rs. per hectare)			
			Production cost	Gross income	Net profit	B:C ratio
SRI* with NPK	290	46.91	37,000	89,766	52,766	1.42
SRI with FYM	252	46.20	37,800	78,884	41,084	1.09
SRI with NPK + FYM	304	45.71	40,300	96,056	55,756	1.38
SRI without NPK or FYM	208	46.79	34,300	71,946	37,646	1.09
SRI with NPK + FYM (20x20 centimetre)	295	44.91	40,300	92,049	51,749	1.28
Recommended practice**	257	47.09	36,500	81,113	44,613	1.22
Farmers' practice***	253	47.69	36,500	81,702	45,702	1.26
CD (0.05)	35.7	1.82	-	-	-	-
CV (%0)	8.8	1.44	-	-	-	-

Source: Hussain et al., 2009

Practice	Age of the seedling	No. of seedling per hill	Spacing (cm)	No. of weedings	Irrigation
*SRI	16	1	25x25	2 rotary weeding	AWD
**Recommended practice	35	3-4	15x15	1 HW	3-5 centimetre submergence
***Farmers' practice	35	5-8	Random planting 32-35 hills square mtr	1 HW	3-5 centimetre submergence up to flowering

Similar field experiments were conducted to evaluate the influence of SRI management practices on seed yield and the quality of rice cv. ES-18 at the Agricultural Research

Station (Paddy), Sirsi during 2004-05 (Krishna et al., 2008). It was observed during this experiment that plants grown under SRI methods with FYM and RDF treatments recorded an increased number of productive tillers. These plants flowered and matured earlier as compared with other experiments and interactions. The probable reason for this could be the delayed accumulation of threshold levels of photosynthetic substances that carry the plant from the vegetative to the reproductive phase. SRI methods with RDF produced significantly higher seed yield (3.33 tonnes per hectare) over traditional methods (2.60 tonnes per hectare). The B:C ration was also significantly superior to the B:C ratio under traditional methods in all treatments (Table 24).

Table 24. Interaction effects due to methods of cultivation, manures and fertilizers on grain yield and economics

Treatments	No. of productive tillers square meter	Days to 50 % flowering	Grain yield (t per hectare)	Vigour index	BC Ratio
Interactions of CxMETER					
C_1 M_1	23.2	93.6	3.01	2,351	1.51
C_1 M_2	15.9	94.2	2.76	2,276	1.38
C2 M_1	7.6	98.9	2.33	2,127	1.17
C_2 M_2	4.4	98.6	2.23	1,973	1.12
SEm	0.9	0.2	0.19	28	0.18
CD (p=0.05)	7.4	0.6	0.57	87	0.54
Interactions of CxF					
C_1 F_1	24.2	93.3	3.33	2,504	1.67
C_1 F_2	19.1	93.8	3.17	2,329	1.59
C_1 F_3	15.2	94.8	2.19	2,108	1.10
C_2 F_1	9.2	97.8	2.60	2,151	1.30
C_2 F_2	7.2	99.7	2.29	2,068	1.15
C_2 F3	6.1	99.7	1.94	1,931	0.97
SEm	1.1	0.2	0.27	45	0.22
CD (p=0.05)	3.2	0.6	0.90	135	0.66

Source: Krishna et al., 2008

Methods of cultivation: C_1 = SRI method C_2 = Traditional method
Fertilizers: F_1 = RDF (75:75:87.5 kilogram NPK/hectare) F_2 = 50 % RDF F_3 = No Fertilizer
Manures: M_1 = FYM @ 10 tonnes per hectare M_2 = Vermicompost @ 5 tonnes per hectare

Nutrient management experiments were also conducted during the experiments at Maruteru, of the Godavari delta, during the wet seasons of 2003-2005 (Raju and Sreenivas, 2008). The trial was laid out with five treatments of different combinations of organic and inorganic fertilizers in a randomized block design with four replications. The crop was planted during third week of December, during the dry season of 2003-04.

Table 25. Effect of integrated nutrient supply system on rice yields under SRI

Treatments	Panicles square meter	Filled grains per panicle	Grain yield (t per hectare)
Sole chemical fertilization (120 kilogram N, 60 kilogram P2O5, 40 kilogram K2O kilogram per hectare)	323	158	4.32
60 kilogram N through press mud (5 tonnes per hectare) + ½ as chemical N (Urea)	365	175	5.77
60 kilogram N through press mud (5 tonnes per hectare) + ½ as chemical N (Urea)	402	201	6.48
60 kilogram N through FYM (5 tonnes per hectare) + ½ as chemical N (Urea)	391	193	6.13
60 kilogram N through FYM (5 tonnes per hectare) + ½ as chemical N (Urea) + 1 tonnes gypsum per hectare	480	225	7.56
CD (p=0.05)	65	21	0.36

Source: Raju and Sreenivas, 2008

It was found that the combination of organic and inorganic fertilizers resulted in significantly higher yields than solely through chemical fertilization. The combined application of FYM at the rate of 5 tonnes per hectare along with half the recommended quantity of Fertilizer N through chemical and gypsum at the rate of 1 tonne per hectare registered the highest yield (7.6 tonnes per hectare). The superiority of INM might be due to the presence of humic acid compounds which helps in the dissolution of minerals and the chelation of micronutrients.

The ideal solution for enriching of the soil is a combination of tank silt (40–50 tonnes per hectare), FYM or compost (15 tonnes per hectare) and in-situ incorporation of 45-60 day-old green manures such as sunhemp or *dhaincha.*

Another possible solution could be growing Glyricidia *(Glyricidia maculata)* on the rice field bunds and fences. This plant contains 2.3 per cent nitrogen, 0.1 per cent phosphorus, 1.8 per cent potassium and 1.2 per cent calcium. It is a root-nodulating, nitrogen-fixing, multipurpose legume tolerant to pruning. Planting stem cuttings will serve as a regular source of green manure from the third year onwards; from well-grown Glyricidia trees, 100-200 kilogram of green leaves can be obtained in a tear. Straw can also be recycled after decomposition. From the above, it is clear that using available local natural resources such as organic manures makes SRI a viable and healthy practice, which serves to protect and preserve the environment while ensuring fertile soil, a healthy crop and higher returns.

3.4.6.2. Soil microbial activity and crop physiology

Soil microbes play an important role in maintaining soil fertility and productivity, because they regulate the transformation processes of elements in the soils and, at the same time, control the build-up and decomposition of organic matter. The microbial activity, and in turn the physical and chemical properties and soil nutrient dynamics, are improved by the adoption of SRI components in the rice ecosystem. Organic manures, besides supplying essential nutrients, add to favourable conditions for soil microbes as they are a source of organic carbon.

The role of microbes, even if fertilizers are applied, cannot be ignored. For example, when urea is applied, nitrogen will be available to the plants only if the amide form of nitrogen in urea is converted into its inorganic form (NH_4 or NO_3) by the microbes *Nitrosomanas* and *Nitrobacter*. It should also be anticipated that the plants will take up nitrogen in its inorganic form only; they do not recognize whether the source of nitrogen is organic or inorganic.

A field experiment was conducted by the Department of Rice, TNAU, Coimbatore, during rabi season 2006-07. Its objective was to evaluate different crop establishment methods in transplanted CORH 3 hybrid rice (Ancy, 2007). In the microbial study, ICM registered a higher total count of bacteria and *Pseudomonas*, while SRI recorded higher fungi populations.

Introducing changes, including the age of transplanted seedlings, cultivation with the help of a mechanical weeder, AWD irrigation and green manure with fertilizers, had a positive effect on the populations and activities of beneficial organisms in the soil rhizosphere (Gayathry, 2002). At the active tillering stage, the numbers of all bacteria were 58 per cent higher; *Azospirillum* was 53 per cent high, *Azotobacter* 127 per cent, diazotrophs 60 per cent and phosphobacteria 77 per cent higher in SRI rhizospheres than in the rhizospheres of conventionally-grown rice.

Table 26. Microbial populations in the rhizosphere soil in rice crop under different crop management conditions

Microbes	Crop growth stage							
	Active tillering		Panicle initiation		Flowering		Maturity	
	CMP	SRI	CMP	SRI	CMP	SRI	CMP	SRI
Total Bacteria	9.35	14.66	14.91	21.64	9.73	10.99	7.64	7.51
Azospirillum	4.69	7.17	7.39	9.05	3.13	4.23	1.42	1.52
Azotobacter	8.88	20.15	25.57	31.17	10.45	10.92	5.26	6.45
Total diazo-trophs	9.11	14.62	10.52	22.91	7.14	7.68	4.71	5.43
Phosphobacteria	9.15	16.19	17.65	23.75	7.76	13.79	2.28	2.66

Source: Gayathry, 2002

(Numbers are square root transformed values of population per gram of dry soil)

CMP - Conventional Management practices; SRI - System of Rice Intensification

Table 27. Microbial activities in the rhizosphere soil in rice crop under different crop management conditions

Microbes	Crop growth stage							
	Active tillering		Panicle initiation		Flowering		Maturity	
	CMP	SRI	CMP	SRI	CMP	SRI	CMP	SRI
Dehydrogenase activity (µg TPF g^{-1} soil 24 h^{-1})	81	369	263	467	78	139	16	42
Urease activity (µg NH_4-N g^{-1} soil 24 h^{-1})	189	230	1794	2840	457	618	87	173
Acid phosphate activity (µg p-Nitrophe-nol g^{-1} soil 24 h^{-1})	1800	1984	2123	2762	957	2653	214	686
Alkaline phos-phate activity (µg p-Nitrophe-nol g^{-1} soil 24 h^{-1})	261	234	372	397	332	324	120	146
Nitrogenase activity (nano mol C_2H_4 g^{-1} soil 24 h^{-1})	-	-	3.15	3.70	7.63	11.13	1.94	1.87

Source: Gayathry, 2002

(Numbers are square root transformed values of population per gram of dry soil)

Addition of recommended organic manures such as FYM, compost or weed biomass makes the soil rich in organic carbon. This in turn triggers tremendous biological processes by the extant diverse population of the soil's biota (including bacteria, fungi and protozoa). Similarly, plants respond to diverse environment signals in order to survive different stresses, such as drought. Various physiological parameters have been associated with drought and drought-tolerance. An attempt was made to elucidate the information on plant-water relations under different water-stress scenarios and possible role of the selected ameliorative measures in mitigating the ill-effects of the stresses in both SRI and TPR (traditionally planted rice) methods of cultivation of the ADT 43 variety of rice at TNAU, Coimbatore, during the dry season of 2007 (Sumathi and Mohandoss, 2009). The results of this attempt as elucidated below:

Table 28. Effect of planting methods, water stress and ameliorants on plant water relations and grain yield of rice (ADT 43)

Treatments	RWC (%)	LWP (MPa)	Proline (µmoles g^{-1})	LDR (s per (cm)	Transpiration rate (µg H2O centisquare meter s^{-1})	Grain yield (kilogram per hectare)
M_1	89.5	-0.94	2.78	0.147	46.64	6,665
M_2	84.5	-1.70	7.96	0.177	39.34	5,574
CUBIC METERS	87.7	-1.05	2.62	0.151	42.08	6,045
M_4	83.6	-1.86	8.22	0.188	33.99	5,011
SEd	1.4	0.02	0.09	0.002	0.250	36.5
CD (p=0.05)	2.9	0.04	0.19	0.005	0.613	89.3
S_1	81.6	-1.61	4.30	0.180	34.58	5,261
S_2	88.2	-1.32	5.61	0.162	42.72	6,024
S_3	83.9	-1.51	4.64	0.173	37.47	5,613
S_4	88.3	-1.31	6.01	0.161	43.06	6,163
S_5	89.7	-1.20	6.41	0.153	44.74	6,309
SEd	1.7	0.03	0.12	0.003	0.477	69
CD (p=0.05)	3.6	0.06	0.29	0.007	0.972	140

Source: Sumathi and Mohandoss, 2009

M_1 – SRI with conventional irrigation	S_1 – Control
M_2 – SRI with stress at PI and Flowering stages	S_2 – 0.5 ppm Brassinolide
CUBIC METERS – TPR with conventional irrigation	S_3 – 100 ppm Salicylic acid
M_4 – TPR with stress at PI and Flowering stages	S_4 – 1 % Potassium Chloride
	S_5 – 106 Pink Pigmented Facultative Methylotroph (PPFM) Bacterial isolate

- The results showed that, at the flowering stage, the stressed plants of SRI (M_2) maintained higher values than those from the TPR methods of planting. The SRI plants maintained the following vales: RWC (relative water content) - 84.5 per cent; LWP (leaf water potential) -1.7 megapascals; Proline - 7.96 µmoles per gram; LDR - 0.177 s per centimetre; transpiration rate - 33.34 µgrams of H2O centisquare meter per s. The TPR (M4) method of planting led to the following vales: RWC - 83.64 per cent; LWP -1.86 megapascals; Proline – 8.22 µmoles per gram; LDR - -0.188 s per centimetre; transpiration rate -33.99 µgrams of H_2O centisquare meter s^{-1}).
- The foliar spray PPFM (S_5) performed better than the other treatments. The water-stress treatment led to mean grain yield reductions of 22.3 and 31.6 per cent under SRI and conventional transplanting methods respectively. With supplements of stress ameliorants, this could be narrowed down to 6.5 and 12.3 per cent, respectively.
- It can be inferred that the stressed plants cultivated using SRI maintained higher values of parameters of plant-water relations than those cultivated using TPR methods. This ultimately translates into higher grain yield under SRI. The chosen amelioratives generally resulted in higher values of RWC, LWP, Proline, LDR and transpiration rate in the leaf cells of rice plants from both systems of planting. A special reference can be made about the use of 106 bacterial isolate of PPFM, namely *Methylobacterium* sp. (10 milliliter per liter) to mitigate the ill-effects of water stress.
- The RWC of the leaves is often considered to be a measure of plant-water status, reflecting metabolic activity in tissues. This was found to be higher in SRI plots (89.5 per cent) than in conventional plots (87.7 per cent).
- The LWP is a dependable indicator of plant-water status, especially in environments were water-supply is limited. The SRI plants recorded a lower LWP of -0.94 megapascals as against -1.05 megapascals under the conventional management.
- Proline acts as compatible solute and a protective agent for cytoplasmic enzymes and structures. Increased accumulation of proline under SRI practices was possible because of restricted water supply as compared to the constant flooding practiced under the conventional method of planting.

4. FLOURISHING OF SRI IN TAMIL NADU THROUGH TN-IAMWARM

SRI is a system of strategic rice cultivation, designed to address the present-day requirements of farmers, including the requirement for reducing water consumption. However, the area that has been brought under SRI cultivation is not much more than one per cent of the 43 million hectares used for rice cultivation in India. As mentioned before, despite very positive results, the progression of SRI across the country has been highly variable and rather constricted. Due to the tendency of farmers to avert risks and a lack of awareness about the scientific facts behind the components of SRI, these techniques have been adopted variably, usually partially, using only some of the principles SRI. This has led to incongruous results in different farmers' fields. Thus, SRI, although it is a promising as well as a sustainable yield-enhancing tool, has so far encountered many challenges that have prevented its take-off on a large scale.

4.1. TN-IAMWARM – An Introduction

The Tamil Nadu Irrigated Agriculture Modernisation and Water Bodies Restoration and Management (TN-IAMWARM – 2007-2013) project is a unique World Bank-funded initiative which was implemented in Tamil Nadu from 2007 in 63 selected sub-basins. Its prime objective is to maximise the productivity of irrigation water and improve farm incomes and yield. SRI became the central thrust of the TN-IAMWARM project due to its scope for sustainable productivity and water saving. TN-IAMWARM has provided an ambient platform for large-scale demonstration and awareness-creation endeavours to promote SRI in Tamil Nadu, and has also provided technical and financial assistance.

4.2. Events of Awareness-Creation and Up-Scaling Measures

The main obstacles identified in the process of SRI adoption include the traditional mindsets of the farmers, a lack of awareness, non-cooperation of planting labourers, the inability to deliver regulated irrigation water and the non-availability of critical implements (such as markers and mechanical weeders) at the right time. The probability of disseminating SRI on a massive scale has increased only after the inception of the TN-IAMWARM project. A few innovative steps have been taken under this project to popularise SRI in the state, which led to promising results.

4.3. Information, Education and Communication (IEC) Activities

The basic objectives of IEC activities are:

- Changing the traditional mindset of the farmers
- Educating the beneficiaries about the technical skills related to SRI techniques
- Imparting knowledge to farmers through various extension techniques

Awareness creation campaigns through wall paintings and hoardings depicting the magnitude and importance of SRI have been planned. Additionally, strategies for awareness creation include arranging informal meetings with the stakeholders, distribution of folders, leaflets or booklets on SRI practices and training farmers and farm labourers in SRI production technologies.

4.4. Events of Motivation

- Exposure Visits: Farmers were taken to successful SRI farmers' fields before the commencement of the season as exposure visits, a fundamental tool for disseminating information on SRI and imparting training. Interaction with the SRI farmers also helped other farmers to understand the practical problems of SRI as well as ways to solve them.
- Field Days: At various important stages of crop growth and cultural operations – viz., square transplanting using markers, mechanical weeding and harvesting – field days were organised to disseminate information about SRI technology to the neighbouring farmers.
- SRI Field Flags: In order to demarcate the SRI fields, these have been uniquely flagged. This measure acted as a mode of attracting attention and thereby creating awareness and motivating the fellow farmers to adopt SRI methods.
- Greetings: In order to boost the self-confidence of the SRI farmers, greetings were sent to beneficiaries on the occasion of Pongal (Tamilar Thirunal).
- Advertisements: Advertisements have appeared as a publicity measure in all leading dailies and on FM stations and All-India Radio (AIR).
- SRI Book and CD: A comprehensive self-learning book in regional languages and a compact disc on SRI practices were prepared. The films were played during the night meetings with farmers.

- TN-IAMWARM-On-Wheels: A mobile campaign with a propaganda van comprising displays of various SRI technologies was designed to answer immediately all farmers' queries. A short film on SRI was played at farmers' gatherings.
- Gram Sabha Meetings: The Gram Sabha meetings, conducted by the village panchayat were used as a platform to propagate SRI technologies and as a medium to consult with farmers on how to upgrade technology.
- Field Days with VIP Participation: The impact of introducing new technology as a public venture will usually be greater if it is backed by the administration. Thus, it was planned to draw the exclusive attention of the administrators. Accordingly, frequent field visits were arranged at the demonstration sites to convince them of the positive ramifications of SRI methods and to create a solid affirmative imprint in their minds.

4.5. Prospects of Scaling up SRI Adoption in Tamil Nadu

Any intervention towards improving agricultural productivity should be integrated with endeavours to sustain soil fertility and crop yield in an economically viable, socially acceptable and eco-friendly manner.

The sparkling spread of SRI in Tamil Nadu is a solid articulation of the above principles. It should be unsurprising that SRI has progressed with quantum increases in yield and tremendous expansion in areas under the TN-IAWMARM project. The area being cultivated with SRI methods grew substantially by 7892 hectares from 2007 to 2010. The overall performance of SRI introduced in the project area of TN-IAMWARM is given below:

Table 29. Beneficiary-wise analysis of SRI in Tamil Nadu under TN-IAMWARM project (2007-10) with respect to per cent increase in yield over the conventional rice cultivation

Year	Per cent increase in yield over the conventional						
	< 10%	10-20%	20-30%	30-40%	40-50%	>50%	Total no. of beneficiaries
2007-08	337	311	363	301	144	-	**1456**
2008-09	-	568	678	1004	387	392	**3029**
2009-10	71	567	543	331	2,790	943	**5245**
Total	**408**	**1446**	**1584**	**1736**	**3321**	**1335**	**9730**

Source: Pandian, 2010a

Despite the initial scepticism of the farmers, SRI has proved its merit beyond reservations in Tamil Nadu. From the beneficiary-wise analysis, it can be observed that a majority of the farmers have reaped a 40-50 per cent increase in yield by following SRI strategies (Pandian, 2010a) (Table 29).

Table 30. SRI outreach in Tamil Nadu under TN-IAMWARM project (2007-10)

Year	Yield (kilograms/hectares)		Per cent increase	Area total (hectares)
	SRI	Conventional		
2007-08	5709	4465	28.3	1311
2008-09	6710	5035	33.3	2581
2009-10	7058	5139	37.3	4000

Source: Pandian, 2010

In general, an increase in rice productivity through SRI methods, as against the conventional system of rice cultivation, has been observed over these three years. This has created a remarkable consciousness among the rice growers of the State. The widespread adoption of SRI has put aside many more theoretical queries about its adoption at the field level, which is evident from the increasing percentage of yield (from 28.3 per cent increase in 2007-08 to 37.3 per cent increase in 2009-10) (Pandian, 2010b) (Table 30). Above all, SRI has revived the interest of many rice growers who had intended to give up rice cultivation due to numerous difficulties.

4.6. SRI Farmers' Association

The rice-growing farmers in Thumbal, a village 25 km away from Salem, set a benchmark in agriculture by forming the first SRI Farmers' Association. Nearly 200 beneficiaries of this village were made aware of and given training on SRI practices in 2007-08. Th. P. Baskaran, a post-graduate farmer, took the initiative to form an SRI Association to show the other farmers that SRI is a solid way of obtaining greater productivity and income in rice cultivation. The Thumbal Semmai Nel Sagupadi Farmers' Association was formed and registered under his leadership. Rice-growing farmers from various districts of Tamil Nadu and other states have visited Thumbal to understand and experience SRI at field level. Farmers from Pillekothur village, in the Ponnaiyar sub-basin in the Krishnagiri District have registered another association called the Water Saving Farmers' Association.

A persuasive media programme called 'Oru Nellu Oru Nathu' (Single Seed, Single Seedling) for farmers was broadcast from January 2009 for 13 weeks in Tamil on All-

India Radio (AIR), Trichy. Satisfied SRI farmers shared their experiences and views to motivate neighbouring farmers.

4.7. Experiences of the TN-IAMWARM Project

An attempt was made to study the performance of SRI in comparison with the conventional method of rice cultivation in the Manimuthar sub-basin area, under the TN-IAMWARM project in 2007-08 and 2009-10 (Veeraputhiran et al., 2010). Under this project, on-farm demonstrations of SRI techniques were carried out in 431 farms spread over 300 hectares in the Sivagangai and Madurai districts of Tamil Nadu. The results revealed that adoption of SRI techniques favourably influenced all yield attributes of rice, including the number of productive tillers produced per square meter and number of grains per panicle. A 26.7 per cent yield increment under SRI cultivation also demonstrated the superiority of SRI as compared with conventional methods of rice cultivation. Additionally, higher grain yield coupled with substantial water saving (approximately 23.6 per cent) resulted in higher water-use efficiency (WUE) of rice under the SRI methods.

Higher gross income, higher net profit and a more favourable B:C ratio were also positively associated with SRI. The cost of cultivation was comparatively less under SRI, leading to an additional net profit of Rs. 13,981 per hectare (Table 31).

Table 31. Comparison of SRI and conventional method of rice cultivation on grain yield, water use efficiency and economics

S. No.	Particulars	Pooled mean (2007-2010)	
		SRI	Conventional
1.	No. of productive tillers meters^{-2}	627	531
2.	No. of grains panicle^{-1}	216	185
3.	Yield (kilograms hectares^{-1})	5,485	4,329
4.	Per cent yield increase	26.7	-
5.	Total water use (mm)	1,061	1,360
6.	Per cent water saving by SRI	23.6	-
7.	Water use efficiency (kilograms hectares^{-1} mm^{-1})	5.18	3.15
8.	Cost of cultivation (Rs. hectares^{-1})	20,364	23,001

Source: Veeraputhiran et al., 2010

TNAU, Coimbatore, introduced SRI in the Pellaekothur village, Krishnagiri district, Tamil Nadu, through the TN-IAMWARM project (Ravichandran et al., 2009). Pellaekothur is a small village on the Hosur-Krishnagiri highway, which depends predominantly on agriculture for livelihoods. Krishnagiri is a newly-formed district, carved out of the backward Dharmapuri district. The village falls in the ayacut area of the Kelavarapalli reservoir (which serves areas in between the Pennaiyar and Krishnagiri sub-basins). Here, rice is the principal food crop.

Training was imparted to planting labourers, who mostly belonged to less resource-endowed families. Then, during planting, initially well-trained labourers were placed between two to three labourers to monitor and train the latter. In the first instance itself, 20 labourers were able to plant 1.8 acres in less than four hours. The most striking part of this is that by following the SRI methods, the labour requirement dropped by 50 per cent. While under the conventional method, 40-45 labourers are required to plant one hectare, only 20-22 labourers were needed to complete the same task under SRI methods. The women of the farm were acquainted with the usage of mechanical weeders and taught how to operate them. This led to an additional reduction in labour for weeding (about 30 per cent).

Table 32. Yield increase in SRI over conventional rice cultivation in Tamil Nadu under TN-IAMWARM project

SRI (kilograms hectares^{-1})			Conventional (kilograms hectares^{-1})			Per cent increase over conventional
Min	Max	Mean	Min	Max	Mean	
8047	6477	7275	6048	4708	5375	35.3

Source: Ravichandran et al., 2009

*Yield observations in 16 localities across Tamil Nadu in 7973 hectares

SRI methods helped in increasing the rice yield by more than 33 per cent, while the farmers' income increased by about 35 per cent. Water was saved by about 33 per cent by following AWD irrigation methods. The community action facilitated better social relations within the farming community.

5. STRENGTHS-WEAKNESSES-OPPORTUNITIES-CONSTRAINTS ANALYSIS FOR SRI

In recent years, rice farmers have become unmotivated and frustrated with the constraints of rice cultivation. There is a tendency to abandon rice cultivation and either cultivate difference and diverse crops or leave agriculture entirely. Another consequence of these pressures is that many traditional rice farmers are selling their lands for real estate development. It is crucial that rice cultivation be revitalised with proper management practices that address the diverse problems encountered by farmers. There is a need to usher in sustainability for rice farming. Although SRI has generally been identified as a solution for present-day constraints, for a technology to be viable, its strengths and weaknesses have to be identified and analyzed to maximise its benefits.

5.1. Strengths and Opportunities

5.1.1. Reduced cost of cultivation

SRI farmers use 5-8 kilograms of seeds as compared to conventional farmers, who require 40-50 kilograms. Such cost saving is particularly significant for the spread of hybrid rice, as the price of its seeds is almost ten times the price of non-hybrid rice (Barah, 2009). A substantial reduction in cost of cultivation is experienced also owing to the following:

- Nursery area (to plant one hectare) is reduced from 800 square meters to 100 square meters.
- Seed requirement is reduced from 30-60 kilograms to 5.0-7.5 kilograms per hectare.
- Nursery maintenance time is reduced from 25-30 days to 10-14 days.
- Nursery costs are reduced by 68 per cent.
- Seedling pulling cost to remove plants from the nurseries is reduced from Rs 800 to Rs 150.
- Labour requirements for planting is reduced from 60 to 35 man-days.
- Labour requirement for weeding is reduced considerably as well.
- About 30 per cent of water is saved due to AWD irrigation methods.
- Savings of electricity for pumping and of labour costs for irrigation occur as well.

5.1.2. Use of mechanical weeders

The use of the mechanical weeder – either the cono weeder or the rotary weeder – is one of the critical steps in SRI and should be carried out from 10 DAT at weekly intervals for the next 40 days. For a single weeding of an acre, three labourers are enough. The frequent disturbance of the soil leads to an improvement of the physical and chemical and biological properties of the soil. Root pruning triggers tillering, resulting in the bursting out of tillers. Mechanical weeding should never be disregarded, because it is the main cause of higher yield under SRI. It adds nutrients and organic carbon to the soil, activates the soil microbial, physical and chemical dynamics and, further, enhances root activity during weed incorporation.

5.1.3. Square planting with wider spacing

High density among plants inhibits their growth and performance. It is crucial to recognise that spacing needs to be optimised rather than maximised so as to get the greatest number of large and fertile panicles per unit area. Therefore, square planting with 25x25 centimetre gaps between seedlings ensures that the plants will have enough space for the efficient utilisation of resources. Additionally, it makes it easier to use the cono- or rotary-weeders in both directions for more efficient weed management. Although it appeared that the labour requirement for transplanting in SRI would be high, recent practical experiences have showed that where farmers used to engage 45-75 labourers for conventional planting, they now need only 22-48 labourers for SRI square planting, the average being 60 and 35, respectively – a big reduction.

5.1.4. Saving of water

SRI becomes the more attractive alternative particularly in the context of water saving due to AWD irrigation, which leads to the same or more yield, especially in the rain fed areas where water is available at a premium. Irrigation, measured by the number of irrigation days, has shown a substantial decrease and corresponding saving of water, with SRI practices. The average water saving is 37 per cent, but varies from 22 per cent to 38 per cent across various farms of different sises. Negligible inter-farm variation implies equity in water use. Under acute scarcity of precious water, the water saved may be used to irrigate more areas or for more crops (Barah, 2009).

5.1.5. Increased productivity

Undeniably, an increase in rice productivity under the SRI techniques over the conventional system of rice cultivation is observed. In a farm survey conducted among various size categories, the yield varied from five tonnes per hectare to 7.5 tonnes per hectare under SRI, as against the reported average of 3.45 tonnes per hectare under the conventional method. It was seen that small farmers in particular benefited from the increase in yield from SRI methods (Barah, 2009). The increase in yield due to SRI practices has been found to vary from four per cent to 26 per cent across different farm size groups (Table 33). Although the yield across different farm sizes is neutral to scale under both practices, the yield is 15-20 per cent higher for farmers in SRI than in non-SRI practices.

On an average, 28-37 per cent increase in rice productivity in SRI was registered consistently under the TN-IAMWARM project. This favourable transformation was achieved under the SRI mode of cultivation due to the use of young and single seedlings, wider spacing, weeder operations and AWD irrigation. All of these have been found to have a positive influence on the growth of plants as well as on soil dynamics in a manner that is not found in the conventional system at all.

Table 33. A comparison of rice yield with and without SRI across farm-sise in selected districts of Tamil Nadu

Farm sise	Coimbatore		Kanchipuram		Ramanatha puram		Tanjore	
	SRI	Non-SRI	SRI	Non-SRI	SRI	Non-SRI	SRI	Non-SRI
Marginal	6.20	5.95	6.83	--	5.08	4.03	5.10	4.70
Small	6.48	6.06	6.48	5.46	5.08	4.25	5.18	4.90
Medium	6.42	6.17	6.42	5.34	5.16	4.38	4.95	4.71
Large	7.00	--	6.30	5.25	--		5.03	4.80

Source: Barah, 2009

5.1.6. Socio-economic benefits

A study was conducted in Tamil Nadu to evaluate the performance of SRI methods on farmers' fields with the objectives of evaluating the economic and ecological advantages of SRI practices and quantifying the impact of input savings (land, water, farmers' time and seeds) on production efficiency, particularly among the small farmers (Barah, 2009). Farmers derived multiple benefits from SRI, including a higher yield, less input–cost and higher income, when compared with conventional farms.

Table 34. A comparison of costs and return with without SRI in Tamil Nadu

Particulars	Coimbatore		Kanchipuram		Ramanatha puram		Tanjore	
	SRI	Non-SRI	SRI	Non-SRI	SRI	Non-SRI	SRI	Non-SRI
Seed cost (Rs. hectares^{-1})	504	1,800	187	2,250	562	2,160	217	1,575
Labour cost (Rs. hectares^{-1})	9,546	12,705	7,988	11,990	4,960	9,111	10,715	11,524
Yield (t hectares^{-1})	6.52	6.07	6.54	5.41	5.10	4.25	5.06	4.76
Total cost (Rs. hectares^{-1})	16,774	20,283	16,604	18,938	11,589	15,953	16,699	19,010
Gross income (Rs. hectares^{-1})	33,329	34,848	34,233	32,325	27,745	25,216	31,575	31,653
Net income (Rs. hectares^{-1})	16,555	14,564	17,629	13,386	16,145	9,263	14,875	12,643
Cost (Rs. q^{-1})	261	335	257	350	229	376	331	400
Benefit cost ratio	1.99	1.72	2.06	1.71	2.39	1.58	1.89	1.67
No. of irrigation	24	34	25	34	25	32	20	33
Saving (%)	28		27		22		38	
Adoption of SRI (%)	45		18		20		59	

Source: Barah, 2009

On the whole, the combined effect of reduction in cost and higher yield has resulted in an increased net return (31 per cent). The average cost of production has been worked out to be Rs 269/-per quintal of rice under the SRI practice and Rs 365/- per quintal under conventional practices. This is an advantage of 26 per cent (Table 34). The net income recorded with SRI is Rs 22,985/- on average, which is Rs 11,492/- higher than the income accrued from conventional methods of rice cultivation. In terms of capital investment, intervention of SRI technologies resulted in savings of Rs 2369 in labour- and input-costs per hectare (TN-IAMWARM, 2009).

5.1.7. Equitable gender participation

This is an important benefit of SRI, which is particularly observed in specialised operations such as the transplanting of tender seedlings, harvesting and weeding. Women labourers find the ergonomically-manufactured weeders more user-friendly. Moreover, skilled labourers earn higher wages in specialised operations. The use of family labour is higher in SRI, varying from 38 per cent to 49 per cent of the total labour used, while the same varies from seven per cent to 37 per cent under the conventional practices.

5.1.8. Scope for mechanisation

Although there is greater yield advantage in SRI, the dependence on manual labourers remains an unsolved problem. SRI in fact it takes additional manpower during the early stages of adoption, because the execution of the project relies on skilled technicians. Since the SRI method of cultivation is being promoted on a large scale, there is great interest in for mechanisation of SRI, particularly its transplanting and weeding operations, with the help of mechanical transplanters and power-operated weeders.

The measurement of efficiency is a derivative of the input-output relationship at a particular point of time. Technical and economic efficiencies were estimated using the Data Envelopment Analysis Program (DEAP) in a linear programming framework (Barah, 2009). The farmers using SRI practices were found to be more efficient as compared to farmers using conventional practices for rice cultivation across differently sized farms in selected districts. SRI farms demonstrated higher technical as well as economic efficiency as compared to conventional methods (Table 35):

Table 35. Relative efficiency of SRI and non-SRI farms in Tamil Nadu

Particulars	Technical efficiency				Economic efficiency			
	Marginal	Small	Medium	Large	Marginal	Small	Medium	Large
Coimbatore								
SRI	0.95	0.98	0.97	1.00	0.87	0.93	0.90	0.96
Non-SRI	0.70	0.71	0.74	na	0.61	0.61	0.63	--
Kanchipuram								
SRI	1.00	0.96	0.94	0.90	1.00	0.91	0.88	0.84
Non-SRI	--	0.84	0.82	0.80	na	0.62	0.60	0.61

Particulars	Technical efficiency				Economic efficiency			
	Marginal	Small	Medium	Large	Marginal	Small	Medium	Large
Ramanathapuram								
SRI	0.88	0.93	0.93	Na	0.75	0.76	0.73	--
Non-SRI	0.79	0.68	0.86	na	0.50	0.49	0.52	--
Tanjore								
SRI	1.00	0.97	0.96	0.91	0.89	0.90	0.86	0.78
Non-SRI	0.72	0.69	0.66	0.62	0.55	0.55	0.50	0.50

Source: Barah, 2009

5.1.9. Other benefits

- The seedlings establish themselves quickly without a prolonged period of transplanting shock.
- There is enhanced and profuse root activity during the entire growth period, especially during later growth stage. This is an important physiological characteristic of rice plants grown with SRI. In flood-irrigated rice cultivated, roots become brown and less active after panicle initiation.
- Profuse tillering occurs due to constant stirring of soil with the mechanical weeder from 10 DAT onwards.
- Leaves remain green until harvest, accruing higher photosynthetic activity during the grain filling period.
- There is less lodging of water even during heavy rains.
- There are higher number of productive tillers, number of grains per panicle and less sterility.
- Farmers have also realised that the conservation of water and soil ensures long-term sustainability. On account of early transplanting of 8-12-day-old seedlings, vis-à-vis 30-40-day-old transplants in the case of conventional practices, SRI practice reduces the length of the growing period. The land is vacated at least 20 days sooner due to the earlier harvest, which can potentially lead to crop diversification and crop intensity.
- SRI insists on the use of organic manure, green manure and other biological sources for nutrient supplementation. Thus, the use of expensive fertilisers and other agro-chemicals is minimised, which is a cost-saving advantage.

- It has been observed that incidence of pests and diseases is less in SRI, due to sturdy, hard stems and leaves that repel insects.
- SRI is the most suitable option in the rabi season, which is relatively risk-free. In addition, it also provides an opportunity for greater employment of family labour, which remains idle during the growing season.

5.2. Weaknesses and Constraints of SRI and Tangible Measures to Overcome Them

5.2.1. Lack of scientific knowledge-base of the farmers

Although most of the rice-growing farmers now know about SRI, they are still unaware of the scientific facts behind each component thereof. A questionnaire-based survey in an area in Krishnagiri district, (Krishnagiri and Hosur Taluks), where SRI practiced had been adopted, revealed that only 18 per cent of the respondents had adopted the technique for more than five seasons. Additionally, 24 per cent had adopted it for three to four seasons, while more than half (58 per cent) had adopted SRI system for only one to two seasons (Alagesan and Budhar, 2009).

Table 36. Percentage of adoption of SRI components

SRI components	Farmer respondents	Adoption (%)
Knowledge of SRI		
Aware	50	100
Not aware	-	-
Age of seedling (d)		
12-15	15	30
16-19	28	56
25	7	14
Seedlings per hill (no.)		
Single seedling	43	86
Two seedlings	7	14

SRI components	Farmer respondents	Adoption (%)
Spacing		
22.5x22.5 centimeters	21	42
20x20 centimeters	7	14
Different spacing	22	44
Cono weeder operation		
Use of cono weeder	21	42
Not used	29	58
Use of leaf colour chart		
Aware	14	28
Not aware	36	72

Source: Alagesan and Budhar, 2009

It was interesting to note that all of the respondents said that they would follow the technology in the future. The reasons for discontinuing the practice were elicited through a multiple-response analysis. In the order of priority as perceived by the respondents, these were: lack of skill in handling 14-days old seedlings (i.e., difficulty in pulling and transplanting small seedlings); shortage of skilled labour for mat nursery preparation; poor coverage of planting area and labour; lack of appreciation of the importance of the cono weeder (i.e., a lack of understanding of the advantages of soil stirring, aerating the root zone as well as incorporating the weed matter into the soil); non-availability of cono weeders; non-availability of the LCC; and lack of skill in interpreting LCC and performing cono weeder operations. Thus, despite efforts made through many outreach programmes, the lack the knowledge about some SRI components makes wide adoption of the practice difficult to achieve. Hence, there is a need to train the farmers and to provide them with more information about the advantages of each SRI component.

Measures to overcome:

- Field demonstrations should be carried out with all the components of SRI in each village in an easily accessible area.
- Field visits to SRI farms should be conducted at the time of harvest.
- Exposure visits should be arranged more frequently.

5.2.2. Lack of skill in raising mat nurseries

Since young seedlings are to be planted in the main field, it is obvious that care must be taken to acquire healthy and sturdy seedlings within 14 days. The roots of these young seedlings are sensitive and should not be damaged while pulling. Therefore, the preparation of the nursery with a suitable medium requires skill. Nurseries for SRI practices can be raised according to local preferences, availability and suitability of resources.

Measure to overcome:

Community Nursery: The establishment of community nurseries should be advocated and promoted as a means to make sure that SRI practices are adopted. It is certain that the role of community nursery would have great success in promoting and establishing SRI practices in the coming years, for they would be able not only to bring more areas under SRI cultivation but also to reduce the cost involved with nursery labour, maintenance and mechanised transplanting.

5.2.3. Apprehensions about planting single seedlings in squares

Most farmers consider transplanting in a grid to be tedious, which is a major impediment to the adoption of SRI practices, where transplanting seedlings into square grids is highly recommended. Preparing a square grid in the main field requires optimum soil moisture at the time of transplanting. If the soil moisture is too high or too little, transplanting in a square grid will not be possible.

Measure to overcome:

SRI Markers: Though the concept of square planting is seen as a tedious operation, the timely operation of SRI markers could make legible impressions over the field, facilitating square planting. This suggestion has been taken favourably by the farming community. In many areas, even without markers, farmers have started to transplant seedlings in a square grid with the help of ropes marked at appropriate spots.

5.2.4. Difficulties in the use of the rotary and cono weeders

Most of the problems related to the mechanical weeders pertain to the labourer using the weeder. At the field level, while some labourers experience no problems in using the weeder, others find it tedious to operate, mainly due to a lack of training in using weeders correctly according to the soil type. In some of the SRI-adopted areas, modifications in the design and usage of mechanical weeders are being made according to the soil type by the farmers themselves. This is a positive sign; its implication is that there is no apprehension when it comes to engaging with the technology. Rather, there is a desire to use the mechanical weeders to their full potential.

Measures to overcome:

- Square planting at wider spacing eases the problem that existed with mechanical weeding using the rotary weeder.
- The possibility of mechanising weeding should be explored to avoid the drudgery of the operation.

In the TN-IAMWARM project, the greater commitment and curiosity shown by the farmers was apparent from the way they responded during the cropping period, modifying the weeders according to their needs. Bashir Ahmed, an SRI farmer from the Varaghanadhi sub-basin, modified and used the single drum weeder effectively by placing a brick over the front float and moving the weeder continuously. Raju, a farmer from Thumbal (Vazhapadi, Salem, Tamil Nadu), modified the rotary weeder by removing the float in the front altogether. The weeder was then turned upside down to facilitate easier movement. Raju was then able to move the weeder back and forth, and left and right, while walking across the rows. By this method, the total distance that the farmer needs to cover on foot in the field is reduced considerably. To plant one acre of the field, the labour requirement was about 13, with 10 persons for planting, two for holding ropes and one for supplying the seedlings. The time taken for SRI planting in this manner was 4.5 hours per acre.

5.2.5. Farmers’ apprehensions about single-seedling-transplantation

Farmers whose fields make use of canal irrigation cannot follow AWD irrigation, because they do not have control over the water supply. Since transplanting younger seedlings is expected in SRI, there is a general apprehension that uncontrolled irrigation would damage the younger seedlings, especially in areas with heavy rainy days.

Measure to overcome:

In situations where the problem is that of mortality of seedlings due to salinity, excess water seepage or poor levelling, it is advised to transplant two seedlings instead of one. This does not lead to any reduction in yield.

5.2.6. Non-availability of implements

Limited availability of implements for square transplanting and weeding is a great impediment to the popularisation of SRI on a large scale. Measures must be taken to make these implements available to the farmers locally.

Measure to overcome:

- Rural Artisan Training: The key to the spread of SRI in rural areas are the cono weeders, rotary weeders and SRI markers. Training must be imparted to rural artisans or Self Help Groups SHGs for using and servicing of these key inputs. This will ensure the timely supply and the availability of these machines.

5.2.7. Inability to provide controlled irrigation

The less water-consuming AWD irrigation is sensitive to water stress, and farmers strongly depend on a reliable source of water to compensate for unexpected dry spells and the dry season. AWD can thus only be achieved through highly permanent irrigated infrastructure. In many rice-based systems, a great part of water enters the field as canal irrigation, surface irrigation or spills over from adjacent fields.

Measure to overcome:

- Care must be taken both to ensure continuous supply of moisture during dry spells as well as to drain excess moisture during wet spells in the canal cascade system of irrigation.

5.2.8. Lack of precise land levelling

Transplanting and water management requires a higher level of perfection in levelling the field. The field must be levelled with great care to avoid any trauma to the young seedlings and water stagnation that leads to the rotting of seedlings.

Measure to overcome:

- Care may be taken to ensure proper levelling of the land with the help of a tractor-mounted land leveller.

6. POLICY IMPLICATIONS

The SRI method of cultivation not only increases rice yield, but also improves the efficiency of land and labour use, reduces production costs and increases sustainability. Exploitable yield gaps in rice can be improved effectively by using SRI strategies, through adopting participatory and holistic approaches:

- The gaps between the yield at research stations and the yield in farmers' fields are still substantially large due to gaps in initiatives, resources and extension outreach programmes. Bridging these gaps would improve the productivity and efficiency of rice production and, eventually, lead to food security.
- The crop management practices in SRI are seldom static and must often be adjusted to soil and environmental conditions. There is a strong need to understand, standardise and propagate interactions between crop varieties, environmental conditions and crop management practices.
- The first batch of SRI farmers are in need of continuous guidance technically and operationally from the extension workers, for raising nurseries, marking the field, transplanting and weeding.
- The National Rural Employment-guarantee Programme (NREGA) has caused greater constraints in the availability of agricultural labour for regular farm operations. In this context, SRI, which demands technically sound labour, is unable to progress.
- There has not been much progress on the researchable issues related to SRI even after five years of its inception and acceptance by Indian farmers.
- Big farmers, who depend mainly on hired labour, find it difficult to tackle the initial resistance raised by labourers. Greater work and the need for continuous monitoring in the field makes them reluctant to take up SRI in large areas.
- There is a need to promote close collaboration between researchers, extension personnel and the stakeholders so as to identify the specific practical constraints of SRI practices and to work out location-specific technologies and solutions.
- Institutional and policy support to farmers is crucial for ensuring that they obtain agricultural implements and inputs required for SRI.

7. CONCLUSIONS

Rice has been a major part of people's lives for centuries in most parts of the world. However, major constraints in rice-based systems have cast a shadow of doubt on the sustainability of rice cultivation. These constraints have assumed greater importance in the context of unsustainable resource utilisation, mounting production costs and decreasing profitability. There is a need to make the crop more competitive. The diversity of rice cultivation systems makes it difficult to adopt a common path of transformation across the globe.

So far, experiments in rice management systems have been aimed mostly at maximising yield. This should be extended towards the effective and economic utilisation of resources such as land, water and labour. A holistic system-based approach could help resolve the production constraints and deploy sustainable technological developments to maximise returns. The System of Rice Intensification (SRI) is one such holistic approach, integrating the aforementioned measures in rice production.

While working through this compendium, it might have been observed that the conclusions drawn about SRI are consistent. An appropriate holistic approach will include location-specific concepts, well-crafted policy interventions, a thorough understanding of the farmers' actual constraints, refining SRI technologies with possible mechanization and increasing the level of adoption in an integrated manner with adequate institutional support for farmers. Such integration could have a very desirable impact on the successful implementation of SRI. Although SRI could be a viable antidote to many hazards besetting rice farming in Tamil Nadu, increased understanding and acceptance of the components of SRI amongst the farmers and thereby increasing their participation in modifying and further improving SRI methods should be a part of transforming outputs to suit exact environmental and socioeconomic needs.

Thus, there is a need for a more effective linkage mechanism, which can be achieved through close collaboration between research, extension personnel, stakeholders, non-governmental organisations and the private sector, aimed at identifying, developing and publicising location-specific technologies and taking concerted actions to bridge the gaps mentioned above through a participatory approach. An effective technology transfer and linkage mechanism is of vital importance. Moreover, institutional and policy support to farmers is crucial for ensuring SRI inputs and implements (such as, dapog or mat nurseries, markers, mechanical weeders, etc.,) supplies, farm credit, price guarantees and adequate marketing systems for sustainable and increased production.

Clearly, scientific facts required for the evaluation and refining of SRI methods needs to be experimented with and explored further. Researchers need to pay attention to the insights and principles for attaining higher yield with SRI methodology to fill in fundamental knowledge gaps and to address the synergies of individual SRI components for diverse rice production systems. It is quite obvious that there are no shortcuts to achieving an increased and sustainable crop yield. Hence, comprehending the complexity of plant growth and yield under SRI management needs further critical appraisal through detailed research.

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ABOUT THE NATIONAL CONSORTIUM OF SRI (NCS)

The National Consortium on SRI is a coalition of practitioners, policy makers, resource institutions and scientists, who are keen to spread SRI on a large scale in the country. The NCS is conceptualized as a think-tank and resource-pool in which the members have come together voluntarily to advance the science, strengthen practice and take up policy advocacy in favour of SRI.

1. **Science of SRI:** This includes the identification of the enabling factors for the full expression of the genetic potential of the rice plant; conservation of natural resources; reduction in cost of cultivation; and improvement of soil health and nutrient mining.
2. **Practices of SRI:** This includes an evaluation of the tangible benefits of SRI; understanding the realities of adopting and dis-adopting SRI practices; measuring the efficiency and efficacy of the use of inputs and conservation of resources such as seeds, water, fertilisers and labour as well as organic supplements; design and spread of suitable implements; and preparation of user friendly tools and resource materials.
3. **Policy on SRI:** This includes influencing mainstream programmes and strategies for scaling up SRI; advocating for an innovative institutional architecture of extension for wider adoption and impact; convergence of multiple programmes; and evolving new forms of partnerships.

Future Road Map of the NCS:

1. Evolve more insights into the science of SRI and other similar agro-ecological innovations to drive the new green revolution
2. Take up action research on the farm in collaboration with scientists and practitioners including farmers, to pilot new ideas
3. Develop more clarity on the social impacts of SRI techniques Evolve strategies for capacity building of stakeholders on an ongoing basis
4. Advocate for supportive policy strategies.

This publication is an effort by the NCS in showcasing to the world the current state-of-the-science on SRI. This book presents before the policy and scientific audiences, a synthesis of various Indian scientific works on SRI.

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