SRI

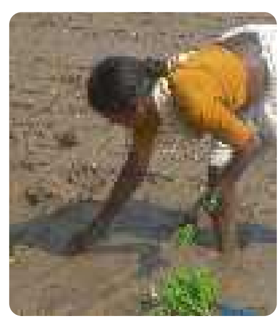
Transforming Rice Production with SRI (System of Rice Intensification) Knowledge and Practice

Reducing Agriculture Foot Print and Ensuring Food Security

T.M.Thiyagarajan

Biksham Gujja

2012


NATIONAL CONSORTIUM OF SRI (NCS)

AgSri

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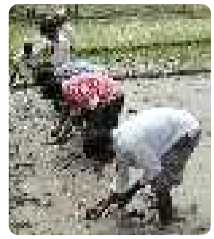
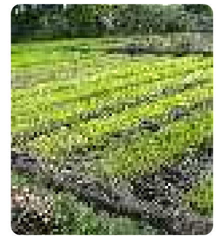


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ACKNOWLEDGEMENTS

SRI is known in India since 2000. The awareness on SRI to the scientific community had been very lukewarm and limited to a few individuals. When the benefits of SRI were known from field experimentations and evaluations in farmers' fields, SRI extension began slowly from 2003 onwards. Once Civil Society Organizations showed their interest in promoting SRI there has been a tremendous boost to popularize SRI. Unfortunately there has been very little research interest on the innovative principles of SRI that could be applied to other crops also. Today SRI is known in all rice growing areas of the country but the adoption by rice farmers has been limited to some areas where there is sustained extension campaign. Policy support has been extended by some state Governments but a national thrust is still evading.

The benefits of SRI is multifold, especially in resource conservation (water, land, energy, seeds and labour), rice production and addressing the challenges of climate change. Thus, SRI requires a serious attention from national policy makers.

Being a knowledge intensive approach rather than input intensive modern agriculture, adoption of SRI by farmers requires several knowledge disposal mechanisms and hands on experience in carrying out the SRI practices. Though the effect of SRI principles on the rice soils and rice crop is still to be understood more thoroughly, sufficient scientific explanations are available on the better performance of rice crop under SRI.

This book is an attempt to explain the origin, principles and practices of SRI and the developments so far in communicating the importance of SRI to rice farmers, students, scientists and policy makers so that the material could be used for extension, research and policy support. The contents have been assembled from various sources, especially from SRI websites, WWF-ICRISAT project and its partner organizations and Institutes, presentations made in national SRI symposia, publications and reports on SRI, field visits and interaction with farmers.

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Some of photos included in this book are sourced from power point presentations and websites and we place our sincere thanks to the concerned authors.

We are grateful to all the colleagues Dr.V.Vinod Goud, Dr. N. Loganandhan, Mr. Sraban Kumar Dalai, Ms.Manisha Agarwal, Mr. TVVV Rao and Ms. R.Suhasini of the former WWF-ICRISAT Project and AgSri who have offered their support in several ways. Our special thanks to Dr.V.Vinod Goud for his sustained interest and help in completing the process of bringing out the book.

We express our sincere gratitude to Dr.M.S.Swaminathan, Dr.Ayyappan and Dr.Norman Uphoff for readily agreeing to write the foreword.

T.M. Thiyagarajan

Biksham Gujja

FOREWORD

Rice is life to a majority of people in Asia. The cultivation of rice represents both a way of life and a means to livelihood. Enormous progress has been made since World War II in improving the productivity and profitability of Indica rice. Such progress has been due to the development of semi dwarf, non-lodging and photo insensitive strains based on the DEE-GEE-WUN gene from China. Later, hybrid rice became a reality, thanks to the identification of cytoplasmic male sterile genes from Hainan Island in China. Higher yields also require higher inputs, particularly fertilizer and pesticides. Breeding for high yield should therefore be accompanied with methods of feeding the rice plant for high yield. This has to be done in a manner that the contribution of rice to climate change is minimized. Also, environmental problems associated with the excessive use of fertilizer and pesticides will have to be avoided.

About 25 years ago, when I was at the International Rice Research Institute, I organized a meeting jointly with the World Health Organisation on methods of avoiding the breeding of malarial mosquito in rice fields. We came to the conclusion that it will be important to introduce alternate drying and wetting in the field, so that the mosquito breeding cycle is disrupted. Flood irrigation will have to be avoided. These approaches led to the development of the Asian Network on Sustainable Rice Farming. Meanwhile, thanks to the tireless efforts of Dr Norman Uphoff of the Cornell University a procedure of rice agronomy knows as "The System of Rice Intensification (SRI)" was developed. The present publication gives information on the work done by Drs Thiyagarajan and Dr Biksham Gujja on the development of the SRI System of rice cultivation. SRI helps to reduce the quantity of irrigation water needed and also involves much lower seed rate. When properly adopted, SRI helps to increase yield and income per drop of water.

This method originally developed in Madagascar has now spread in various rice growing countries. It will be particularly suitable for adoption in conjunction with hybrid rice since there will be considerable saving on seed rate. I hope this timely book will be read widely and used for increasing the productivity, profitability and sustainability of rice farming in our country. The techniques described in the Book are particularly relevant in the context of climate change. Therefore, SRI should become an important component of climate resilient agriculture.

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FOREWORD

The System of Rice Intensification (SRI) technology emphasizes on making effective utilization of resources, especially water and use of organic manures. System of rice intensification is a technology development to save water and also enhance the rice yield. The main feature of the method is raising raised bed nursery, transplanting young 8-10 day old seedling with a wider spacing, maintaining water to saturation level, weeding and incorporation weeds in the soil and application of organic fertilizers. System of Rice intensification is primary aimed to save water. Tamil Nadu Agricultural University (TNAU) first SRI introduced in India in 2000 when researchers at the initiated experiments involving SRI principles in a collaborative project on growing rice with less water. The results of experimentation and their validation on farmers' fields revealed an average increase in grain yield by 1.5 tons/ha in both basins with reduced input requirements and even 8% reduction in labor requirement. This evaluation provided a basis for officially recommending SRI adoption to farmersin2004. The area under SRI increased in Tamil Nadu from 4.209 mha during 2007-08; to 8.160 mha by 2010-11 with average yield of 7-8 MT. Significant yield increases under SRI over conventional irrigated rice cultivation, generated nationwide interest.

The SRI results in saving of 30-40% irrigation water; 85% in seed, chemical fertilizer, and promotes soil microbial activity which improves the soil health. SRI even offers advantages for seed multiplication. On account of multiple advantages, the SRI is gaining popularity in several states.

The present publication entitled "Transforming Rice Production with SRI Knowledge and Practice" covers all majors topics of SRI such as Main field preparation and Transplanting; Water Management; Nutrient Management; Weed Management; Pests and Diseases in SRI; Effects of SRI on soil and Crop; Benefits of SRI; Sri Extension, Adoption and Constraints; and Rice Market.

The efforts of Dr. T.M. Thiyagarajan , Former Director (Center for Soil and Crop Management Studies), Coimbatore and Former Dean, Agriculture College & Research institute, Killikulam and Dr. Biksham Gujja, Founder and Chairman of AgSri deserve appreciation for compiling latest information on this important subject for sustainable rice cultivation in india. It is hoped that the publication will be prove to be highly useful to the researchers, students, development officials and farmers, alike.

S. Ayyappan

Director General

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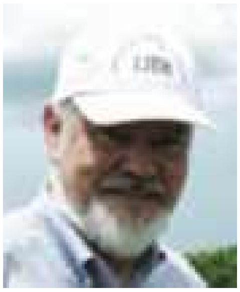
New Delhi

13th January, 2012

FOREWORD



'Rice is life' has become a worldwide mantra since the International Year of Rice in 2004. This is true more for India than for most other countries, as explained in this book. However, it is also true that both rice and life are now in some peril because of a confluence of trends that could become 'a perfect storm' with terrible consequences.

The rice sector in most countries but especially in India faces diminishing quantity and quality of both the land and water resources that it needs for growing rice. Moreover, rice producers face rising costs forfertilizer and agrochemical inputs, and there are diminishing returns to fertilizer in many areas, with certain pests and diseases developing resistance to biocides. This makes the input-dependent strategies of 'modern agriculture' less cost-effective and less sustainable.

The constraints presented by climate change are growing year by year, with high and low extremes of both temperature and rainfall increasingly affecting rice and other crops. Monoculture and a shrinking pool of geneticresources have ratcheted up our vulnerability to crop failure,which is a possibleconsequence of the prevailinggenocentricstrategy for agricultural development. And overall, production shortfalls portend rising prices that will adversely affect one-third of the world's people who depend on rice for much of their sustenance, especially the poorest households in every country.

Some of these problems – declines in soil health and fertility, the cost-price squeeze affecting farmers, agrochemical pollution of water and especially groundwater – are directly associated with the technologies associated with the Green Revolution. While this produced many benefits for both farmers and consumers in the latter third of the previous century, this strategywas best suited to better-endowed regions and farmers,and it did not uplift lives across the board. In recent years, the yield gains fromthis technological approach have slackened while its associated costs, both economic and environmental, have been accumulating.

The question arises -- for researchers, for policy makers, and especially for farmers -- what should be done now for an encore? Can we succeed in meeting the food needs for our still-growing populations by doing essentially more of the same? Or must some other directions be developed?

As this book lays out, there is at least one very promising new path to pursue, one that applies and takes advantage of various agroecological principles and practices. The System of Rice Intensification (SRI)is not a new technology, not a fixed package of practices. Rather it is a set of ideas and insights, some old and some new, all focused on how to get more benefit from available resources. SRI concepts and methods are showing how to create better growing environments for rice and other plants, thereby raising the productivity of the resources -land, labor, water, seeds, and capital - that are already controlled by farmers.

This book places SRI's innovations in crop management within the context of Indian history and culture, moving from traditional rituals to contemporary pest and disease control, from local indigenous rice varieties to global marketing. It covers an encompassing range of topics, including specifics about how SRI can be utilized, and why its practices achieve the remarkable gains in productivity that are reported from most if not all situations.

The validity of SRI's alternative management principles has been demonstrated in a wide range of circumstances, from high mountain regions in northern Afghanistan (Thomas and Ramzi, 2011) to the edge of the Sahara Desert in the Timbuktu region of Mali (Styger et al., 2011), from the marshes of southern Iraq (Hameed et al., 2011) to the tropical conditions of The Gambia (Ceesay et al., 2007) and Panama (Turmel et al., 2011). This book presents SRI in the many and highly-varied contexts of India, which itself embodies a kind of global agroecological diversity.

Two of the persons who have given the most leadership to the introduction and spread of SRI in India have collaborated to produce this book. Rather than stand on the sidelines when they first learned about SRI opportunities, or become deniers without doing proper empirical evaluations, both in their respective states of Tamil Nadu and Andhra Pradesh took up the challenge of understanding and testing the claims and mechanisms of SRI. They sought to determine whether, where, to what extent, and at what cost, could the reported advantages of SRI management be achieved by farmers -- and how could these benefit farmers, consumers, and the environment.

Dr. T.M. Thiyagarajan, while director of Tamil Nadu Agricultural University's Center for Crop and Soil Management, was the first agricultural scientist in India to take SRI ideas seriously enough to test them under trial conditions, starting in 2000. He subsequently supervised on-farm comparison trials on a broader scale in the Tamiraparani and Cauvery river basins in 2003-04. Having demonstrated significant impacts convincingly --such as net income per hectare of $519 with SRI management compared with $242 using standard practices -- Thiyagarajan got the university, the state's Department of Agriculture, and then the World Bank's India office to become engaged with further evaluation and promotion of SRI, leading to Tamil Nadu's becoming the leading state for SRI in India.

Starting in 2004 in the neighboring state of AP, Dr. Biksham Gujja, a senior advisor for the Worldwide Fund for Nature (WWF) based in Gland, Switzerland, launched a three-year evaluation of SRI methods after he learned about SRI. This research was done under WWF's joint Dialogue Project on Food, Water and Environment with the International Crop Research Centre for the Semi-Arid Tropics (ICRISAT) in Hyderabad.The study involved scientists from the state's agricultural university (ANGRAU), the Directorate of Rice Research for the Indian Council for Agricultural Research (ICAR), and ICRISAT.

With extensive and systematic data confirming SRI advantages for both raising productivity and for saving water, taking pressure off already water-stressed ecological systems, Gujja with WWF support and then other agencies' contributions convened a series of National Colloquia on SRI – in Hyderabad in 2006, in Agartala in 2007, and in Coimbatoire in 2008 – to consolidate experience and learning about SRI from all over India.

By the third colloquium, with 350 participants coming from states and territories that represented>98% of India's population, the evidence was clear that Indian governments, NGOs, banks, private sector, and particularly its farmers should be capitalizing on the new opportunities that SRI was opening up for rice production, and even for other crops beyond rice.

This book shares with readers what Drs. Thiyagarajan and Gujja have learned about the Indian rice sector in general – its history, its constraints, its challenges – and about SRI in particular – its potentials, its mechanisms, its limitations, its variations, and its continuing evolution. They embrace and endorse the emphasis in SRI upon farmer participation and adaptation to local conditions, an approach rather different from that of the Green Revolution. This earlier strategy regarded farmers more as adopters than as adapters. SRI in contrast, rather than enjoining farmers to follow certain instructions, expects them to understand and utilize principles of good agronomy. Italso invites farmers to contribute to an ongoing a process of empirically-grounded improvement such as that which launched SRI in Madagascar under the guidance of Fr. Henri de Laulanié in the early 1980s.

I have been privileged to work with these fine colleagues and with many others like them in India over the past decade, and to work with them in the finalization of this book. The introduction, adaptation and spread of SRI in their country has been truly a collective enterprise with a great variety of individuals from many walks of life, from PhD agronomists to farmers to senior IAS officers to NGO workers to journalists to teachers, all contributing in their respective ways. The spread has been propelled by three powerful motive forces that are often underestimated: ideas, ideals, and friendship. These I learned about from a previous engagement with farmers and professional colleagues in Sri Lanka, seeking to introduce and improve participatory irrigation management there (Uphoff, 1996; Wijayaratna and Uphoff, 1997; Uphoff and Wijayaratna, 2000). The SRI experience has confirmed how potent these three factors, more mental than material, can be.

The SRI story is about more than agriculture; it is equally about people, their needs, their capabilities, their limitations, their altruism, and their creativity. It is about social, economic, cultural and other relational phenomena as much as it is about physical and material relationships. In many respects, SRI is about potentials – socio-cultural and bio-physical – and about the expression of potentials within plant seeds, within soil systems (Uphoff et al., 2006), and within human minds and spirits.

While we can gain much knowledge by working within certain areas of inquiry, usually delimited in disciplinary terms, there is much more knowledge beyond this to be gained by working across disciplines and even across domains as broad as the bio-physical, the socio-cultural, and the political-economic. Indeed, we can gain even more by working across sectors, institutions and statuses. SRI would not have reached its present stage without farmers themselves making important contributions to the improvement of SRI thinking and practice and to the dissemination of this innovation to peers.

SRI originated from the close working relationships between a French priest and hundreds of Malagasy farmers, all focused on drawing out the maximum productivity from plant seeds and from their supportive growing conditions. This kind of collaborative bond should be maintained and extended, beyond rice and to other areas where problem-solving and innovation are needed. The challenges of the 21st century, from food security and coping with climate change to creating productive livelihoods and achieving better governance, cannot be dealt with just through the endeavors of specialists, however diligent. While their knowledge needs to be expanded and utilized in our problem-solving efforts, the advances seen with SRI should encourage, even embolden us to proceed with more participatory, democratized enlistment of ideas and commitments from all walks of life.

I believe that India has opened enough doors and minds now in the 21st century that it can in the next few decades make up for many past deficits. India's human resources are immense. But they must, in the first instance, be adequately fed and nourished. The exploitation of SRI potentials will not solve all of the problems of India, or of any other country. But especially if the agroecological insights of SRI can make the production of rice and other food crops more efficient and more sustainable, surmounting these other challenges can become more possible. Conversely, if we cannot assure every personanadequate, inexpensive and healthful sustenance, it is unlikely that we can succeed with the many other challenges that we face. Jai SRI!

Norman Uphoff

Ithaca, New York, USA

November 17, 2011

1 RICE BASICS

For more than half of humanity, rice is life itself. Life and livelihood without rice is simply unthinkable. This grain has shaped the cultures, diets, livelihoods and economies of most of Asia.

Rice produces the maximum calories per unit of land among all the cereals, and this feature, combined with the capacity of rice plants to withstand inundation and their ability to adapt to varied climatic and agricultural conditions, accounts for the crop's importance. China, India and Indonesia, three of the four most populous countries in the world, are the highest producers and consumers of rice.

Rice ensures food security for people in many parts of the globe. This is reflected in the recent increases in rice production in Latin America and Africa, especially in the lower-income and food-deficient countries. In Europe, rice is the major crop in certain regions of Italy and Spain, and rice-based dishes are gradually substituting for other traditional dishes in Europe and the Americas, at least for some meals. Today, rice is widely consumed all around the world.

Rice is used in a number of different ways, sometimes far removed from its traditional uses that one would be aware of. It is used in the preparation of infant foods, snacks, breakfast cereals, beer, and fermented products. Brown (unmilled) rice is appreciated as a healthy food for the treatment of hypertension and Type II diabetes, and rice bran oil inhibits cholesterol synthesis and lowers blood pressure. Rice wine, traditionally prepared in Asia, is still the major alcoholic beverage in East Asia.

The coarse, silica-rich hulls or husks of rice can be used to make briquettes, construction material, and are even used as fuel. Rice straw, except from the modern varieties, is still an important cattle feed throughout Asia. Because rice flour is nearly pure starch and free from allergens, it is the main component of many infant formulas and face powders. Its low fibre content makes rice powder quite suitable for polishing camera lenses and expensive jewellery (http://jeanross.ricepurple.com/A/index.htm).

Rice is a versatile crop grown in all most all agro-climatic zones except at very high altitudes. The cultivation of rice as an important agricultural crop really began only after the techniques of puddling and transplanting developed. These techniques, used in rice paddy cultivation, were initially practiced in the wetlands of China and were later adopted in Southeast Asia, roughly 4,000 years ago. From thereon, these wetland cultivation techniques were embraced by people in Indonesia, and later in Japan, over the next 2,000 years. Rice spread to Europe at a much later date, with the invasion of the Moors in 700 A.D. In the last 400 to 500 years, rice travelled to the New World with the initial explorers and settlers (http://www.encyclopedia.com/topic/rice.aspx).

Rice is grown on an estimated 155 million ha in 114 countries, in an area lying between the latitudes 53° north and 35° south. Asia accounts for nine of the top ten rice-producing countries. Globally, the 55 percent of the area under rice cultivation that is irrigated contributes 75 percent of the total rice production (Photo 1.1)

Photo 1.1
Typical irrigated ecosystem in a delta

The name of the grain used globally, rice, probably has its roots in India. According to the Microsoft Encarta Dictionary (2004) and the Chambers Dictionary of Etymology (1988), the word 'rice' has an Indo-Iranian origin. It came to English from the Greek word *óryza*, via the Latin *oriza*, the Italian *riso*, and finally the Old French *ris*. It has been speculated that the Indo-Iranian word *vrihi* was itself borrowed from a Dravidian word *vari* or even from a Munda language term for rice; the Tamil name *arisi* could have given rise to the Arabic *ar-ruzz*, from which the Portuguese and Spanish word *arroz* originated (http://en.wikipedia.org/wiki/Rice).

1.1 Rice and India

Rice is not everything in India, but everything in most parts of India starts and ends with rice, from birth to death. It is an integral part of Indian culture. It is lifeline that has extended into more than 540 of India's 604 districts.

In India, rice cultivation probably began in the upper and middle Ganges between 2000 and 1500 B.C. It expanded quickly after irrigation works spread from Orissa State to the adjoining areas of Andhra Pradesh and Tamil Nadu in the Iron Age around 300 B.C. (http://www.cambridge.org/us/books/kiple/rice.htm).

Rice is first mentioned in the Yajur Veda (1500-800 BC) and then is frequently referred to in many Sanskrit texts, which distinguished summer varieties grown in the rainy season from winter varieties. Shali or winter varieties were the most highly regarded in times past. The name of Annapurna, the Hindu god of rice, comes from the Sanskrit word for rice, anna.

In peninsular India, there are numerous festivals connected with the sowing, planting and harvesting of rice. Major harvest festivals include Pongal in Tamil Nadu, Onam in Kerala, and Huthri in Coorg (Kodagu). Rice tinted with the auspicious yellow colour of turmeric is showered onto newly-married couples, and is part of numerous rites and celebrations. It is offered to the deities and used as an oblation in the sacred fire of Hindu ritual. Rice is used in many Indian celebrations, including weddings.

India is one of the richest countries in the world for diversity in rice varieties. There are so many different varieties of rice depending on variations in the weather, soil structure, plant characteristics, and purposes of use. According to Dr. R.H. Richharia, one of the most eminent rice scientists of the world to date, 400,000 varieties of rice probably existed in India during the Vedic period. He estimated that even now, as many as 200,000 varieties of rice exist in India, which is an exceptionally high number. Even if a person eats a new rice variety every day of the year, he can live for over hundred years without eating again the same variety. Every variety has a specific purpose and utility (http://www.rice-trade.com/).

Two rice species are the main cereals of importance for human nutrition: *Oryza sativa*, grown worldwide, and *O.glaberrima*, grown in parts of West Africa. Rice provides 21% of global human per capita energy and 15% of per capita protein. Cultivated rice is generally considered a semi-aquatic annual grass, although in the tropics it can survive as a perennial crop, producing new tillers from nodes after harvest (ratooning).

At maturity, the rice plant has a main stem and some number of tillers. Each productive tiller bears a terminal flowering head, called a panicle, with grains that are harvested when mature. Plant height varies by variety and environmental conditions, ranging from approximately 0.4 m to more than 5 m in some floating rice (Maclean et al. 2002).

The growth duration of rice plants ranges between 3-6 months, depending on the variety and on the environment under which it is grown. During this time, rice completes two distinct growth phases: vegetative and reproductive. The vegetative phase is the most variable, markedly influenced by day-length and temperature in photoperiod or thermosensitive varieties. Temperature and day length are the main determinants of total growth duration of any variety. A long-duration variety is characterized by longer vegetative phase than a short-duration one. The vegetative phase is subdivided into germination, early seedling growth, and tillering; the reproductive phase commences from panicle initiation and is subdivided into the time before and after heading, that is, panicle exertion. The time after heading is known as the ripening period. Reproductive and ripening phases are constant for most varieties.

Potential grain yield is primarily determined before heading, but actual yield, which is based on the amount of starch that ultimately fills the spikelets, is largely determined after heading. Hence, agronomically, it is convenient to regard the life history of rice in terms of three growth phases: vegetative, reproductive, and ripening. A 120-day variety, when planted in a tropical environment, spends about 60 days in the vegetative phase, 30 days in the reproductive phase, and 30 days in the ripening phase (ICAR, 2010; http://www.ikisan.com/Crop%20Specific/Eng/links/ap_ricegrowth.shtm).

1.2 Rice Production in India

India has the world's largest area devoted to rice cultivation, and it is the second largest producer of rice after China. Over half of its rice area is irrigated, contributing 75% of the total production. Notably, this area also consumes 50-60% of the nation's finite freshwater resources. Of the country's 1.15 billion inhabitants, 70% rely on rice for at least a third of their energy requirements. India's population is projected to grow to 1.6 billion in 2050, putting tremendous future strain on its land and water resources.

India provides around 21% of global rice production from its 28% of the world's rice area. Rice area in India has fluctuated fairly stably around 43 million hectares during the last two decades, with a maximum rice area of 45.5 million hectares in 2008-2009 (Figure 1.1). Total rice production was also the maximum during this year (99.2 million tonnes). Rough (unhusked) rice productivity, which was at 1,002 kg ha^{-1} in 1950-1951, reached a maximum of 3,303 kg ha^{-1} in 2007-2008. Interestingly, rough rice productivity during the early 20th century was around 1,600 kg ha^{-1}, declining to 1,139 kg ha^{-1} during 1940-1941 (Figure 1.2).

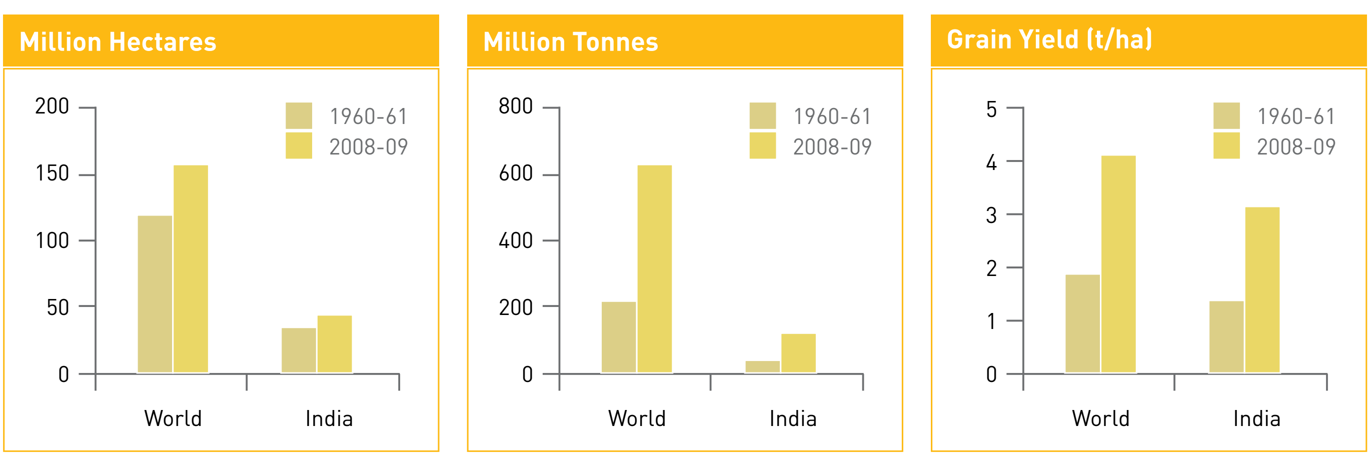


Figure 1.1 Rice area, rough rice production, and productivity in the world and India during 1960-1961 and 2008-2009.

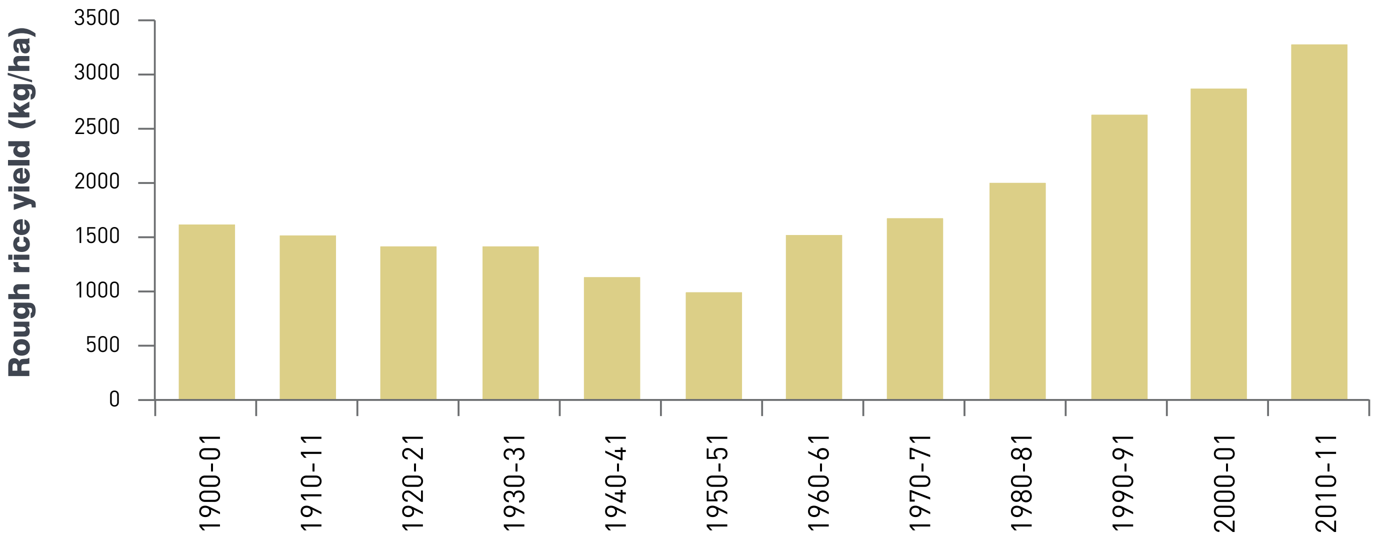


Figure 1.2 Rough rice yield in India since the beginning of 20th century. The data for 1900-1901, 1910-1911, 1920-1921 and 1930-1931 are averages for 1900-1901 to 1904-1905, 1910-1911 to 1914-1915, 1920-1921 to 1924-1925 and 1930-1931 to 1934-1935, respectively (Source: Baljit Singh, 1945. Whither Agriculture in India. N.R. Agarwal & Co, Agra). The data for 2010-2011 are estimates.(Source: Directorate of Economics and Statistics, Agricultural Statistics at a Glance 2010, Department of Agriculture and Cooperation, Ministry of Agriculture, Govt.of India, New Delhi.)

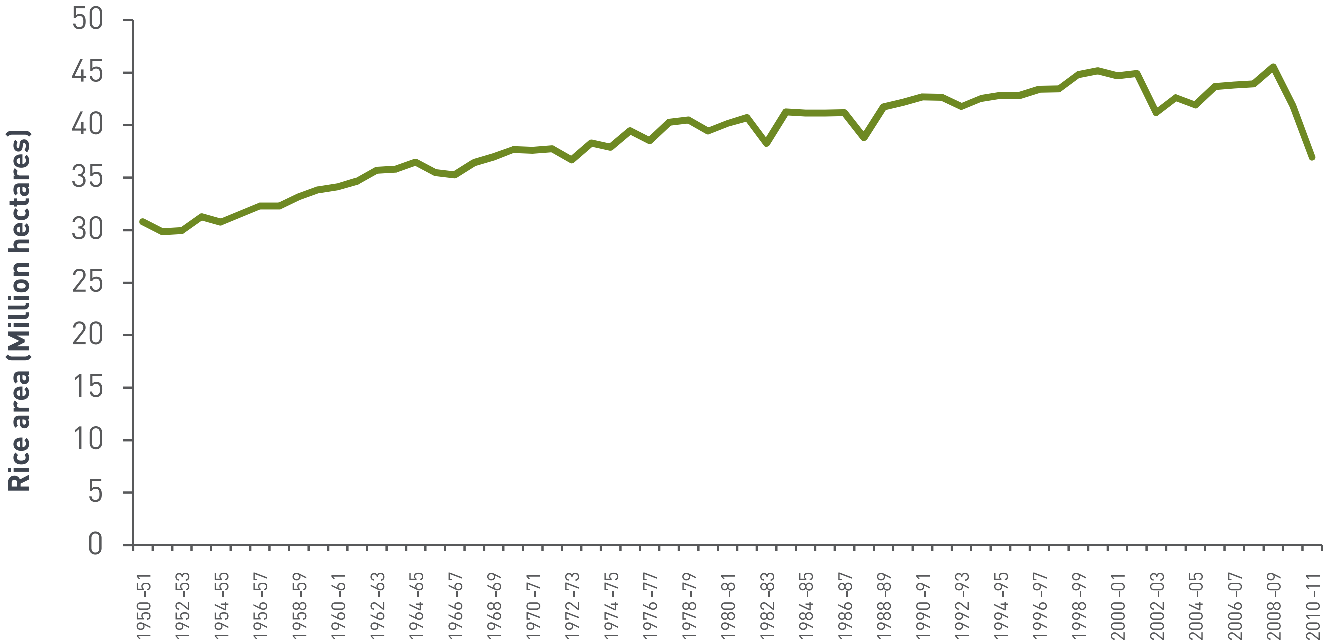
In India, rice is grown mostly in two major seasons, kharif (June – October) and rabi (October – February),while in some parts it is grown throughout the year in more than two seasons. Most of the rice area and production are in the kharif season (Table 1.1), but rice productivity in terms of yield is 57% higher in the rabi season.

Grain production in the mid-1960s, before the Green Revolution began, was about 60 million tonnes per annum. Thirty years later, production had grown to twice that, around 120 million tonnes, but the pace of growth has slowed since the late 1990s (Figure 1.3). The highest annual average increase in grain production was 6.1%, recorded during the 1980s; but the annual increase in grain production dropped to 1.5% in the 1990s.

Table 1.1 Rice area, production, and productivity in kharif and rabi seasons in India (2005-2006)

Season	Area (m ha)	Rough rice production (m tonnes)	Rough rice productivity (kg ha^{-1})
Kharif	39.3	117.3	2,985
Rabi	4.3	20.0	4,691

Source: Rice in India: A Handbook of Statistics. 2007. Directorate of Rice Development, Patna)


Rice area (Million hectares)
50
45
40
35
30
25
20
15
10
5
0
1950-51
1952-53
1954-55
1956-57
1958-59
1960-61
1962-63
1964-65
1966-67
1968-69
1970-71
1972-73
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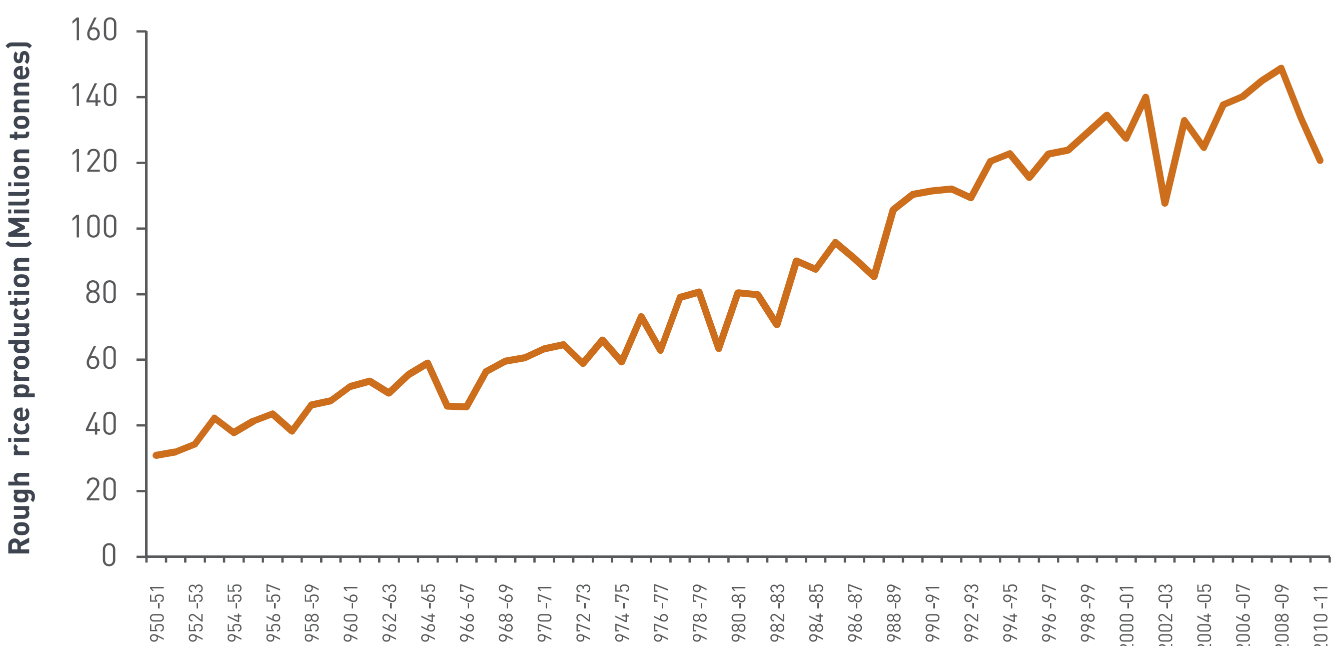
Rough rice production (Million tonnes)
160
140
120
100
80
60
40
20
0
1950-51
1952-53
1954-55
1956-57
1958-59
1960-61
1962-63
1964-65
1966-67
1968-69
1970-71
1972-73
1974-75
1976-77
1978-79
1980-81
1982-83
1984-85
1986-87
1988-89
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1994-95
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1998-99
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2002-03
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2006-07
2008-09
2010-11

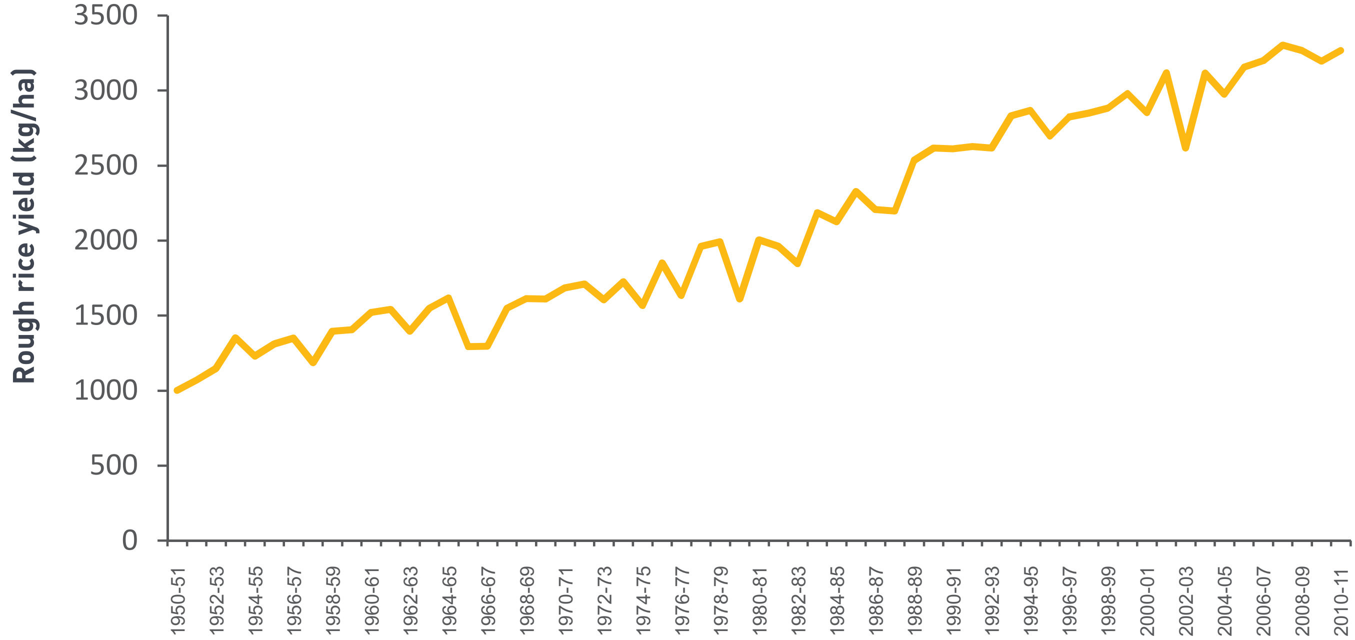
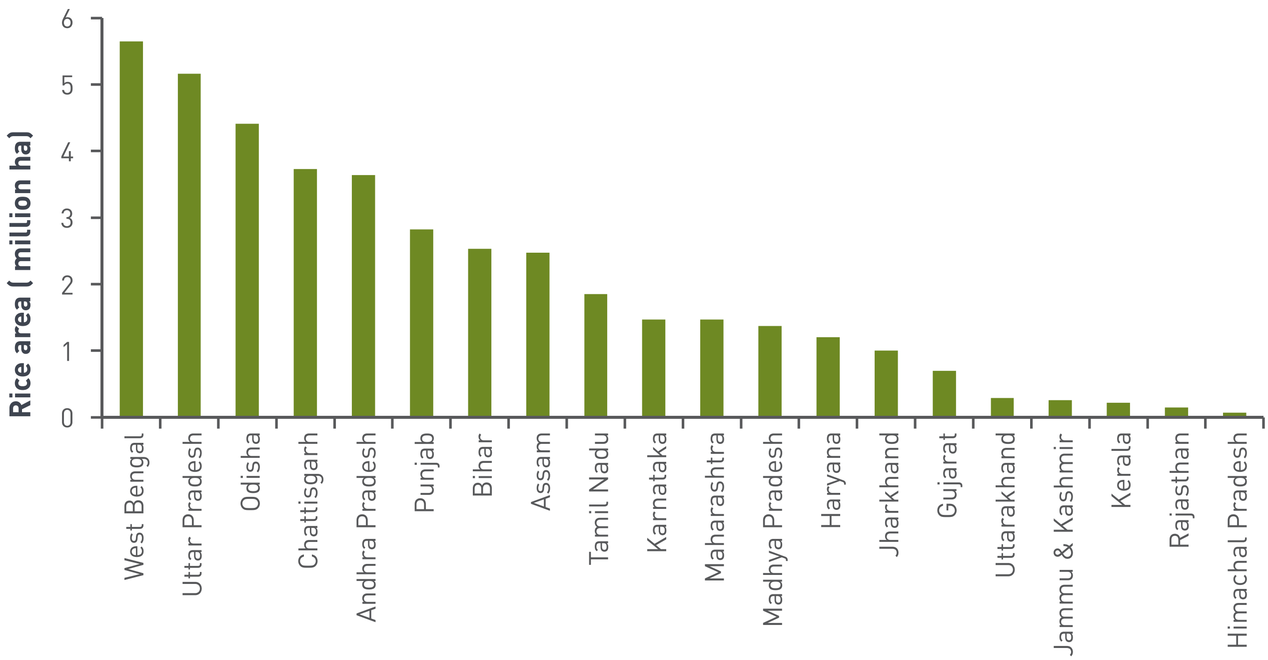


Figure 1.3 Rice area, rough rice production, and productivity during 1950-1951 to 2010 - 2011 (Data for 2009-2010 and 2010-2011 are estimates)

Source: Directorate of Economics and Statistics, 2008. Agricultural Statistics at a Glance 2010. Department of Agriculture and Cooperation, Ministry of Agriculture, Govt.of India, New Delhi.

Back in 1913-1914, India produced about 40 per cent of the world's exportable surplus of rice. This scenario changed subsequently, and the country faced a severe and world-famous famine in 1943. Export of milled rice was a mere 0.5 million tonnes in 1989, but reached a high of 6.7 million tonnes during 2001.

During 2009, the state of West Bengal had the largest rice area in the county and also the highest paddy production (Figure 1.4). Rough rice productivity was below 3 t ha^{-1} in Assam, Bihar, Gujarat, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Maharashtra, Odisha, and Rajasthan; and below 2 t ha^{-1} in the states of Chhattisgarh and Madhya Pradesh. In fact, the country's average productivity (3.31 t ha^{-1}) is lower than all the neighbouring countries of Southeast Asia. The Asian average is 4.23 t ha^{-1}, while the world is averaging 4.18 t ha^{-1}. During the period 1960-1961 to 2007-2008, the productivity increase in India has been lower (122%) than the global increase (131%). In this period, China achieved an increase of 248% from 1.9 t ha^{-1} to 6.61 t ha^{-1}. Globally, Australia with 13.5 t ha^{-1} in 2007-2008 ranked number one in rough rice productivity, followed by Egypt (10.1 t ha^{-1}).


Rice area (million ha)
6
5
4
3
2
1
0
West Bengal
Uttar Pradesh
Odisha
Chattisgarh
Andhra Pradesh
Punjab
Bihar
Assam
Tamil Nadu
Karnataka
Maharashtra
Madhya Pradesh
Haryana
Jharkhand
Gujarat
Uttarakhand
Jammu & Kashmir
Kerala
Rajasthan
Himachal Pradesh

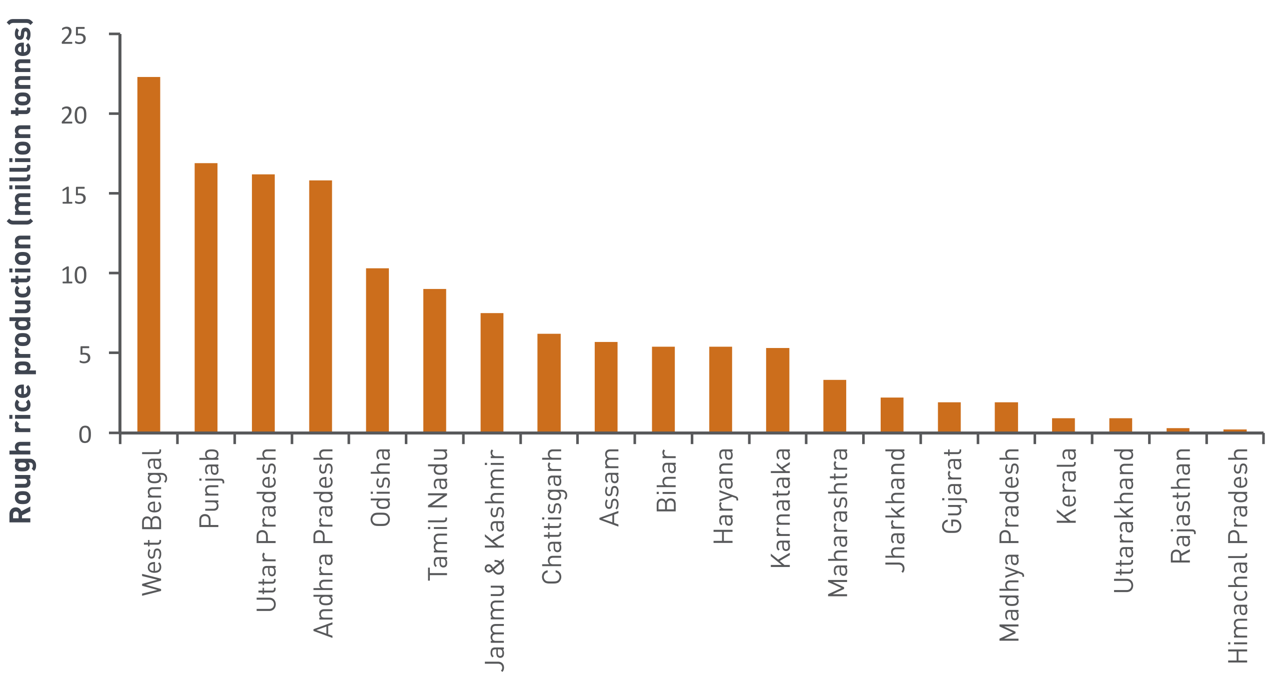

Rough rice production (million tonnes)
25
20
15
10
5
0
West Bengal
Punjab
Uttar Pradesh
Andhra Pradesh
Odisha
Tamil Nadu
Jammu & Kashmir
Chattisgarh
Assam
Bihar
Haryana
Karnataka
Maharashtra
Jharkhand
Gujarat
Madhya Pradesh
Kerala
Uttarakhand
Rajasthan
Himachal Pradesh

Figure 1.4 State-wise paddy area, production and productivity in India (2009). Source: http://geo.irri.org:8180/wrs/

1.3 Quest for Improving Rice Yields

Indian farmers and rulers have long focused on improving the yields as an effective way of improving food security. While investments by rulers have gone into expanding the area under cultivation, the efforts and innovations by farmers have continued to attempt to improve yields per unit of area. Until the last five decades or so, these efforts have been largely or even exclusively farm-based, selecting suitable varieties for different agro-climatic zones while improving the soil, water and organic input management to achieve maximum yields.

When the authors were examining why in a country with such long experience of rice cultivation there did not appear to have been any previous attempts to increase rice yield with reduced inputs, we found that there had indeed been such a prior innovation. A simple investigation plus a bit of luck have revealed that there was such an approach known to Tamil farmers a century ago. Today, the System of Rice Intensification (SRI) has become known to many rice farmers of Tamil Nadu as 'Ottrai Natru Nadavu' (single seedling planting). But, to our surprise, we have found that single-seedling planting method for higher yield was known 100 years ago in Tamil Nadu.

A century ago, an innovative farmer in Tamil Nadu had the idea of modifying the existing agronomic practices for rice cultivation by using single seedlings, also wider spacing, and some intercultivation operation, with a reported yield of 6,004 kg ha–1. This method, called the *gaja* method, employed inter-row spacing of 1½ feet (45 cm) and within-row spacing of 1 foot (30 cm) between single rice plants, resulting in a sparse plant population of only 7–8 plants m–2.

Further research into the history of rice cultivation in Tamil Nadu has revealed that in 1911, several farmers published articles in Tamil language on such single-seedling planting (Kulandai Veludaiyar, 1911, Anonymous,1911). The scanned copies of these articles in Tamil and their English versions have been published separately in Thiyagarajan and Gujja (2009). It was also found that this single-seedling planting was popularized by the then British Government in the Madras Presidency. By 1914, single-seedling planting was reportedly being adopted in 40,468 ha (Chadwick, 1914).

Vaidyalingam Pillai's reported yield of 6,004 kg grain ha^{-1} with gaja planting methods in Thanjavur district was 2.7 times greater than what had been obtained from the same field the previous year, when using standard bunch planting. Yanagisawa (1996) had estimated that the average rice yield in Thanjavur District in 1911 was 1,693 kg paddy ha^{-1}, while the average yield in this district for the period 1911-1915 was 1,492 kg ha^{-1} (Sivasubramanian, 1961). Thus, the gaja method increased standard rice production by several multiples.

It is fascinating that such high yields were being obtained by farmers with their own innovations a century ago, when no chemical fertilizers were applied. Unfortunately, such farmer innovations have disappeared after scientific recommendations were promoted by the Green Revolution.

Rice Breeding

Developing improved varieties has been one of the major thrusts of rice research since its beginning. The rice breeding programme in India was started in 1911 by Dr. G. P. Hector, the then Economic Botanist in undivided Bengal, which had its headquarters at Dacca (now in Bangladesh). Subsequently, in 1912, a crop specialist was appointed exclusively for rice in Madras Province. Prior to the establishment of the Indian Council of Agricultural Research (ICAR) in 1929, Bengal and Madras were the only provinces which had specialists exclusively assigned to improve the rice crop. After the establishment of ICAR, rice research projects were initiated in various states of the country, and by 1950, there were 82 research stations established in 14 states of the country, fully devoted for rice research projects.

More than 800 improved varieties have so far been released in the country by national and state research establishments. Improved varieties are a precursor to hybrids, which depend are produced through inter-breeding which capitalizes on the phenomenon of heterosis to achieve a 15-20% increase in yield from the hybrid vigor of crossing lines. In-bred high-yielding varieties started in the 1960s and 1970s as a basis for the Green Revolution. Some of the landmark varieties developed in India were: GEB-24, T 141, Jaya, MTU-7029, BPT-5204, Basmati 370, PusaBasmati-1 for irrigated agroecologies; TKM 6, SLA 12, MTU 15 with stem borer resistance; CO 25 with blast resistance and N 22 for drought-prone conditions (http://agropedialabs.iitk.ac.in/i3r/sites/default/files/Rice%20yield%20improvement%20and%20maintainance%20breeding.pdf)

Soil and Crop Management

Besides introducing high-yielding varieties, various management practices for better nutrient supply, soil and water management, protecting the crop from pest and diseases, and exploiting more fully the genetic potential of the crop, have been developed and are being continued now. These practices are recommended to farmers for adoption. The major thrusts of these recommendations were to increase the use of chemical fertilizers and plant-protection chemicals.

Green Revolution

The Green Revolution is usually dated from about 1967, reaching a peak of adoption around 1978. It involved improvements in crop genetic materials and agricultural practices, especially increases in external inputs that dramatically increased food production, especially wheat and rice. The government began to develop facilities for expanding farmland area and introduced modern irrigation systems, making it possible for farmers to plant two crops a year instead of one. Most notably, Indian farmers planted genetically-improved seeds that greatly increased crop yields. Within a decade, India became one of the world's largest producers of farm products. In some years, farmers produced more food grains than the Indian people needed, so the excess was sold to other countries. Famine in India, once accepted as inevitable, has not returned since the introduction of Green Revolution crops (http://www.bigsiteofamazingfacts.com).

In wheat, for example, production increased by a third from 12.3 million tonnes in 1964-1965 to 16.6 million tonnes in 1967-1968, and 20 million tonnes in 1969-1970. Rice production increased more slowly (due to the later introduction of IR-8), growing from 30.5 million tonnes in 1964-1965 to 40 million tonnes in 1969-1970. More importantly, these gains in yield were resilient to fluctuations in the monsoon, the primary natural driver of Indian macro-level food shortages. An early example of this was seen in the poor weather of 1968-1969, when there was a decrease of 2% against the previous year's record yield. By 1977, India no longer required significant cereal imports, and in later years it became an intermittent exporter. Clearly, these statistics show that India achieved the primary goal of the Green Revolution, the restoration of agricultural self-sufficiency on the national level (Arena, 2005).

The achievements through the Green Revolution have come with a price, however, as many traditional varieties were ignored or lost, and reliance on chemical fertilizers grew, forgetting to maintain the organic sources of soil fertility restoration from animals and plants, and most importantly, making farmers totally dependent on others not only for their seeds, fertilizers, and pesticides, and even for their knowledge and cultivation methods. By the end of the Green Revolution, with erosion of local varieties, replacement of organic fertilizer, and dependence of farmers on scientific institutions for guidance and advice, this has resulted in agriculture being driven by factors other than the farmers themselves in every sphere.

Significant impact events on rice in India	
1906	Introduction of Single Seedling Planting in Madras Presidency
1911	Introduction of Gaja Planting in Madras Presidency
1912	Beginning of systematic study on rice in Coimbatore
1946	Establishment of the Central Rice Research Institute at Cuttack
1951	Introduction of the Japanese method of rice cultivation
1965	Launching of All-India Coordinated Rice Improvement Project (ICAR)
1969	Introduction of IR8 variety, surge in expansion of rice area in Punjab
2000	First evaluations of SRI, followed by trials in other states
2006	First National SRI Symposium in Hyderabad, followed by annual symposia in Agartala (2007) and Coimbatore (2008)

1.4 Concerns in Rice Production

Much of the Green Revolution's gains have been achieved through highly intensive agriculture that depends heavily on fossil fuels for inputs and for energy. Whether more food can be produced without damaging the soils, fresh water cycles and supplies, and crop diversity is questionable as these food-producing bases are being degraded in many places.

Rough rice production has increased in India over 4.5 times in the last 57 years – from 30.9 million tonnes (1950-1951) to 148.4 million tonnes (2008-2009). Enhancement in rice production is mainly attributed to productivity-led increases since the harvested rice area for the corresponding period expanded only by 42%, from 31 m ha to about 44 m ha.

Grain demand in India is estimated to reach about 300 million tonnes per annum by 2020, necessitating an increase of about 91 million tonnes from the estimated 2005-2006 production level of 209 million tonnes. Since there is no probability of much further increase in the area under cultivation over the present 142 million ha, the needed 37% increase in grain production will have to be attained by enhancing the productivity per unit area. The production of milled rice per hectare has to be increased from 2,077 kg to 2,895 kg by 2020, an average annual increase of about 5% (NAAS, 2006). This is three times more than the expansion rate during the 1990s.

A historical analysis by Barah (2005) shows that over the decades, the pace in increase in rice production has been uneven, and regional disparities among the States as well as across the diverse agroecosystems have been notable. The gains due to modern rice technology have by-passed most of the resource-poor areas, which are predominated by small and marginal farmers. The analysis brings out a distinct production divide between irrigated tracts and rainfed areas, which corresponds to inter-regional disparities in production and productivity in rice. About 36% of the districts covering 44% of total rice area in the country have achieved productivity levels of more than 2 t ha^{-1} (approx 3 t ha-1of rough rice). During 1970-1979, the average rice yield was in the range 1-2 t ha^{-1} in 90% of the rice area of eastern India. By 1990-1997, this had changed substantially, as only 47% of the rice area was in this low yield range, and 51% of the area had yield levels higher than 2 t ha^{-1}.

The rice production data for 2006-2007 show that rough rice productivity is below 2 t ha^{-1} in about 18.7 % (8 million ha) of total paddy area spread over 150 districts, contributing 9.0% of total production (Table 1.2). This situation after four decades of Green Revolution and huge investments speaks to the disparate (and sometimes desperate) rice production conditions of these areas.

Table 1.2 Rough rice productivity range in India, 2006-2007

Yield (t ha^{-1})	No. of Districts	Area (000'ha)	Production (000'tonnes)
< 1	33	444	369
1 – 1.5	56	3,139	3,957
1.5 2	61	4,626	8,198
2 – 2.5	106	8,646	19,343
2.5 3	68	4,559	12,528
3 – 3.5	58	5,294	17,038
3.5 4	65	5,944	22,516
> 4	106	11,235	55,257
Total	**553**	**43,887**	**139,206**

The growth rates of rice area, production and productivity during 1994-1995 to 2009-2010 were -0.04%, 1.15% and 1.04%, respectively. The growth rate of area went down by 8.30% in 2002-2003, and the highest growth of 4.18% was during 2005- 2006. The negative growth rates for production and yield were highest during 2002-2003 (Figure 1.5). The impact of the delayed and sub-normal monsoon was reflected in reduced area under rice cultivation during 2009-2010 compared to 2008-2009, reduced by 14.3% (Annual Report 2009-2010, NABARD).

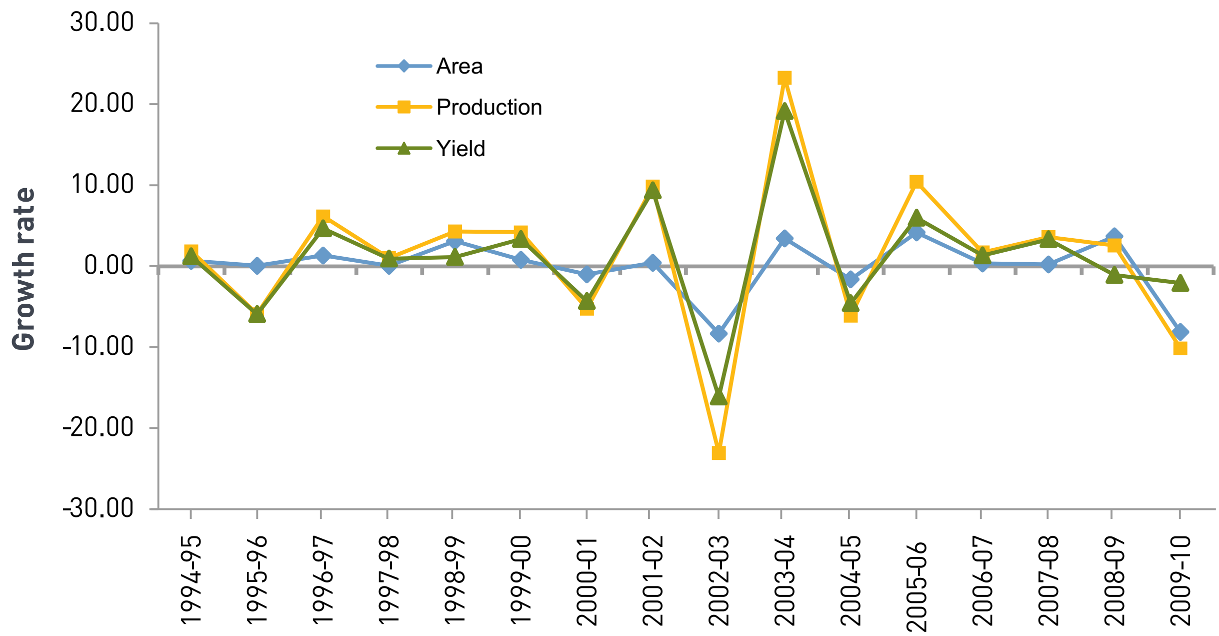


Figure 1.5 Growth rates in rice area, production and yield during 1994-1995 to 2009-2010 (Data for 2009-2010 and 2010-2011 are estimates).

Source: Directorate of Economics and Statistics, 2008. Agricultural Statistics at a Glance 2010. Department of Agriculture and Cooperation, Ministry of Agriculture, Govt.of India, New Delhi).

The per capita net availability of rice which was at 159 grams day-1 during 1950-1951 increased to 200–208 grams day-1 during 1990-2002, but has been below 200 grams day-1 again after that.

Rice cultivation is in crisis the world over, and India is no exception with its shrinking area of rice cultivation, its fluctuating annual production levels, stagnant yields, water scarcity, and escalating input costs. The cost of cultivation of paddy has consistently been increasing, owing to escalating costs of labour and agrochemical inputs. With increasing labour scarcity due to urbanization, sustaining the interest of the farmers in rice cultivation itself has become a challenge.

Current productivity in India is much lower than many other rice-producing countries, and it needs to be enhanced under the circumstances of little hope for increased in area and irrigation potential. During the last decade, the percent of irrigated rice area has been fluctuating around 53%, showing no appreciable increase.

Rice production today faces a number of problems that threaten many rice-producing Asian countries' ability to meet the food needs of their rapidly growing populations. These constraints include pest outbreaks, diseases, soil degradation, scarcity of water, conversion of rice lands for industrial use, soil salinization, and adverse soil conditions. Contrary to the claims of genetic-engineering (GE) proponents, the real cutting-edge solutions to the problems of rice production lie not in developing GE rice, but rather in developing and/or adopting strategies that take better advantage of ecological principles within agricultural systems, and that integrate traditional farming practices with modern scientific knowledge. Existing biodiversity of rice varieties and their nutritional composition needs to be explored and better utilized before depending on transgenics (Borromeo and Deb, 2006).

Water Crisis

India's post-independence agricultural growth involved huge investments in irrigation projects that have resulted in more than a tripling of the gross irrigated area, going from 22.6 million hectares (1950-1951) to 76.3 million hectares (1999-2000). This has contributed to a drastic reduction in per capita fresh water availability, from 5,410 cubic meters to 1,900 cubic metres during that period.

The greatest growth of irrigation has been through the installation of wells. In some regions, the over-exploitation of groundwater supplies through pump extraction is leading to serious declines in ground water levels. India is the largest user of groundwater in the world (over a quarter of the global total); 60% of irrigated agriculture and 85% of drinking water supplies in India are dependent on groundwater extractions.

According to the World Bank, if current trends continue, within 20 years, about 60% of all aquifers in India will be in a critical condition. This will have serious implications for the sustainability of agriculture, long-term food security, livelihoods, and economic growth. It is estimated that over a quarter of the country's harvest will be at risk. There is thus an urgent need to change the status quo.

The 'Report of the Expert Consultation on Bridging the Rice Yield Gap in the Asia-Pacific Region', published by the UN Food and Agriculture Organization in October 1999 says: "Countries like India and China are approaching the limits of water scarcity." Along the same lines, the International Water Management Institute (IWMI), in its Working Paper No. 23, mentions that India is already experiencing "physical water scarcity," which is defined in terms of the magnitude of primary water supply (PWS) development relative to potentially utilizable water resources (PUWR).

Physical water-scarce conditions are considered to be reached once a country's primary water supply exceeds 60% of its PUWR. This level means that even with the highest feasible efficiency and productivity of water, the country's PUWR is not sufficient to meet the demands of agriculture, domestic and industrial sectors, while addressing also environmental needs. Experts have estimated that by 2025, the gap between the supply of, and demand for, water for irrigation in India will be 21 billion cubic meters (BCM). In addition to this absolute water constraint, other factors such as improper management of available water resources, suboptimal farm management, poor crop husbandry, ineffective infrastructure, and unplanned capital development continue to subvert agriculture in India.

A study by the Asian Development Bank, entitled 'Pro-Poor Intervention Strategies in Irrigated Agriculture in Asia,' which was released in July 2005 following field surveys of irrigation systems in Andhra Pradesh and Madhya Pradesh, states: "Poverty rates are higher in the tail-ends of systems where water is less and productivity is low. Strangely, though, poverty rates are not necessarily lower in the head reaches, even though they are nearer to the water source. Poverty rates are consistently higher in non-irrigated rather than irrigated areas. However, in rainfed areas surrounding the studied systems, poverty levels were reduced by factors of non-farm income, larger landholdings, and groundwater use. Within systems, the poor generally receive less irrigation water than the non-poor in both dry and wet seasons."

The future of country's rice production will depend heavily on developing and adopting strategies and practices that will use irrigation water more efficiently at farm level. To meet its food security needs, the country needs its increase its paddy production at the rate of 3.75 million tonnes per year until 2050. The paddy productivity in most states must be considerably enhanced from the current level.

Rice farming is witnessing a phase where sustaining the interest of the farmers in growing rice itself is becoming an issue, and rice farmers are switching to other less demanding crops. The current scenario could be summarised as follows :

- Vagaries of monsoon are causing droughts and floods
- Increases in grain productivity have stagnated
- Factor productivity is declining continuously
- Management and efficiency of the country's surface irrigation systems are in serious disarray
- Groundwater resources are being overutilized, so water table is falling
- Soil quality is declining
- Subsidizing chemical fertilizer is proving to be very expensive
- Excessive focus on varietal changes for productivity enhancement
- Existing extension systems are overstretched
- Labour scarcity is threatening the continuance of rice farming

It is necessary that these challenges be met with care, consistency, and a positive approach to achieve national and household food security.

1.5 Summary

The current situation in India with respect to food security in relation to rice presents a number of imperatives: (1) increasing rice productivity and production, (2) reducing the irrigation water used for rice cultivation, (3) minimizing the costs of cultivation for farmers, (4) enhancing the profitability of rice farming (5) reducing environmental health risks from chemical inputs, so that soil and water quality are maintained, and (6) sustaining the interests of farmers in rice cultivation. This is a very demanding agenda for rice scientists and practitioners and for the policy-makers who support them.

One of the opportunities that is now available for the rice sector in India, based on a decade of experience and now offering means to achieve all of the above objectives, is the adoption and further adaptation of the System of Rice Intensification (SRI), the subject of the rest of this book.

2 RICE CULTIVATION

In India, the rice area extends from 8 N to 34 N latitude and from below sea-level (Kuttanad, Kerala) to altitudes above 2,000 m (in parts of Jammu and Kashmir). The crop is grown in different seasons and with different methods of crop establishment. But water availability dictated by the monsoons is the major factor that influences the rice production scenario in most of the country. Varying rice landscapes can thus be seen from north to south, from east to west (Photos 2.1 to 2.4)

Photos 2.1 and 2.2 Rice landscapes in the plains

2.1 Rice Environments

The International Rice Research Institute (IRRI) has identified and categorized four rice agro-ecosystems: irrigated rice ecosystems, rainfed lowland rice ecosystems, upland rice ecosystems, and deepwater rice ecosystems. Across the globe- except for Africa - irrigated rice ecosystems as seen in Figure 2.1 dominate over the other agroecosystems. In India, most rice production is irrigated and/or supplemented by rainfed production. Of the approximately 44 million hectares under rice cultivation in the country, around 23 million hectares (53%) are irrigated, 14 million ha (32%) are rainfed lowland, 5.3 million ha (12%) are upland, and about 1.3 million ha (3%) are deepwater areas.

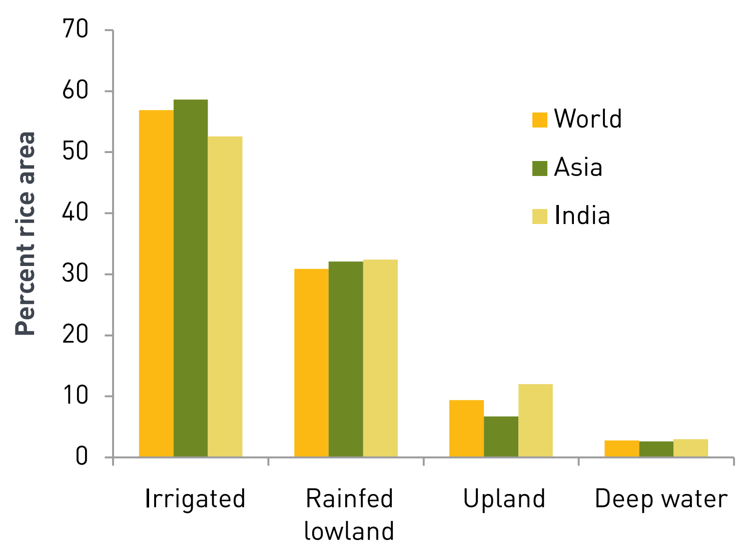


Figure 2.1 Percentage of distribution of rice crop area by environment, 2004-2006

Source: FAO database 2007 for rice area, Rome

The method of crop establishment in the different ecosystems depends mainly on the source and availability of water (Table 2.1).

Table 2.1 Rice systems, landscapes, sources of water and methods of crop establishment in India

Rice system	Landscapes	Sources of water	Methods of crop establishment
Irrigated	• Bunded low lands in plains • Basins in undulating terrains • Bunded terraces in hilly / undulating terrains	• Perennial River (rainfed, reservoir-fed, snow-fed) • Seasonal river (rainfed, reservoir-fed, snow-fed) • System tanks filled by river water • Seasonal tanks filled with rainwater • Ground water (whole season) • Ground water (supplementary)	• Transplanted in puddled soil • Seeds broadcast in puddled soil • Drum seeded in puddled soil • Seedling throwing in puddled soil • Direct seeded in dry condition and converted into wetland after rains
Rainfed wetland	• Bunded low lands in plains • Basins in undulating terrains • Bunded terraces in hilly / undulating terrains	• High rainfall	• Transplanted in puddled soil • Direct seeded in dry condition and converted into wetland after rains
Rainfed dryland	• Bunded lands in plains • Bunded terraces in hilly / undulating terrains • Slopy lands in undulating terrains	• Low rainfall	• Seeds broadcast in dry condition • Line sowing behind plough in dry condition • Seed-drill sowing (animal drawn) in dry condition • Seed-drill sowing (tractor drawn) in dry condition
Deep water	• Depressions in flood plains • Basins in undulating terrains	• Rainfall flooding	• Seeds broadcast in dry condition and fields flooded with rain water

Photos 2.3 and 2.4 Rice landscapes in undulating terrains

Eastern India (states of West Bengal, Orissa, Bihar, Assam, eastern Uttar Pradesh and eastern Madhya Pradesh) is the most important rice-growing (about 63.3% of India's rice area) and -consuming area in India. Although 35% of the people live in this region, their demand is about 49% of the rice grown in the country. The annual per capita rice consumption in this region is 133 kg versus 37 kg in the western region, 39 kg in the northern region and 113 kg in the southern region. The average rice yield in five of the six states is 2.7 t ha^{-1}. About 78.7% of the rice farming in the region is rainfed (Singh and Singh, 2000).

Rice Seasons

A combination of temperature, photoperiod, and light intensity determines the growth period and crop performance of rice. There are two main seasons for growing rice in India, although three crops are taken in some parts of Tamil Nadu and Kerala where sufficient water is available. The kharif season is dictated by the southwest monsoon, with abundant rainfall and high relative humidity; cloud cover lowers the light intensity, and there is a gradual shortening of the photoperiod and a gradual fall in temperature as the climate changes from peak temperature and rainfall to more normal conditions. The cyclonic weather associated with the monsoon can cause extremes of wind and rain, but a more important characteristic of the monsoon season is the (growing) variability in its onset. Either great delay or failure of the monsoon has a huge impact on rice farmers' success in kharif season.

During rabi, the winter season, starting when day-length is at its shortest, there is a gradual rise in temperature, brighter sunshine, near-absence of cloudy days, a gradual lengthening of the photoperiod, and lower relative humidity (ICAR, 2010). This presents quite contrasting conditions for rice crops, and low temperature at the start of the season can be a constraint on rabi crop establishment in some areas. Rice seasons across the year often have been given different names in different parts of the country. In some areas with benign climate, one can see rice crops at different growth stages at any point of time throughout the year.

2.2 Irrigated Rice

At the global level, around 57% of all rice is obtained from irrigated fields, although regional ratios vary. Looking more closely at the top ten rice-producing countries, however, one discerns a different pattern (Table 2.1). Worldwide, rice cultivation absorbs 85% of all irrigation water. In Asia, about 84% of water withdrawn from surface or underground sources is used for agriculture, mostly in flooded rice irrigation. Globally, the rice crop today accounts for about 45 percent of total area under irrigation.

Rice crops receive 2-3 times more water per hectare than the other irrigated crops, and it is estimated that irrigated rice uses 34–43% of the world's water used for irrigation and some 24–30% of the world's developed freshwater resources. It is also estimated that by 2025, 15-20 million ha of irrigated rice area will suffer severe water scarcity.

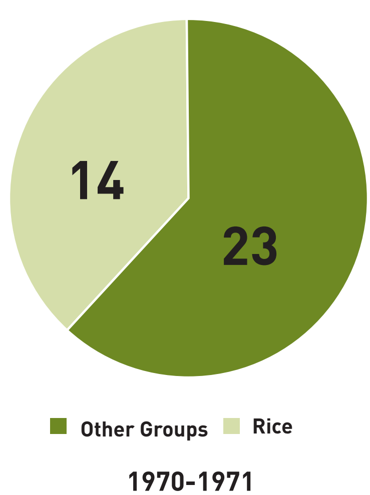
Table 2.1 Irrigated rice area in different regions and in the top ten rice-producing countries

Region	Total rice area (m. ha)	Irrigated rice area (percent)
Asia	135.00	58.6
Africa	7.82	2.8
Latin America	5.40	48.3
USA	1.30	100.0
Europe	0.60	100.0
Australia	0.05	100.0
World	150.10	58.6

Country	Total rice area (m. ha)	Irrigated rice area (percent)
China	29.0	93.0
India	43.1	52.6
Indonesia	11.7	60.1
Bangladesh	10.7	40.0
Thailand	10.1	25.0
Vietnam	7.4	53.0
Myanmar	7.0	30.0
Philippines	4.1	68.0
Brazil	3.5	35.5
Republic of Korea	1.0	100.0

Source: irri.org

In India, the acreage under irrigated rice cultivation increased from 14.3 m. ha in 1970-1971 to 23.3 m. ha in 2004-2005. Irrigated rice area was 38% of gross irrigated area in the country during 1970-1971, and 29% in 2004-2005 (Figure 2.2).



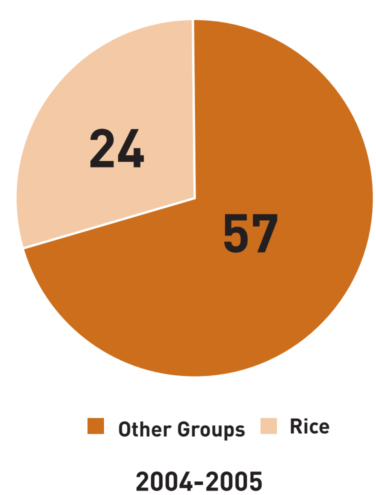


Figure 2.2 Change in proportion of irrigated area (million ha) under rice compared to area under other crops in India over three decades (1970-1971 to 2004-2005).

Rice fields under a conventional irrigated environment have sufficient water available through the growing seasons (one or more) with controlled shallow water depths ranging between 5 and 10 cm. Irrigated rice is grown under both lowland and upland conditions. Water sources are canals of river systems, tanks that get filled with water from canals (system tanks) or from rainfall and ground water. Some of the river irrigated systems have a perennial source of water while the others are seasonal. Irrigated ecosystems are important as they contribute 75% of the country's rice production with rough rice yields of about 4.5 t ha^{-1}, compared to an unirrigated average of 1.8 t ha^{-1} (Figure 2.3). Irrigated ecosystems are predominant in the states of Punjab, Haryana, and western Uttar Pradesh, Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala.

Most of the irrigated rice is grown in the kharif season (June-November), utilizing the south-west monsoon and supplemented with ground and tank water. While the rabi season is considered as a dry season in the rest of India (getting its water supply from reservoirs and ground), in Tamil Nadu this is a predominant monsoon season supplied by the northeast monsoon with water supply from canals and tanks and supplemented from the ground. In some parts of the country, there is a spring season with irrigated rice (January-May).

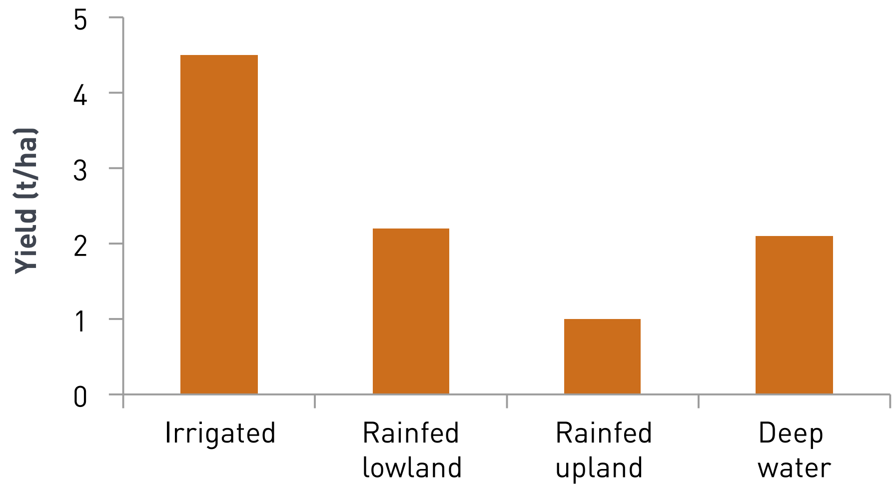


Figure 2.3 Rough rice yield in different rice environments in India
Source : http://www.fao.org/docrep/003/x6905e/x6905e09.htm

Transplanted Rice

Irrigated rice is mostly transplanted. Seedlings are first raised in a nursery, and seedlings 4 to 6weeks old are transplanted into puddled soil with standing water. Under these conditions, the rice plants have an important headstart over a wide range of competing weeds, which leads to higher yields. Transplanting, like puddling, provides farmers with the ability to better accommodate the rice crop to a finite and uncertain water supply by shortening the duration of the crop in the main field (since seedlings have been grown separately and at higher density in the nursery), with the opportunity to make adjustments in the planting calendar according to water availability.

The practices of puddling the soil - turning it to mud – and transplanting seedlings were likely refined in China. Both operations have become integral parts of rice farming and remain widely practiced to this day. Puddling breaks down the internal structure of soils, making them much less subject to water loss through percolation as a plough pan (hard layer) is formed that holds water in the surface layer of soil. In this respect, it can be thought of as a way to extend the utility of a limited water supply (Maclean et al. 2002).

The agronomic practices involved are raising wet nursery and transplanting in the main field. Seedlings are raised in wet or dry nursery beds (their size being 8-10% of the total area for transplanting) depending upon water availability. The dapog method developed in the Philippines is also one of the recognized methods where a thick stand of seedlings is raised in plastic sheets without any contact with soil.

Organic manures are generally used in the beds. Seed treatment with chemicals for protection against diseases is recommended. Certain biofertilizers are also used to treat the seeds. Seeds are soaked in gunny bags for 24 hours and then incubated for another 24 hours with occasional sprinkling of water. Sprouted seeds are then sown uniformly on the bed. Seedlings of 4-6 weeks old are removed from the nursery, bundled and transported to the main field.

The main field will have been prepared sufficiently earlier with dry ploughing followed by wet puddling and leveling. Organic manures of different dosages depending upon availability are applied before puddling. Seedlings are planted at random or in lines with a spacing of 20x10 or 10x10 cm. Although 2-3 seedlings per hill are recommended to be planted, more seedlings (4-6) are generally planted, with the expectation this will ensure the plants' establishment across the whole field. Farmers generally worry that their seedlings will not survive, even though dense planting has its own negative effects in terms of pests and disease incidence, inter-plant competition for nutrients, and shading that limits growth.

Although agronomists recommend that water depth be limited to 2 -5 cm, usually farmers do not maintain strict water control and tend to keep their fields flooded as much as possible, thinking that this will ensure water availability.

Weed management is generally done with hand weeding twice or thrice, and use of herbicides is also practiced. Nutrient management involves use of organic materials to the extent of their availability and is widely supplemented by chemical fertilizers. Various recommendations on the doses and timing of application of fertilizers prevail across the regions. Pest control is attempted mostly through the use of chemicals. Organic rice cultivation is also practiced to some extent as a matter of choice rather than necessity. Mechanized planting is also becoming increasingly popular (Photos 2.5 to 2.10).

Photo 2.5
Conventional nursery

Photo 2.6
Conventional planting

Photo 2.7
Conventional method of distributing seedlings and random planted field

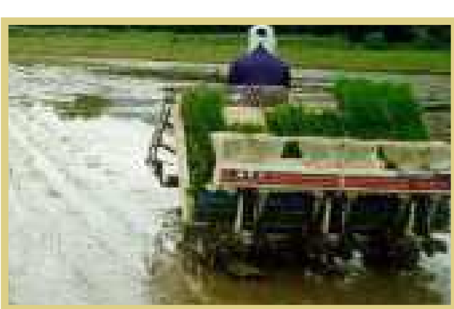


Photo 2.8
Machine transplanting

Photo 2.9
Conventional hand weeding

Photo 2.10
Conventional flood irrigation

Direct-seeded Rice

Broadcasting sprouted seeds directly onto a puddled and leveled field is also practiced to some extent. The land, time and expenditure spent on the nursery and the costs of pulling up seedlings and transplanting them are completely eliminated by this method. The drawbacks are using the main field for a longer time and extended irrigation costs, besides the possibility of more weed problems. Using a drum seeder facilitates line sowing and intercultural operations (Photos 2.11 and 2.12).

Photo 2.11 Drum seeder

Photo 2.12
Sowing with a drum seeder

Seedling Throwing

Random throwing of conventionally-raised seedlings directly in puddled and leveled field is also practiced under irrigated conditions, but is not very popular. Transplanting costs are eliminated in this method.

2.3 Rainfed Rice

Rainfed rice is grown under both lowland and upland conditions at the mercy of the monsoon rains. Rainfed lowland rice fields are bunded and get flooded and filled with rainwater for some period of the crop growth. Depending on the duration of rainfall, rainfed shallow lands exhibit uncontrolled shallow water depth, ranging 1–50 cm. The system occurs mainly in the states of Uttar Pradesh (eastern parts), Chhattisgarh, Odisha, Bihar, West Bengal, Assam, Tripura, and Manipur, where rice is directly-seeded in puddled or ploughed soils. Because of a welter of biotic and abiotic stresses, the average rough rice productivity in this system is lower (2.2 t ha^{-1}).

Rainfed upland rice is characterized by dryland conditions without irrigation and usually unbunded fields. This type of rice is being cultivated in parts of Uttar Pradesh (eastern parts), Chhattisgarh, Bihar, Odisha, West Bengal, Karnataka, Andhra Pradesh, and the hilly regions of Himachal Pradesh and Uttarakhand as well as in Mizoram, Arunachal Pradesh and Nagaland. Using draught animals to prepare the land after receiving rainfall is common, and tractor use is also becoming popular.

Seed is either broadcast in ploughed dry soil or dibbled into non-puddled soil. Sowing behind a country plough is common. In general, traditional tall varieties combining early maturity and drought-tolerance are preferred, and hardly any chemical fertilizers are used. Bullock-drawn implements for sowing and intercultivation are also being used by some farmers (Photos 2.13 and 2.14).

Erratic rainfall distribution, brief periods of drought, and flash floods, are the major production constraints. Rough rice productivity is low (about 1 t ha^{-1}) in view of several biotic and abiotic and social constraints.

Photo 2.13 Seed drill used for rainfed rice in Karnataka

Photo 2.14 Bullock-drawn harrow for intercultivation

2.4 Deepwater Rice

Deepwater rice fields occur in low-lying/depressed locations where runoff water from catchment areas accumulates during later crop growth stages. The initially aerobic soil conditions are converted into anaerobic soil conditions on the receipt of the runoff water. Specially-adopted rice varieties that literally float on water are grown, and they cope with rising water level by exhibiting remarkable stem elongation aided by ethylene production. This ecosystem occurs chiefly in the states of Uttar Pradesh (eastern parts), Chhattisgarh, Bihar, and West Bengal. Rough rice productivity with such management is about 2.1t ha^{-1}.

2.5 Semi-dry Rice

Deepwater rice fields occur in low-lying/depressed locations where runoff water from catchment areas accumulates during later crop growth stages. The initially aerobic soil conditions are converted into anaerobic soil conditions on the receipt of the runoff water. Specially-adopted rice varieties that literally float on water are grown, and they cope with rising water level by exhibiting remarkable stem elongation aided by ethylene production. This ecosystem occurs chiefly in the states of Uttar Pradesh (eastern parts), Chhattisgarh, Bihar, and West Bengal. Rough rice productivity with such management is about 2.1t ha^{-1}.

2.6 Organic Rice

Growing rice organically is nothing new as this was the practice before the arrival of chemical inputs. The Green Revolution, although it has been responsible for greatly reducing food insecurity, saw the disappearance of many traditional cultivars and practices. Cattle use dwindled as tractors became more widely used, leading to the non-availability of farm yard manure which was an important source of nutrients to the crops.

The growing awareness among consumers of food-safety issues and the realization of desirable benefits of reviving organic fertilization and management of crops are making a considerable impact on the growing of rice without reliance of inorganic chemicals. A number of NGOs throughout the country are actively involved in promoting organic rice production. This can be done in any of the agroecosystems discussed above, but it is most relevant for irrigated rice, for which agrochemical use has become most intense and widespread.

2.7 Need for Ecologically-sound Cultivation Techniques

On the one side, there is a crisis in production, and on the other, the demand for rice is growing globally. Thus, there is an urgent need to find ways to grow more rice but with less water and less agrochemical inputs. The yield potential of rice, despite decades of investment in plant breeding, has remained relatively unchanged since the introduction of the first semi-dwarf variety (IR-8) in the mid-1960s. Agricultural experts and governments are prompted to look at other practical ways of increasing rice production without further degrading ecosystems.

This is the global challenge. There are no known technical solutions presently available to improve rice productivity significantly. The much-publicized GM rice and the breakthrough hoped for with C4 technology to alter the photosynthetic pathway for rice plants have not made any contributions to higher production so far. It would take at least 10–15 years of dedicated and costly work by global scientific teams for some positive results to emerge, and positive results are not certain.

Improved technologies have certainly increased yields. However, in many countries yield growth rates have slowed down over the past decade. The implication of this fact is that the ever-increasing demand for rice can only be met by bringing more land into cultivation, which in turn would require drawing more water from surrounding ecosystems to meet the requirements of this 'thirsty' crop.

Several technologies or sets of practices that promise to boost paddy yield per hectare and which require less water have been in use for the past few decades. Some of these offer other economic and environmental benefits as well. Of these practices, SRI is a well-documented methodology that has given demonstrable results in India and elsewhere as per its promise.

Rice farmers in many countries have been switching out of rice production to more commercially-profitable crops. In some districts of China, farmers are being advised to desist from sowing paddy, in order to reduce their demands for water. This reflects the rice-sector crisis discussed in Chapter 1.

2.8 Summary

Expanded rice production, particularly of irrigated rice, will continue to play a central role in reducing hunger and improving nutrition levels in India and elsewhere. But this can happen in a sustainable and environmentally-responsible fashion, only if water is used more productively, getting 'more crop per drop.' Better management of natural resources, particularly water and reversing soil fertility declines, is critical for addressing both production and productivity issues.

In this context, the focus should be on identifying and introducing rice cultivation methods that use water more productively than under the conventional (inundation) methods. The System of Rice Intensification (SRI) represents such a methodology, presently available at little or no cost.

Under the present situation, our country cannot afford to continue growing rice with overuse of water, degradation of soil, excessive use of seed, and relatively unproductive use of labor. Already five years ago, an expert committee chaired by Dr. M.S. Swaminathan recommended that SRI be taken up as one of the best ways to cope with the impending water scarcities in the agricultural sector (MWR, 2006).

3 INTRODUCTION TO SRI

The System of Rice Intensification, widely known as SRI, is a method of rice cultivation developed in an unconventional way and now known and being practiced in more than 40 countries. This spread in a decade's time is due to the fact that it addresses many of the challenges faced by rice farmers across the world.

3.1 History of SRI

The SRI methodology was synthesized in the early 1980s by Fr. Henri de Laulanié, S.J. (Photos 3.1 and 3.2). Trained in agriculture at the Institut National Agronomique in Paris before entering seminary in 1941, Laulanié was sent to Madagascar in 1961 to serve as an agricultural technician for 10 years. However, he fortuitously extended his stay, spending the next (and last) 34 years of his life working with Malagasy farmers to improve their agricultural systems, and particularly their rice production, since rice is the staple food in Madagascar. Fr. de Laulanié established an agricultural school in Antsirabe on the high plateau (1,500 MASL) in 1981 to help rural youths gain an education that was relevant to their vocations and family needs.

The key element in SRI was discovered almost by accident in 1983-1984. Over the previous 20 years, Fr. Laulanié had assembled or improvised a number of beneficial practices that enhanced the growth and productivity of rice plants. But the keystone in the SRI 'arch' was established serendipitously. The nursery prepared for planting the school's demonstration rice crop had already been established for 15 days when it was decided to plant another small nursery to expand the school's planted area. When some rains began 15 days later, both nurseries were transplanted, with little expectation or hope for the younger seedlings. To plant 30-day seedlings was already a big departure from the usual practice in Madagascar of transplanting large seedlings at 60-70 days.

Photos 3.1 and 3.2
Father Henri de Laulanié
(Source : Association of Tefy Saina)

The 15-day seedlings were unimpressive, even disappointing, for the first month. But then they began tillering vigorously, supported by the other practices of single seedlings planted in a square pattern and with aerobic soil conditions (no continuous flooding, and soil-aerating weed control). Given the very high number of tillers obtained per plant with this unintended experiment, more than 20 per plant, this age for seedlings was adopted at the school as the latest time for transplantation. Still earlier transplanting of seedlings was tried - at only 12 days, 10 days, even 8 days after seedlings emerged in the nursery. It was found that this led to a substantial increase in the number of tillers per plant, up to 60, even 80 or more, and to more grains when all the SRI practices previously assembled were used together with young seedlings.

Such was the beginning of the System of Rice Intensification. Yields rose substantially with the increase in tillering and grain formation, but the exact reason for this increase could not be explained. The reason was found from reading Didier Moreau'sbook, entitled L'analyse de l'élaboration du rendement du riz: Les outils du diagnostic, published by the French NGO, GRET. It introduced the concept of phyllochrons to Father

Laulanié and others. This analysis could account for the large number of tillers produced when rice is transplanted at an early age, before the start of its fourth phyllochron.

The tillering model developed by the Japanese scientist T. Katayama in the 1920s and 1930s, but not published until after World War II (in 1951) showed why transplanting before the 15th day would be less traumatic for rice plants and preserve their growth potential. With this analysis, the System of Rice Intensification could become more than a matter of pure empiricism and could be understood in terms of demonstrable scientific explanations (Laulanié, 1993).

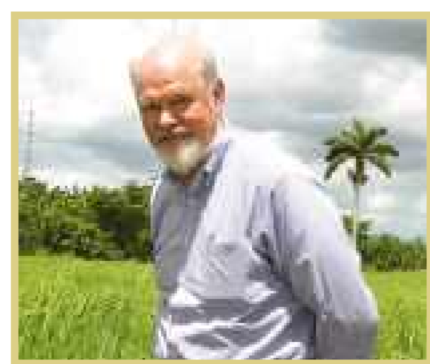
Laulanié paid little attention to the issuance of genetically-improved and input-responsive modern varieties. By manipulating the other agronomic factors including their interactions, he recorded spectacular yield increases from the available local varieties (Stoop et al. 2009).

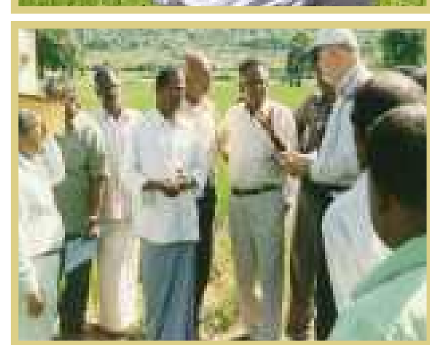
Though SRI was 'assembled' in 1983, benefiting from some serendipity, it took some years to gain confidence that these methods could consistently raise production so substantially. In 1990, Fr. de Laulanié together with a number of Malagasy colleagues established an indigenous non-governmental organization (NGO), Association Tefy Saina, to work with farmers, other NGOs, and agricultural professionals to improve production and livelihoods in Madagascar.

In 1994, Tefy Saina began working with the Cornell International Institute for Food, Agriculture and Development (CIIFAD) in Ithaca, New York, to help farmers living around Ranomafana National Park to find alternatives to their slash-and-burn agriculture. Unless they could increase their poor yields grown on their limited irrigated lowland area, about 2 t ha^{-1}, they would need to continue growing upland rice in this manner destructive to Madagascar's precious but endangered rain forest ecosystems.

Fortunately, by using SRI methods, these same farmers could average 8 t ha^{-1} during the first five years that these methods were introduced around Ranomafana. A French project for improving small-scale irrigation systems on the high plateau during this same time period also found that farmers using SRI methods averaged over 8 t ha^{-1} (Uphoff, 2002).

Once CIIFAD was persuaded that SRI methods were indeed productive, giving farmers more output with a reduction in external inputs, but with more labour and management inputs, it took several more years to get the methods evaluated outside of Madagascar. In 1999 the first such trials began in China and Indonesia, and in India the next year. Even with positive results, it took another 10 years before SRI became widely known in the rest of the world, due in considerable measure to the persistent initiatives of Dr.Norman Uphoff of Cornell University, Director of CIIFAD from 1990 to 2005 (Photos 3.3 and 3.4). Now, SRI has spread to more than 40 countries and is supported by innumerable success stories. Efforts are now on-going to generate and establish scientifically the exact physiological and other mechanisms responsible for the observed SRI results, heretofore often beyond belief or dismissed as too good to be true.





Photos 3.3 and 3.4
Dr. Norman Uphoff interacting with farmers and scientists

3.2 What is SRI?

The System of Rice Intensification involves cultivating rice with as much organic manure as possible, starting with young seedlings planted singly at wider spacing in a square pattern; and with intermittent irrigation that keeps the soil moist but not inundated, and frequent intercultivation with weeder that actively aerates the soil.

SRI is not a standardised, fixed technological method. It is rather a set of ideas, a methodology for comprehensively managing and conserving resources by changing the way that land, seeds, water, nutrients, and human labour are used to increase productivity from a small but well-tended number of seeds. As Father de Laulanié observed, SRI is an amalgamation of multiple beneficial practices.

During two decades of observation and experimentation, he gained many insights into how to provide rice plants with a more favorable growing environment. By altering certain age-old practices for growing rice, Laulanié assembled the System of Rice Intensification which enables farmers to obtain more productive phenotypes from any rice genotype (variety) by applying fewer rather than with more external inputs. Fr.Laulanie died in Madagascar in June, 1995.

The generic agronomic practices for growing transplanted rice, i.e, raising a nursery, transplanting, irrigation, weed management, and nutrient management, are all there in SRI, but there are striking changes made in the way that these are carried out. The rice plants respond in a different, more productive way, resulting in previously unseen crop growth.

SRI agronomy at the level of practice represents an 'integrated' production system. Through integrated management of its various crop-soil-soil biota-water-nutrient-space-time components, SRI seeks to capitalise on a number of basic agronomic principles that should not be controversial. They are aimed at optimizing the above- as well as below-ground plant growth and development, and improving the performance of the crop as a whole (Uphoff, 2008)

3.3 SRI Principles

The elements of SRI include: transplanting young seedlings, before the start of their 4th phyllochron of growth; reducing plant populations by as much as 80-90% per m2; converting paddy soils from anaerobic, flooded status to mostly aerobic conditions, by alternate wetting and drying; active soil aeration, with mechanical weeders; and increased soil organic amendments. While some of the practices appear counterintuitive – getting more production from fewer plants, with less water application, and with reduced reliance on chemical fertilizers – the beneficial effects of each practice can be explained and justified scientifically (Uphoff, 2008).

The principles of SRI which are fundamental to achieving the expected benefits, get translated into certain practices, adapted in their fine points to local conditions (Table 3.1).

Table 3.1 Principles and Practices of SRI

S. No	Principle	Practice
1	Very young seedlings should be used, to preserve the plant's inherent growth potential for rooting and tillering	8 – 15 day old seedlings with 3 leaves are grown in a raised-bed nursery
2	Transplanting single seedling per hill should be done quickly, carefully, shallow and skillfully, in order to avoid any trauma to the roots, which are the key to plants' success	Single seedlings are planted with a minimum time interval between the time they are taken out from the nursery and planted carefully at a shallow depth (1-2 cm)
3	Reduce the plant population radically by spacing hills widely and squarely, so that both the roots and canopy have room to grow and can have greater access to nutrients, sunlight, etc.	Planting at grids of either 20 x 20 cm or 25 x 25 cm (or 30 x 30 cm or even wider if the soil is very fertile) using a rope or roller marker to achieve precise inter-plant distances (to facilitate intercultivation)
4	Provide growing plants with sufficient water to meet the needs of roots, shoots and soil biota, but never in excess, so that the roots do not suffocate and degenerate	Up to panicle initiation: Irrigate to 2.5 cm depth after the water ponded earlier disappears and hairline cracks are formed on the soil surface. (Heavy clay soils should not be permitted to reach the cracking stage, but still are issued less water than with usual flooding.) After panicle initiation : Irrigate to a depth of 2.5 cm one day after the water ponded earlier disappears
5	Active soil aeration improves rice crop growth by benefiting both roots and beneficial aerobic soil organisms.	Intercultivation with a mechanical weeder at intervals of 10-12 days, starting 10-12 days after transplanting and continuing until the canopy closes, passing between the rows, and making perpendicular passes across the field
6	Augmenting organic matter in soils, as much as possible, improves performance of the rice crop, by improving soil structure and functioning and supporting beneficial soil organisms.	Application of cattle manure, green manure, bio-fertilizers, and vermi-compost is recommended. Chemical fertilizer can be used, but it does not have the same beneficial effects on soil systems.

Source: Uphoff, 2008

The six principles form the 'SRI Hexagon,' and when adopted together they have a profound effect on the growth of rice plants (Figure 3.1).

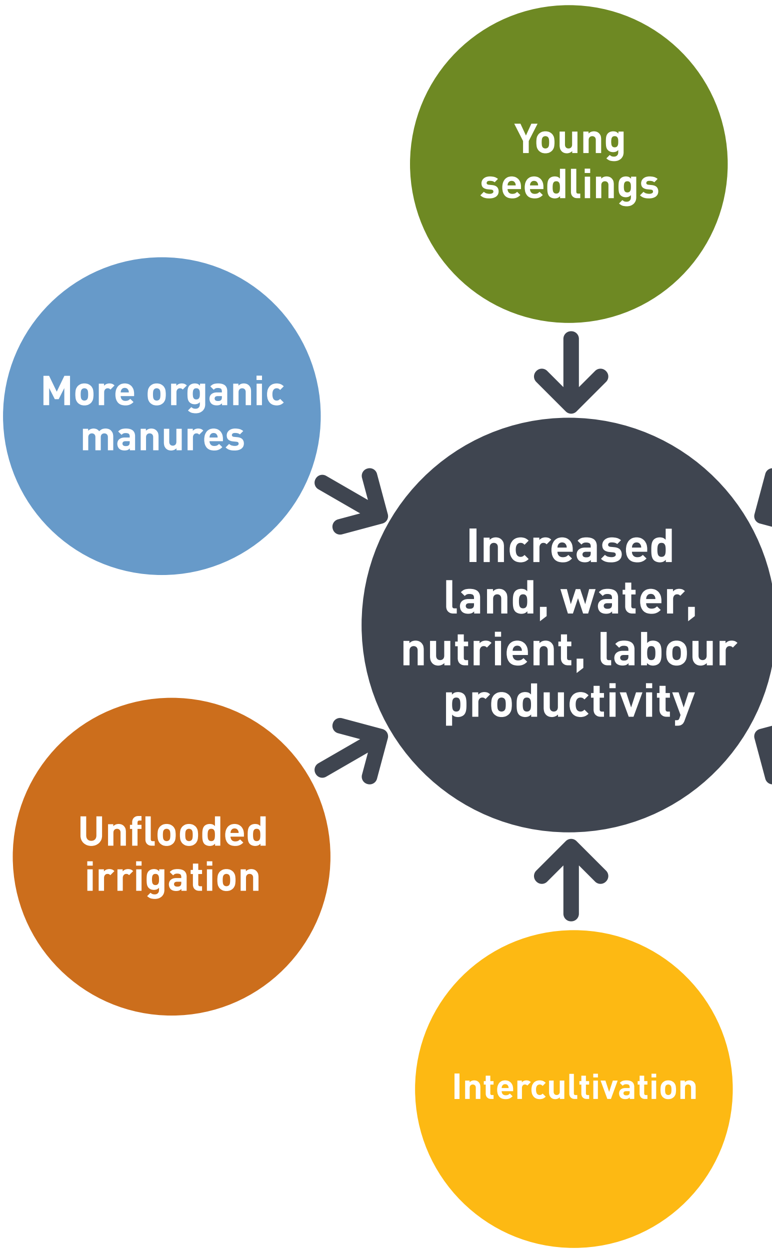


Figure 3.1 SRI Hexagon

A comparison of the conventionally-recommended practices with SRI will show how SRI practices are completely different from what farmers have been advised to do (Table 3.2). The extent of differences can vary with different regions.

Table 3.2 SRI vs. conventional methods of rice cultivation

Practice	Commonly recommended methods	Farmers' practice	SRI methods
Seed rate (kg ha^{-1})	20	50- 75	5 – 7.5
Seedling age (days)	25- 30	25 - 40	8-14
Plant spacing (cm)	15 x 10 / 20 x 10	Usually random planting	25 x 25 (square planting)
Number hills m^{-2}	50 – 66	Varying	16
Number of seedlings $hill^{-1}$	2-3	3 – 6 or more	Single
Water management	Irrigate to 5 cm depth one day after disappearance of previously ponded water.	Continuous flooding to various depths	Only moist conditions with shallow flooding
Weed management	Hand weeding twice, at 15 and 35 days after planting, or application of herbicide plus one hand weeding	2 -3 times hand weeding; herbicide also is used by some farmers	Weeds are turned back into the field by a mechanical hand weeder
Intercultivation	No	No	Weeder is used 3-4 times in between rows in both directions (perpendicular)
Nutrient management	Integrated nutrient management using organic manures, bio-fertilizers, and chemical fertilizers at recommended levels and timing	Use all recommended manures and fertilizers, but doses and timing vary according to farmers' resources	Emphasis on more application of organic manures

Note: There may be more variations in the recommended and farmers' practices across the country. Only an example of farmer practices is given here.

The calendar of operations that are to be carried out in SRI is given in Table 3.3.

Table 3.3 SRI Calendar

	Field preparation and nursery raising		Planting	Tillering								Panicle initiation		Flowering		Maturity
	Days before planting			Days after planting												
	15-20	1-5		7	10 - 12		20-22		30 - 32		40 - 42					
Main field	Plouging, puddling	Leveling	Providedrainage at the periphery													
Nursery	Prepare raised bed, sow treated and pre-germinated seeds	Spray 0.5 % urea if seedling growth is poor 5 days before planting	Pull out 3 leaf stage seedlings along with soil half hour before planting, root dip with biofertilizers													
Manures	Apply FYM/GM or incorporate	Apply biofertilizers														
Marker use		Use marker on the previous day before planting														
Planting			Plant single seedling at the intersections of marker grid lines or use rope	Fill gaps if needed												
Irrigation	Irrigate to puddle and level	Drain water two days before planting	Irrigate lightly to keep a thin film of water fore planting	Irrigate to 2 cm depth after thin cracks develop on soil surface, drain excess rain water									Irrigate 2 cm water after disappearance of surface water, drain excess rain water			Drain water
Fertilizers		Apply recommended basal dose of N, P, K, Zn					Top dress N and K					Top dress N and K		Top dress N and K		
Intercultivation					First		Second		Third		Fourth					
Hand weeding					Remove weeds left out by weeder											
Pest control	Need-based biopesticides / pesticides															

3.4 Significance of the SRI Principles

Each of the six principles of SRI has an important bearing on the performance of the crop on its own (Table 3.3), but they have also synergistic effects on one another, in addition to direct benefits. Basically these effects arise from the positive feedback between root and shoot growth; both roots and shoots benefit the other. The extent and mechanisms of such synergy have been studied to some extent (see Chapter 10).

Table 3.3 Significance of SRI principles

Principle	Significance
Young seedlings	• Much greater potential for tillering and root growth • Earlier arrival within a better growing environment in the main field extends the time for tillering • No transplanting shock if transplanting is done carefully
Single seedling per hill	• No competition for nutrients, water and space within a hill • Seed requirements are reduced • This practice combined with wider spacing enables all leaves to be photosynthetically active; whereas with crowding, lower leaves do not get enough exposure to sunlight for photosynthesis. This deprives the plant - and especially the roots – of possible supply of photosynthates
Wider spacing	• Promote more profuse growth of roots and tillers • More space (below and above ground) per hill for access to nutrients, water and light • Intercultivation with mechanical weeder is made possible
Moist and unflooded water management regime	• Non-hypoxic condition of soil favours root health and functioning, and also supports more abundant and diverse communities of beneficial aerobic soil organisms • No degeneration of roots, which otherwise will be as much as 75% degraded by panicle initiation under flooding • Exposing the soil to sunlight is favourable for warmth • Water savings of up to 40% • Energy saving where water is pumped
Intercultivation	• Churning up of the soil activates the microbial, physical and chemical dynamics • Triggers greater root growth and tillering • Weed biomass is incorporated into the soil as green manure • Weeding costs can be reduced
Liberal use of organic manures	• Gives better plant growth response than inorganic fertilizers • More sustained supply of nutrients • Favourable growth of soil biota • Enrichment of soil health

The overall effect of adopting SRI practices is an increased grain yield which can be obtained irrespective of the variety planted. While the principles of SRI are constant, there are variations in the practices followed. Farmers have been modifying SRI recommendations in some useful ways to suit their conditions, and in several ways have improved upon the initial methodology.

SRI methods are seen to have the following impacts compared to their conventional counterparts (Uphoff et al. 2009).

- Depending on current yield levels, output per hectare is increased, usually by 50% or more, with increases of at least 20%, and sometimes 200% or more.
- Since SRI fields are not kept continuously flooded, water requirements are reduced, generally by 25–50%.
- The system does not require purchase of new varieties of seed, chemical fertilizer, or agrochemical inputs, although commercial inputs can be used with SRI methods.
- Minimal capital cost makes SRI methods more accessible to poor farmers, who do not need to borrow money or go into debt, unlike with many other innovations.
- Costs of production are usually reduced, probably by 10–20%, although this percentage varies according to the input-intensity of farmers' current production.
- With increased output and reduced costs, farmers' net income is increased by more than their augmentation of yield.

More details on the effects of SRI and the benefits are given in Chapters 10 and 11.

SRI is perhaps the best example of an option for farmers and nations to promote community-led agricultural growth, managing their soil and water resources more sustainably and even enhancing future productive capacity. SRI modifies how farmers manage their plants, not the plants themselves; so it is compatible with genetic improvement strategies, while mitigating the drawbacks associated with monoculture, agrochemical use, and climate change. This makes it a win-win proposition for rural households, countries, and the planet.

3.5 Introduction of SRI in India

Introduction of SRI in India began in 2000 in Tamil Nadu, Puduchery, and Tripura. In Tamil Nadu, Tamil Nadu Agricultural University (TNAU) initiated experiments involving SRI principles, and one farmer tried SRI under organic farming. The source of information on SRI for TNAU was from Dr.Uphoff, and the farmer had learnt about it from the LEISA magazine. In Tripura, some preliminary evaluation of SRI principles was initiated by a rice scientist in the Department of Agriculture, and he started on-farm tirals and demonstrations from 2002-2003. In Puduchery, SRI was tried from 2000 by Auroville Farm.

When the Acharya N.G. Ranga Agricultural University (ANGRAU) introduced SRI in farmers' fields in Andhra Pradesh during kharif 2003, this was based on knowledge gained from a visit to Sri Lanka that had been arranged by Dr. Uphoff. That SRI experience in particular generated nationwide interest, and today SRI is now known to all rice-growing states of the country.

It is estimated that now as many as 600,000 farmers are growing their rice with all or most of the recommended SRI crop management practices on about 1 million hectares distributed across more than 300 of the country's 564 rice-growing districts. This is probably the most rapid uptake of new agricultural practices seen in the country, making SRI a national phenomenon with very limited resources devoted to its extension. A major role has been played by CSOs, especially in the northern and eastern states (Table 3.4). The role of donor agencies like the WWF-ICRISAT project, the Sir Dorabji Tata Trust (SDTT), and NABARD has been critical in promoting SRI through CSOs. After 2006, SRI has spread to almost all rice-growing states.

As far as research on SRI is concerned, experiments were undertaken in IARI starting from 2002. The Directorate of Rice Research and Central Rice Research Institute initiated experiments on SRI from 2003 and 2005, respectively. The Ministry of Agriculture's Directorate of Rice Development based in Patna has been monitoring and assisting SRI since 2005. Many other NARs had taken up experiments on SRI after 2005. SRI was introduced into the National Food Security Mission, as a method to improve rice production in food-insecure districts across the country in 2006.

Both on-farm and on-station evaluations across many states and in diverse growing environments have shown clearly that SRI has the potential to improve yield while reducing water use, production costs, and chemical inputs. Available data from SRI experiments across India show an average increase in grain yield of up to 68% with less cost and often less labour.

Table 3.4 Introduction of SRI in different parts of India

S.No	Year	State	Introduced by
1	2000	Tamil Nadu Tripura Puduchery	Tamil Nadu Agricultural University; Ramasamy Selvam (organic farmer) Dept.of Agriculture Auroville Farm
2	2001	Karnataka	Narayana Reddy, organic farmer
2	2002	Bihar	Rajendra Agricultural University
3	2003	Andhra Pradesh West Bengal	Acharya N.G.Ranga Agricultural University; WASSAN PRADAN
4	2004	Keral Andaman Odisha Punjab Haryana Assam Gujarat	Mitraniketan KVK Central Agricultural Research Institute Central Rice Research Institute ATMA/Dept. of Agriculture POSTER (NGO); Tilda Rice Co. Ltd. Assam Agricultural University Anand Agricultural University
5	2005	Chhattisgarh Maharashtra Uttarakhand Meghalaya Jharkhand	Indira Gandhi Krishi Vishwa Vidyalaya Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth G.B. Pant University of Agriculture & Technology. ICAR Research Complex for NE region Birsa Agricultural University
6	2006	Himachal Pradesh Jammu & Kashmir Nagaland	Peoples' Science Institute Sher-E-Kashmir University of Agricultural Sciences & Technology 'Prodigals Home'

3.6 Extending SRI Principles to Rainfed Rice

Although SRI was developed for irrigated transplanted rice cultivation, the principles of SRI have been extended and adapted to rainfed rice cultivation with some modifications. In eastern India, SRI principles have been applied for both transplanted and direct-seeded rice under rainfed conditions. For transplanted rice, the practices are similar to irrigated SRI except for adjustments in water management which depends upon rainfall. Keeping the paddy fields under standing water (when there is sufficient rainfall) is being avoided with proper drainage. With direct seeding, lowering the seed rate, and wider spacing of rows (in the case of line sowing), thinning of the plant population, and intercultivation have been followed. The main objective is to reduce labour requirements.

In Dharwad region of Karnataka, AME Foundation has been spearheading SRI in rainfed areas (Photo 3.5). AMEF (Dharwad) has developed a 4-row seed drill (Photo 3.6) to sow seeds at 10 inch intervals instead of the 6-row seed drill with 6-8 inch rows already being used by farmers.

Photo 3.5 Rainfed SRI crop

Photo 3.6 Four-row seed drill for rainfed SRI

3.7 Extending SRI Principles to other Crops

The term 'SRI' is more appropriately used as an adjective rather than as a noun. We should avoid the reification of SRI, i.e., making it into a thing when it is better thought about in terms of characteristics and qualities, framing issues and choices as matters of degree rather than of kind. Water management must be done differently in upland compared to lowland areas, but SRI principles for managing water can be made relevant for upland farming. Spreading of SRI should be approached more as a problem-solving exercise than as usual top-down 'extension' (Uphoff, 2008). These developments have taken place in most places due to the enthusiasm of farmers and NGOs assisting them, spurred by their observations on the effects of SRI, without the intervention of any established research systems.

The System of Wheat Intensification (SWI) is becoming popular in Himachal Pradesh, Uttarakhand, and Uttar Pradesh

(Photo 3.7). SWI has been recognized as the 'Innovation of the Week' on the Worldwatch Institute's 'Nourishing the Planet' blog in May 2011 (http://blogs.worldwatch.org/nourishingtheplanet/tag/system-of-wheat-intensification/). In Africa, SWI is being successfully tried in Mali and Ethiopia also. SRI concepts and methods have been extended to other crops also. The Sustainable Sugarcane Initiative (SSI) for sugarcane is being tried in five states and on a fairly large scale in Uttar Pradesh (Photo 3.8).

SRI principles of lower seed rate, limited water use, and intercultivation are being applied to crops like finger millet (ragi), redgram, mustard, pigeon pea, and other crops in various states of India. Intuitive farmers and NGOs are terming the new method of cultivation as the 'System of Crop Intensification' (SCI), the 'System of Root Intensification', or the System of Sustainable Crop Intensification (SSCI). An SRI Secretariat promoted by SDTT and hosted by the "LIVOLINK FOUNDATION" at Bhubaneswar, Odisha, has taken the initiative to document farmers' practices of applying the SRI principles for growing crops like wheat, finger millet, rapeseed/mustard, brinjal, tomato and chilli. (GROWING CROPS WITH SRI PRINCIPLES- http://sdtt-sri.org/wp-content/themes/SDTT-SRI/Document/output.pdf)

Photo 3.7 System of Wheat Intensification (SWI)

Photo 3.8 Sustainable Sugarcane Initiative (SSI)

3.8 Mechanized SRI

Use of simple implements like the marker and weeder in SRI has brought a revolution in partial mechanization of rice cultivation. Motorised weeders and modifications of existing machine transplanters to suit SRI are also being undertaken.

Recognizing that the initial labour-intensive nature of SRI could be a barrier for adoption by farmers with large land areas of Punjab in Pakistan, a set of agricultural implements were designed for mechanizing the operations of SRI which included:(1) a machine for making raised beds and doing precision-placement of compost and fertilizer; (2) a water-wheel transplanting machine that makes pits (~6cm) in the bed at 22.5 cm intervals. Each pit is filled with water, and a single seedling (10-days old) is dropped into the pit by hand; and (3) a tractor-mounted precision weeder. The raised beds allowed water-saving furrow irrigation periodically. Initial trials were conducted in 8 ha during 2009 with 10-day-old seedlings planted at 22.5 cm spacing in both directions. Fertilizer and compost were placed precisely in a band for each hill, and mechanical weeding was carried out. The results showed an average yield of 12.84 t ha^{-1} with a 70% reduction in irrigation water application (Sharif, 2011).

3.9 Summary

The six principles of SRI are not all there is for successful rice growing. There needs to be good land preparation (not unique to SRI), practices like seed selection and/or seed priming, integrated pest management (IPM) to control any threatening diseases or crop predation, etc. SRI is not a matter of abstractions and assertions, but rather is part of a substantial body of agronomic knowledge, and it can be presented as such.

This does not mean that all or even enough is known in scientific terms about how and why SRI practices produce the results that we see over and over again in a wide variety of agroecological environments. There are 10 or 20 years' worth of research still to be done on SRI by hundreds of researchers from many disciplines. The sooner and more comprehensively we get started on this, the better, because there should be many benefits resulting from such work (Uphoff, 2008).

All the current rice production concerns caused by climate change, water scarcity, labour scarcity, need for increasing input-use efficiency, and sustainable productivity can together be addressed by one single strategy: ADOPTION OF SRI.

4 SEEDLINGS FOR SRI

In transplanted rice cultivation, raising the seedlings in a nursery and then transplanting them into the main field is the generic practice.

Recommended seedling age for transplanting is usually 1 week per month of duration of the crop (seed to seed) and thus, for a 105-day,short-duration rice, 25-day-old seedlings are preferred, and for a 135-day medium-duration rice, 32-day-old seedlings are recommended. But in practice, large variations in seedling age can be found among individual farmers, depending upon water availability for the main field, labour availability for pulling seedlings out of the nursery and transplanting them, input availability, and financial constraints. For instance, water availability forces some farmers to delay their planting, so that sometimes 60 to 70 day-old seedlings are planted.

4.1 Importance of Younger Seedlings

In SRI, use of younger seedlings is one of the basic principles. 'Young' is a relative term. It is recommended to use seedlings 8-12 days old as a rule, usually with 15 days as the maximum, before growth potential gets compromised. But the plant grows according to a biological clock, not according to the calendar. So where temperatures are cold, 'young plants' may be 16-18 days old, even 20 days. The physical status of the plant is indicated by the number of leaves, and 'young' means between 2 and 3 leaves (Uphoff, 2008).

The immediate concern to any farmer when he is told to use 8 - 12 day old seedlings will be that the growth may not be sufficient to handle the pulling out and transplanting. Rice seedlings are, however, tougher and more resilient than they appear, provided that their roots are not abused.

One of the reasons for the profuse tillering observed with SRI is the use of younger seedlings. How this happens is still to be fully understood. Rice plant will produce tillers at any of its growth stages after planting. The ratooning (regrowth) of rice will prove this. If higher nitrogen is supplied, a rice crop can produce more tillers even at the panicle initiation stage.

Why transplanting young seedlings, usually before their 15th day after planting, can give better results can be explained in very concrete and convincing terms by understanding phyllochrons (phyllo = leaf, chron = period of time). Phyllochrons are intervals and patterns of plant growth that govern the emergence of phytomers, i.e., units of tiller, leaf and root from the apical meristem at the base of the plant (Nemoto et al. 1995; Stoop et al. 2002). Depending on how favourable or unfavourable are the conditions for plant growth, these periods are shorter or longer, ranging about 4 days (when conditions are ideal) and 10 days (when there are many constraints). If phyllochrons are shorter due to favourable conditions, more periods of growth can be completed before the plant switches from vegetative growth to reproduction (flowering and grain filling) resulting in more tillers and leaves.

According to Laulanié, if transplanting is done beyond the fourth phyllochron (after about 15 days), the first primary tiller does not emerge and all of the descendents of this tiller are lost. Similarly, if transplanting is further delayed by the length of another phyllochron, the second primary tiller and all its descendents 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 is increased, and fewer phyllochrons of growth are completed before panicle initiation.

According to Katayama's theory of tillering in gramineae species (rice, wheat, barley), young rice seedlings before the start of their fourth phyllochron of growth (i.e., up to about 15 days) have a potential for producing a large number of tillers and roots simultaneously because their roots have not been disturbed during the time before the start of root growth beyond the plant's initial tap root. Tiller production in rice happens at regular intervals. Depending upon factors like variety, temperature, and weather, one phyllochron may be 5-8 days, perhaps as short as 4 days if growing conditions are ideal, or as long as 10 days if they are adverse. That is, a new tiller/leaf/root unit, or a set of several or many such units, will be produced from the planted seedling in cycles of every 5-8 days. Then, from the base of each existing tiller, a new unit of tiller, leaf and root will be produced with a lag of one phyllochron. The exception is that the first primary tiller to emerge from the main (or mother) tiller comes after two phyllochrons, rather than one. Thereafter, primary, secondary or tertiary (daughter) tillers emerge continuously after a delay of just one phyllochron.

That there is no emergence or new tillers during the second or third phyllochron, i.e., after the emergence of the first (mother) tiller during the first phyllochron, means that there is a 5-15 period when the infant plant will be least disturbed by transplanting. The tiller numbers will increase semi-exponentially in this manner from the beginning of the fourth phyllochron, as could be seen from Table 4.1. The number of tillers (phytomers) emerging in each successive phyllochron is equal to the sum of those produced in the preceding two phyllochrons, which makes this what mathematicians call a Fibonacci series (http://en.wikipedia.org/wiki/Fibonacci_number).

It has been seen in many controlled trials that transplanting seedlings between their 5th and 15th days (especially in conjunction with other recommended SRI practices) leads to much greater tillering and more root growth (Uphoff, 2008). This is the period of the 2nd and 3rdphyllochrons, during which there are no new tillers or roots produced. This period starts after the plant has produced its first main tiller and its tap root (1st phyllochron) and before the emergence of the 1st primary tiller (4th phyllochron).

Rice plants that are transplanted after the start of the 4th phyllochron have less capacity to achieve their genetic potential, which is, however, also affected by being crowded together and continuously flooded, for example. Fr. de Laulanié only learned about phyllochrons after he had empirically discovered that 'young seedlings' have much more potential for growth. Phyllochrons, discovered by the Japanese plant researcher T.Katayama in the 1920s and 1930s, are not part of SRI, but they help explain the effects of SRI practices and are part of SRI when understood in terms of reasons why these practices produce better phenotypes (Table 4.1).

Table 4.1 Tiller production in rice

Phyllochron	0	1	2	3	4	5	6	7	8	9	10	11	12*
New tillers	0	1	0	0	1	1	2	3	5	8	12	20	31
Total tillers	0	1	1	1	2	3	5	8	13	21	33	53	84

↑ Transplanting (between phyllochrons 1 and 2)

(* 12thphyllochron = at 60 days from sowing if phyllochrons are 5 days long, with 12 leaves from the main stem)

Table 4.2 shows that at 14 days after sowing, if there have been excellent growing conditions and phyllochron length is very short, less than 5 days, there will be three leaves. That is, three phyllochrons would have been completed. Shallow planting of this young seedling with soil particles intact when removed from the nursery, not only avoids transplanting shock, but aids in quick re-establishment of the plant and retains its potential for profuse tillering and strong and deeper root growth that is otherwise lost when seedlings become older. If tillering continues up through the 12th phyllochron (with approximately 9 tillers in main stem – except according to Katayama and Laulanié, the primary tillering off the main stem only goes up to 6,

Table 4.2 Seedling age and leaf production (a field study)

Seedling age (days)	No.of leaves
10	2
13	3
17	4
21	5
27	6

or possibly 7, primaries, each of these starting to produce secondary tillers two phyllochrons after their respective emergences), potentially there would be 84 tillers, although not all of these might have developed. If growing conditions are ideal, and a 13th phyllochron of growth could be completed before the plant stops its vegetative growth and begins its reproductive phase, there could be about 135 tillers. Numbers of tillers over 100 are occasionally seen, and sometimes even over 200 tillers. This means that the plant has completed 14 phyllochrons and is into its 15th phyllochron of growth.

But, when a 27-day-old seedling is planted, already 6 phyllochrons (for example) would have been completed. The narrow spacing between seedlings in the nursery would not provide the seedlings with the environment they need to produce as many tillers as they could within this many calendar days because they would not have completed as many phyllochrons as would have been passed through with better growing conditions (spacing, soil aeration, etc.). When these seedlings are planted at 27 days, less than 6 tillers will have been produced from the main stem.

Transplanting younger seedlings is advantageous for early crop establishment by avoiding or minimizing transplanting shock (Pasuquin et al. 2008). When older-aged seedlings are planted, there will be transplanting shock which extends to a week or more, even two sometimes, without much growth of the plants.So, the avoidance of transplanting shock period also helps to add up to the total number of tillers. Another reason for higher tiller density is the increase in the number of days for tillering as the plants go to the main field 10-20 days sooner, when compared to conventional planting.

4.2 SRI Nursery

Since with SRI management, seedlings are planted singly in hills that have wider spacing, the number of seedlings required for planting an area is drastically reduced (Table 4.3 & Figure 4.1), and thus the seed requirement is accordingly less. That only 5 - 7.5 kg of seeds are required to plant 1 hectare is the first benefit from SRI practices that accrues to the farmer. Since the nursery area gets reduced from 800 m2 per hectare of main field to 100 m2 and since the need to maintain the nursery is only for 14 days, the nursery costs are reduced considerably, another benefit.

Table 4.3 Planting density and seedling requirement

Nature of variety	Hill spacing(cm)	Number of hills per sq.m.	Number of seedlings per hill	Number of seedlings per sq.m.
Conventional cultivation				
Short duration	15 x 10	66	3	200
Medium and long duration	20 x 10	50	3	150
SRI				
All varieties	25 x 25	16	1	16

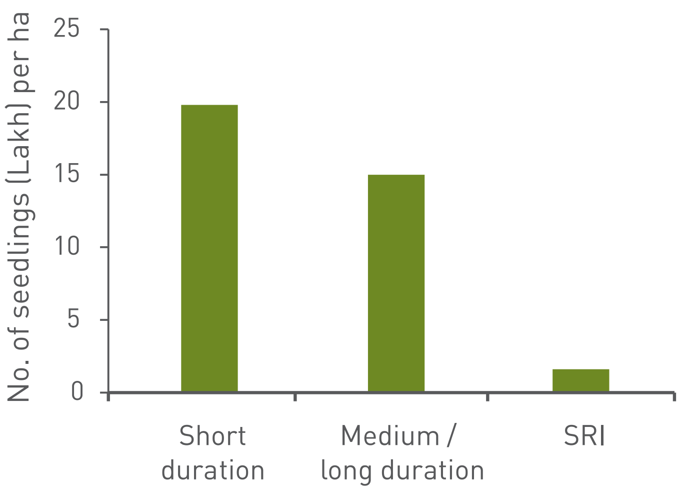


Figure 4.1 Number of seedlings required for conventional cultivation (with short-, medium-and long-duration varieties) and for all varieties in SRI.

Quality seeds are required for getting vigorous seedlings. Seeds which are stored for more than a year should not be used for sowing as the germination capacity and vigour of such seeds are reduced. Also seeds with black spots should be removed to avoid seed-borne diseases.

The density of stored seed diminishes during storage period, affected by place, environment and pest and diseases. Aged seeds like battery cells will lose vigour in due course of time. By using a salt solution in a bucket into which seeds are poured, to let denser seeds sink to the bottom and lighter ones rise to the top, good quality seeds can be separated. Ten litres of water can be put into a plastic bucket of 15-litres capacity. When a good quality fresh egg is dropped into the water, the egg will sink in the water and reach the bottom. Commercial-grade common salt (sodium chloride) is then added little by little and dissolved in water. As the density of the salt solution increases, the egg raise up. The addition of salt is stopped when the surface of the egg to the size of a 25 paise coin is visible above the solution in the bucket. Now the density of water is suitable for separating out quality seeds. To this salt solution, add 10kg of seeds. Those with low density float on the surface of the solution, whereas seeds with high density sink in the solution. The seeds floating on the surface of the solution are removed.

By this method, seeds can be upgraded. Dense, high-quality seeds result in vigorous seedlings (http://agritech.tnau.ac.in/seed_certification/seed_cm_rice%28varieties%29.html).

Since the seedlings are being planted at 14 days or less, it is necessary to raise them properly. For this, the raised bed nursery method has been proposed. With many fewer seedlings required, this greater care and attention becomes more feasible and will not increase time and effort.

SRI nursery should be prepared according to the soil conditions. But it is important to lay out the nursery close to the main field so that seedlings could be moved and re-planted in the shortest possible time. It would be ideal to have the nursery in one corner of the main field or adjacent to it. If farmyard manure is applied to the nursery soil, it should be well-decomposed; otherwise, the seedlings will be scorched.

The nursery to plant 1 hectare of field should be prepared on100 sq.m.area. For this, it is recommended to prepare 20 beds of 1 x 5 m each. Beds of 5 cm height can be prepared by scooping out the soil around the beds so that furrows are formed all around the beds. On the bed, a polythene sheet or used fertilizer bags should be spread as this prevents roots from going deeper, but beds can be prepared without sheets also. On the sheet, about 4 cm soil should be spread. In case the native soil is not so fertile, 95 grams of DAP for each 5 sq.m bed may be mixed into the soil before spreading it. Some farmers use a mixture of soil, sand and compost. Vermicompost is also used by some farmers for its higher quality. Bamboo rods could be laid on the sides of the beds to prevent sliding of the soil.

For each 5 sq.m bed, sprouted seeds (~375 g seeds prior to soaking) have to be sown evenly. The furrows could be irrigated to soak the soil in the beds above the sheet, diffusing laterally. Alternately or in addition, a rose can or watering can can be used to sprinkle water on the soil from above, as a garden would be watered. The nursery bed could be prepared in a wet field or a dry field depending upon the situation. If too much sunlight or fog is expected, the nursery could be covered with coconut fronds or rice straw for the first two days. This will protect against losses to birds or other creatures as well as shade the seeds or keep them warm. The method described above is a guideline only. At farmer level, nursery beds are prepared in different ways (Photos 4.1 to 4.6), but the aim should be to get seedlings ready for planting at the third leaf stage or before that.

Photo 4.1 Nursery bed in wetland

Photo 4.2
Nursery bed prepared with dry soil

Photo 4.3
Bed protected around the edges by bamboo poles

Photo 4.4
Bed prepared by using a wooden frame to have 0.5 sq.m beds

Photo 4.5
Dry nursery bed protected with rice straw in winter season

Photo 4.6
Community wet nursery

The growth environments in SRI nurseries prepared in different ways vary slightly, but this is welcome as farmers adapt the technique to local conditions. In Philippines, some farmers have grown good SRI seedlings in sand, to make separation easy for transplanting, and the seedlings are still dependent on nutrients from the seeds (in the seed sac) for their food supply. It is important to have soil for the seedlings which is very friable so that these can be separated easily, with minimal damage to the seedling roots. Nurseries with seedlings can be seen in Photos 4.7 to 4.10.

Photo 4.7 Mat nursery

Photo 4.8 Nursery prepared by using polythene sheet

Photo 4.9 Nursery reinforced with bamboo poles (Source : Association of Tefy Saina)

Photo 4.10 Nursery beds in strategic location (Source : Association of Tefy Saina)

Photo 4.11. Seedling density in conventional nursery

Photo 4.12. Seedling density in SRI nursery

The lower seedling density in the SRI nursery, in comparison with conventional nursery, can be discerned from Photos 4.11 to 4.12.

Use of 14-day-old seedlings grown in a dapog nursery was previously known in Tamil Nadu but did not catch on. Based on preliminary trials, 14-day-old seedlings were recommended in Tamil Nadu for SRI. At this stage, there will be 3 leaves in the plant. If the nursery bed is properly prepared with sufficient organic manure, the seedling growth will be reasonably easy to handle. Seedlings of 8-12 days are also used by some farmers. Using seedlings with 2 – 3 leaves is in the ideal range.

4.3 Removal of Seedlings from the Nursery

It is important to remove the seedlings carefully from the nursery along with the soil intact around their roots, and to plant them immediately. This helps the seedlings to establish themselves in the main field quickly. In the beginning, this might look cumbersome. But handling a much-reduced number of seedlings and having the nursery near to the planting area (if the nursery is in the same field) will reduce time requirements, and most persons once they gain experience with handling young seedlings find this method less laborious. It is important to gain confidence in the method from experience, since at first there may be some nervousness that the tiny seedlings will not survive. But rice is a member of the grass family, and very hardy if the roots are not injured or misused.

Farmers adopt different ways to remove seedlings from the nursery according to their convenience (Photos 4.13 to 4.18). It is preferable to use a simple tool, like a hand trowel or khurpi, to remove the seedlings out of the nursery lifting from below and causing minimum damage to roots. If the seedlings do not attain good enough growth to plant in one week's time, urea @ 0.5 % may be sprayed to accelerate growth.

In many places, the same labourers who are employed for planting can be used to remove the seedlings from the bed without involving additional cost. By reducing the size and number of seedlings, their task is made easier.

The seedlings being young should be transported to the main field very quickly and planted. In the conventional method, the seedlings are pulled, bundled and transported to the main field which is sometimes far away taking considerable time. Sometimes, the seedlings are planted the next day. These problems do not exist in SRI, which recommends that seedlings have only 15-30 minutes between removal from the nursery and replanting in the main field. In fact, unlike the conventional method, removing seedlings and distributing them for planting is far less expensive as no extra labour is required.

Photos 4.13 to 4.18 Removal of seedlings from nursery beds

4.4 Summary

Seedlings for SRI require special attention as they are to be planted at a very young stage. Selection of good quality seeds and treating them for proper germination and growth are vital to have quality seedlings. There are several improved and indigenous ways of preparing nursery beds. The extra care in raising, removing and transporting good-quality seedlings is more than repaid by better growth, better health, and better yield. Because seedling number is so much reduced, by 80-90% or more, there is not an increase in labour needed. But there is an increase needed in attention to the quality and vigour of seedlings. It is also important to handle the seedlings with care while removing them from the bed without much damage and trauma to the roots. It is self-evident that without good quality seedlings to start with, the result at the end of the season will be inferior.

5 MAIN FIELD PREPARATION AND TRANSPLANTING

Preparing the main field for transplanting properly is important for crop establishment, for water use efficiency, and for control of weeds and certain pests. The process commences much before the nursery is started to get the proper soil tilth. The field is dry-ploughed (if fallow) 2-3 weeks before planting, and a disc harrow or rotovator is used to pulverize the clods. The practice of growing green manure (Sesbania, Sunnhemp, Daincha) before rice and incorporating it in the soil or applying green leaf manure (Gliricidia) is a good way of supplying organic manure. If organic matter is incorporated in-situ, puddling is directly done. Generally, farmers apply farmyard manure before dry ploughing, and sometimes it is done after puddling. Puddling with a gauge wheel-mounted tractor or a mini-tractor is very common. Basal doses of fertilizers are to be applied before the last puddling.

5.1 Field Leveling and Drainage

The field preparation for SRI does not differ from the conventional method, but there is an emphasis on leveling the field as the establishment of young seedlings will be adversely affected in an uneven field. Young seedlings planted in depressions can die from submergence. Also, leveling helps to reduce the water requirement and weed problems. At the same time, it facilitates proper crop establishment and stand. Because land leveling increases yield, it is a good investment. A large part of the increase in yield is due to improved weed control as improved water coverage from better land leveling reduces weeds by up to 40%. Experimental results have showed yield increase up to 24% due to leveling (http://www.knowledgebank.irri.org/landprep).

Photos 5.1 and 5.2 Indigenous field leveling

Leveling is achieved by using a bullock-drawn wooden plank or tractor-drawn implements. Many indigenous ways are also practiced by farmers (Photo 5.1). Laser leveling is also becoming popular in some areas (Photo 5.2). A local mechanic without professional training has developed a tractor attachment that can be used for puddling and simultaneously rotovating and leveling (Photo 5.3). The Tamil Nadu Department of Agriculture is contemplating to introduce laser levelers for SRI on custom hiring (Photo 5.4).

Field drainage is also an important component in SRI that will allow the rapid removal of excess water and avoid flooding for long periods of time. Rice farmers in Sri Lanka doing direct seeding invariably provide sufficient field drains. It is recommended to provide small drains on the peripheries of the main field (Photo 5.5), or across the field. In Tripura, given heavy rainfall, the SRI recommendation is for putting in a shallow drain across the field in place of every 9th row. In some places, drainage channels are formed along with raised beds for SRI (Photo 5.6). Farmers who could not achieve proper leveling as an ad hoc measure may tie a brick into a rope and drag it along depressions in order to facilitate draining of stagnating water.

In many irrigation systems, especially with tanks and in undulating terrains, field-to-field (cascade) irrigation is followed, due to lack of proper irrigation and drainage channels. Thus, there will be no control for either irrigation or drainage. Loss of applied nutrients and social problems crop up in such systems, so it is better to have independent inlets and outlets for each field.

Photo 5.3 Puddling, rotovator-cum-leveler developed by a local mechanic-cum-farmer in Tamil Nadu

Photo 5.4 Laser leveling

Photo 5.5 Drainage channel at the periphery

Photo 5.6 Drainage channel with raised bed

5.2 Transplanting

In SRI, seedlings have to be planted at wider spacing than conventionally practiced. In general, the recommended spacing for short-duration rice is 15 x 10 cm and for medium- and long-duration rice, it is 20 x 10 cm. But, farmers generally do not adopt these recommendations. Mostly random planting is done in strips of approximately 3 m with 30 cm gap in between strips. Since the planting is often done on contract (with payment for a set number of labourers per acre), the plant density is highly variable.

In SRI, 25 x 25 cm spacing is recommended as the optimum spacing in most situations. Though the number of seedlings planted will be only 16 m-2, the management practices in SRI facilitate profuse tillering which could not be seen in conventional practice. The reasons for higher tiller density in SRI are: (1) younger seedlings have higher vigour to produce tillers and additional number of days to produce tillers, (2) competition between plants for light and nutrients is reduced due to wider spacing, and (3) soil churning by weeder has a specific positive effect on the growth of the plants.

The immediate concern of a farmer when told to have only 16 plants per sq.m will be whether there will be sufficient tillers. But this apprehension will be warded off when he sees the field after 3-4 weeks, when accelerated tillering begins. SRI farmers should be forewarned that their crop will look quite inadequate for the first 3-4 weeks. Many are tempted to give up in the first several weeks because neighbours' fields look greener. But they need to have patience and confidence that their young and sparsely planted seedlings – if not suffocated by flooding and if benefiting from soil-aerating weeding – will overtake the more numerous, older plants when they move into their 8th, 9th or 10th phyllochron of growth while the other, more slow-growing plants only attain 6 or 7 phyllochrons of growth before panicle initiation.

5.3 Number of Seedlings Per Hill

The recommendation in conventional cultivation is to use 2-3 seedlings per hill. But in reality, 4-6 seedlings and even more are planted. In SRI, only one seedling has to be planted per hill (Photo 6.6). If the main field has been leveled properly, all the seedlings will establish well. Otherwise seedlings in depressions where water stagnates may die.

Photo 5.7 Single seedling at two leaf stage with soil intact

5.4 Spacing

It is recommended to start with 25 x 25 cm spacing, but to try wider and maybe smaller spacing in some parts of the field, to see what distance is optimum for the farmer's particular conditions. The more fertile the soil, the higher will be the yield attained from having fewer plants, because each plant achieves a larger, deeper and healthier root system, supporting a bigger, better-functioning canopy. In Tamil Nadu, 20 x 20 cm spacing was initially recommended, but many farmers found that the tillering was such that the weeder could not be used after 30 days. After experimental evaluation, the recommended spacing was revised to 25 x 25 cm.

The main objective of square planting is to be able to use the mechanical weeder in perpendicular directions. What is now understood is that this is not only better for weed control, but better for promoting root growth and plant performance. The weeder's dimensions have to suit the spacing. With 20 x 20 cm spacing, only a rotary weeder could be used (see Chapter 8 for more information on this).

It is well known that plants widely spaced grow more profusely, but the objective in rice farming is to maximize the number of fertile tillers per sq. meter, not per plant. When other SRI practices are also implemented, even radically reduced number of plants can produce more tillers per unit area, and the panicles usually have more grains, and the grains themselves are usually heavier (Uphoff, 2008).

There is historical evidence that wider spacing and single seedling was adopted by farmers in Tamil Nadu a century ago. Vaidyalingam Pillai (1911) mentions the use of ropes for row planting, with spacing between rows of 1 ½ feet (45 cm) and within the row, a spacing of 1 foot (30 cm). This spacing was for a single rice crop situation. For rice-rice relay cropping (a new method of rice cultivation described by Vaidyalingam Pillai), the row spacing for the first crop was 2 ½ feet (75 cm), and the relay crop is planted in the middle between the rows when the first crop was at flowering stage. With 45 x 30 cm spacing, the number of seedlings (single seedling per hill) per square meter would be only 7 plants. This was an even more radical reduction in plant density than with SRI.

Spacing has to be adjusted by the farmer according to his field conditions and soil fertility after gaining experience. The goal is to optimize spacing between plants so that they have as the most access to the sunlight and soil nutrients that are available.

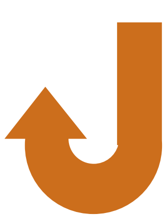
5.5 Method of Planting

Fr. de Laulanié from his decades of work with rice plants discovered what a large difference can be achieved by careful handling of seedling roots, by not letting them dry out, by not knocking dirt off them before planting, etc. Especially he found out, and taught farmers, that seedlings should not be pushed downward into the soil, as this inverts their root tips upward, making the plant's profile like a J, with the root tip pointing upward. This delays resumption of growth for days, even weeks, while the root tip takes time to get reoriented again toward downward growth. Instead of being plunged into the soil (and into hypoxic soil when there is standing water on the paddy field), the tiny plant should be laid into the soil gently, with roots extended as horizontally as possible, so that its profile is more like an L.

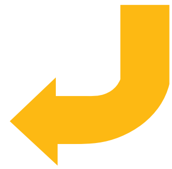
This helps minimize what is commonly called 'transplanting shock.' With such a shape, with root tip not pointed upward, the plant can more quickly resume growing downward again. Any reduction in this post-transplant adjustment time enables plants to complete more phyllochrons of growth before the plant switches into its reproductive phase. It is the latter phyllochrons which give the most profuse tillering (Uphoff, 2008).

It would be ideal if the roots of transplanted seedlings could all point downward, so no time and energy would have to be spent in reorienting the roots to grow downwards. It is practically impossible to get all roots facing downward after transplanting (Figure 6.1). Alternately, it is suggested that the roots be at least horizontally placed. It is observed that this practice is generally not easily adopted by contract labourers, who prefer to continue past ways and to transplant as quickly as possible, rather than to transplant carefully. With explanation and possibly incentives, labourers should be gotten to transplant in a way that respects plants' growth needs and potentials.

Roots pointing downwards



Roots bent upwards



Roots placed horizontally

Rice seedlings when transplanted should be handled very carefully to avoid trauma to the roots, being planted quickly after removal from the nursery, to avoid root desiccation, and shallow (just 1- 2 cm). A criterion is for replanting to occur within 15-30 minutes from removal.

Guiding Spacing

Square planting at the 25 cm spacing recommended for SRI could be achieved by several means. Farmers find their own ways of doing it also. The initial method for getting precise spacing of transplanting was to use ropes (either coconut fibre or nylon) to guide the line of planting (Photos 5.8 to 5.11). Small sticks or coloured cloth pieces can be inserted at 25 cm spacing to show the place of planting within the row. Markings can also be done with paint. The rope can be held by two persons who can move it after every 25 cm row is planted, or it can be tied between stakes, 25 cm apart, on the edges of the field. If a line of seedlings are planted at the two sides of the field, the guide rope could be easily operated. Markings may also be made on a bamboo stick or aluminium pipe.

Photo 5.8 Rope with markings for planting

Photo 5.9 SRI line planting

Photos 5.10 and 5.11 Square planted fields using rope

An innovative farmer put small holes in a bamboo plank at 25 cm and plugged the holes with small plugs to show 25 cm spacing. To guide the between-row spacing, he used a 25 cm rod. A wooden frame with spikes spaced at 25 cm is also used criss-cross by some farmers.

An improvement upon ropes has been the design of roller-markers made of metal rods developed by a farmer in Andhra Pradesh which has become a very useful tool in SRI now. It is interesting that such a roller marker was being used in 1960s (Photo 5.12). When the roller is pulled over the level main field, criss-cross lines are formed on the soil, and the intersecting points indicate the place for planting the seedlings (Photos 5.13 and 5.14). The field should have been leveled well, and the soil condition should be such that the marks made by the marker do not disappear due to excess moisture. If the field is drained the previous day, the required moist condition should be sufficient to pull the marker. Several innovative markers are being developed and used (Photos 5.15, 5.16, and 5.17).

Roller-markers greatly reduce the time required to score precise grids on the surface of the field. They are easy to operate and involve less drudgery than the rope methods for laying out a grid pattern on the field.

Photo 5.12
Roller marker used in 1966
(Stout, 1966)

Photos 5.13 & 5.14 Use of roller marker and planting at intersections

Photos 5.15 & 5.16 A simple wooden marker for square planting and transplanting in Sri Lanka

Photo 5.17 An efficient indigenous marker used in Philippines

For labourers who are used to conventional random planting, square planting might look cumbersome. But they will soon realize they have to plant only 10-20% as many seedlings as they would normally handle. Anyone who sees a field immediately after planting with single seedlings and wider spacing will have apprehension about its productivity. There will be a period of confidence-testing for the farmers when they adopt SRI the first time. This apprehension will vanish after 3-4 weeks, when accelerating tillering begins.

Raising community nurseries with staggered sowing is advantageous to share the resources and also to assist those trying out SRI in some villages.

5.6 Summary

The main field preparation for SRI does not differ much from conventional method, but there is more emphasis on leveling and on provision of drainage. Practice makes square planting easier and less time-consuming. Training of the labourers is essential to avoid resistance initially. Square planting is required to permit intercultivation to be undertaken in both directions. This ensures not just better weed control, but also active soil aeration, one of the main reasons why SRI plants perform better than their conventionally-grown relatives.

6 WATER MANAGEMENT

Developing the water resources and irrigation infrastructure in countries was one of the major achievements of Green Revolution as water application and control was crucial to realize the benefits of high-yielding varieties. The increased food production that the Green Revolution provided was associated with increased water and fertilizer use, together with changes in the varieties planted.

In recent years, further large-scale development of river and groundwater resources is less acceptable and less cost-effective than in the 1960-1990 period, when most of the world's 45,000 large dams were built. Sadly, much of the irrigation water infrastructure built in recent decades is becoming obsolete, as reservoirs are silting up, irrigation networks are crumbling, groundwaterlevels are falling (IWMI, 2002). Human-induced pollution of rivers and groundwater sources poses a serious threat to the utilization of these waters for human consumption and agricultural use, and indeed to the sustainability of agricultural production systems.

On the one hand, the fundamental fear of food shortages encourages ever greater use of water resources for agriculture. On the other, there are competing demands from other sectors to divert water from irrigated food production to other users and to meet the needs of natural ecosystems. Many believe this conflict is one of the most critical problems to be tackled in the early 21st Century (Global Water Partnership, Framework for Action, 2000, p. 58). Deterioration in the distribution structures of canal irrigation systems, over-exploitation of groundwater resources, and the neglect of tank and reservoir systems are seriously affecting the availability of water for agriculture.

The high priority to improving water-use efficiency in agriculture has been well recognized because this sector is the largest consumer of water. Water constraints cannot be resolved without changes in the food production sector (Bindraban et al. 2006). Increasingly, water is becoming a scarce resource in the world as well as in India (Table 6.1).

India's irrigation sources are monsoon-dependent. The agricultural growth during the post-independence period can be attributed to huge investment (Rs. 2,31,400 crores) in irrigation projects which resulted in more than a three-fold increase in the gross irrigated area, from 22.6 m ha (1950-1951) to 76.3 m ha (1999-2000). Exploitation of groundwater has been increasing during this period (Figure 6.1), and in some regions there is over-exploitation, leading to annual declines of 10-20 cm in groundwater levels.

Table 6.1
Changes in per capita water resources in selected Asian countries

Country	Per capita available water resources (m^3)		
	Year 1955	Year 1990	Year 2025
China	4,597	2,427	1,818
India	5,277	2,464	1,496
Vietnam	11,746	5,638	3,215
South Korea	2,940	1,452	1,253
Pakistan	10,590	3,962	1,803
Sri Lanka	4,930	2,498	1,738

Source : Hossain and Fischer, 1995

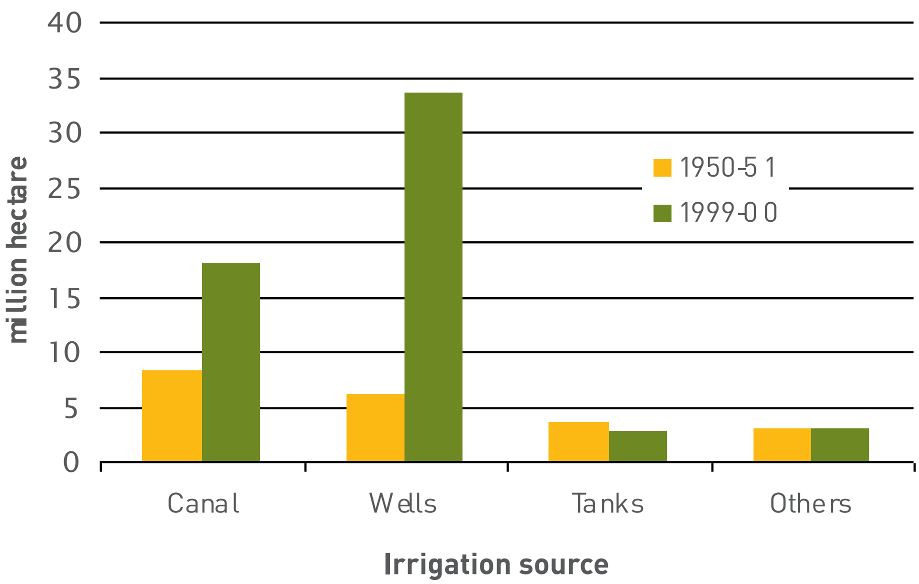


Figure 6.1 Area irrigated by different sources in India

Source: Report of the Sub-Committee on More Crop and Income per Drop, Ministry of Water Resources, Govt. of India, 2006)

Table 6.2
Water availability and utilization for rice in India

Annual precipitation (km^3)[a]	4,000
Annual utilizable surface water (km^3) [a]	690
Annual utilizable ground water (km^3) [a]	396
Water withdrawal for agriculture (km^3) [a]	524
Gross irrigated area, 1999-2000 (million ha) [b]	76.3
Gross rice area, 1999-2000 (million ha) [c]	45.2
Gross irrigated rice area, 1999-2000 (million ha) [d]	25.0
Water withdrawal for rice cultivation (km^3) (Computedbased on the assumption that 32.8 % of total irrigated area is under rice. The actual use will be more as water is impounded in the field for rice, unlike other crops)	172

a Source: Rakesh Sharma et al.(2005)

b Source : http://agrocoop.nic/in

c Source : USDA/ irri.org

d Source : FAOSTAT/ irri.org

Rice cultivation accounts for the major consumption of available water for irrigation in India as in other rice-producing countries (Table 6.2). The country needs to increase its food grain production to 450 million tonnes by the year 2050 to meet its food security needs. Increase in paddy production will have to come from the same cultivated area or even from a reduced area.

6.1 Rice and Water

The estimated water use (by evapotranspiration) of all harvested rice fields in the world is some 859 km3 per year. It takes on an average 1,432 liters of evapotranspired water to produce 1 kg of rough rice. Irrigated rice receives an estimated 34-43% of the total world's irrigation water, or about 24-30% of the entire world's developed freshwater resources (http://irri.org/knowledge/irri-training/knowledge-bank).

Rice is the only cereal that can tolerate water submergence, and this helps to explain the long and diversified linkages between rice and water. For hundreds of years, natural selection pressures such as drought, submergence, flooding, and nutrient and biotic stresses led to a great diversity in rice ecosystems. The plant's adaptation strategies include surviving under submerged conditions without damage, by elongating its stems to escape oxygen deficiency when water tables rise, and conversely withstanding severe drought periods.

Historically, rice cultivation has been a collective enterprise. The investment and shaping of the landscape that are needed for the ponding system (or terraces) requires collective organization within the community. Water management also relies on collective interest; crop and water calendars must be organized for largeblocks of fields in order to manage water efficiently and organize such work asland preparation, transplantation, and drying for harvesting (http://www.fao.org/rice2004/en/f-sheet/factsheet1.pdf).

Rice survives under submerged conditions because it forms air pockets (aerenchyma, a kind of secondary respiratory tissue) in its roots. Around 30 percent of the cortex around the central stele (xylem and phloem) of rice plant roots growing in submerged conditions disintegrates to form these air pockets that allow oxygen to diffuse into root tissues. However, this adaptation limits the plant's ability to absorb nutrients (Uphoff, 2008).

Growing under submergence has the following benefits: (1) assurance of water supply to plants, (2) increased supply of nitrogen and phosphorus and control of organic matter dynamics,(3) neutralization of the soil pH, particularly making acid soils more neutral and facilitating the solubilization and uptake of certain nutrients, (4) prevention of weed development, thereby reducing the need to use herbicides or reducing the amount of labour required,(5) prevention of damage by blight and harmful animals, insects and other living things, (6) maintaining an even soil temperature, (7) generation of water percolation and groundwater recharge,which are often beneficial for other water uses, and (8) capacity for flood control: field bunds have a significant water storage capacity,which reduces peak flows under heavy rains.

The field-level control of water for submerged rice growth has led, over the centuries, to the development of certain water management and cultivation practices that produce some beneficial outcomes. The terrace system inmountainous areas is a typical product of the ponding technique and allows cultivation even on steep slopes. This technique is instrumental in preventing soil erosion and landslides (http://www.fao.org/rice2004/en/f-sheet/factsheet1.pdf).

Under flooded paddy conditions, most – about 75% – of the roots remain in the top 6 cm of soil a month after transplanting, forming a 'mat' close to the surface to capture as much dissolved oxygen as possible from the water. Such shallow roots fail to extract nutrients from a large volume of soil, however, resulting in dependence on inorganic fertilizers. Standing water, in fact, suppresses yield by limiting the ability of the roots to respire.

This slows down the plant's metabolism, its ion transport, and the resulting growth.

One adverse consequence of flooding paddy soils is that anaerobic conditions limit the abundance and diversity, and hence activity, of aerobic soil organisms. These include most of the beneficial soil biota, i.e., N fixers and P solubilizers. Keeping fields inundated also means that rice plants forgo the benefits of mycorrhizal fungi, which enhance the growth and health of about 90% of plant species when functioning as symbiotic endophytes in plant roots and giving plants access to a much increased volume of soil.

Further, the soil in flooded fields will have less good structure since it will have suppressed populations of fungi, all of which are aerobic. Fungi are largely responsible for the production of glomulin in the soil, which is a major factor in the formation of soil aggregates and aggregate stability. Also, without earthworms and other aerobic fauna, pore space will be less extensive, and the passage of water and air through the soil, carrying beneficial nutrients and gases, will be less well-distributed in the soil. Also, the release of harmful gases generated in the soil into the atmosphere will be impeded (Uphoff, 2008).

It is reported that many of the physiological diseases of rice plants are the result of the highly reduced state of the iron and manganese oxides in the soil under flooded conditions (Stout, 1966).

It has been widely believed that rice plants grow and produce better in standing water (De Datta, 1981). But in fact, most irrigated rice roots degenerate by the plant's stage of flowering when grain formation and filling begins, by as much as 78%, according to Kar et al. (1974). Rice plants can survive in standing water - because their roots form air pockets (aerenchyma) through collapse of cortex cells around the stele to permit the passive diffusion of oxygen to sustain cell functioning. But they do not thrive. Both farmers and scientists have perpetuated the belief that flooding gives superior yields, but this is incorrect (Uphoff, 2008)

Rice can be cultivated with the same supply of water as other cereals, and the distinguishing feature lies in the fact that unlike other cereals, rice can tolerate standing water or swampy condition for its growth (Parthasarathy, 1963). Bulandi et al. (1964) have reported that submergence depths of 0,5,10,15 and 20 cm resulted in no significant difference in yields, and that intermittent irrigation produced greater yield than submergence. According to Lafitte and Bennett (2002), rice is not an aquatic species and does not necessarily need to be grown under inundated conditions.

6.2 Water Requirements of Rice

The average water requirement of rice for growing under stable water supply is 220 to 280 g per g of matter. This is almost equivalent to other plants with similar type of photosynthesis as rice (i.e., C3 pathway). However, rice has some sensitivity to water stress and some tolerance to water excess. Flooded rice requires 900-2250 mm of water depending on the water management, soil and climatic factors (Table 6.3). It can be seen from Table 6.3 that on an average, over half of the water provided for rice irrigation is 'lost' in evaporation and transpiration (transpiration being a natural physiological process, this is unavoidable and not exactly a loss), while between 20 and 30 percent is lost to seepage and percolation.

Table 6.3:
Average water requirements of irrigated rice

Farm operation/ process	Consumptive use of water (mm day^{-1})
Land preparation	150 – 250
Evapo-transpiration	500 – 1,200
Seepage and percolation	200 – 700
Mid-season drainage	50 – 100
Total	900 – 2,250

One hectare of an irrigated rice field that yields 4,500 kg of rough rice requires 15,000 cubic meters (15 million litres) of water under current practices of flood irrigation. This means that about 3,400 litres of water are required to produce 1 kg of rice. This water requirement is three to five times greater than what is needed by other cereals like wheat or corn (Table 6.4), and accounts for 20-30 percent of the total variable cost of rice production. Another way of putting this is that the water needed to grow one kilo of rice with standard irrigation methods is the same as what one person requires daily (40 to 50 litres per capita per day) for as long as four months, according to the standards of per capita minimum water requirements set by the World Bank.

Table 6.4
Water requirement per crop

Crop	Typical water ? requirement (litre kg^{-1})
Cotton	7,000 –9,000
Rice	3,000 – 5,000
Sugar	1,500 – 3,000
Soya	2,000
Wheat	900
Potatoes	900

The current recommendation for water management for rice varies with the source of the recommendations in different areas. According to ICAR, in India it is ideal to maintain 2-5 cm water throughout the growing season (ICAR, 2010). Keeping the depth of ponded water at around 5 cm minimizes water losses by seepage and percolation (http://www.knowledgebank.irri.org/factsheetsPDFs/watermanagement). After crop establishment, continuous ponding of water is thought to provide the best growth environment for rice and will result in the highest yields, although this belief is now challenged.

After transplanting, water levels are recommended to be around 3 cm initially, and gradually increased to 5-10 cm with increasing plant height. Water level in the fields should be kept at 5 cm at all times during the reproductive stage (http://www.knowledgebank.irri.org/bmp). This recommendation is at variance with SRI experience and recommendations, however.

In Tamil Nadu state, the recommendation is for irrigating to 5 cm depth one day after the previously ponded water disappears from the surface. This recommendation is not practiced by many farmers, however, due to various reasons, the main being that water is not priced, so they bear no cost for excessive use of water. Usually farmers keep their rice fields flooded as in Photos 6.1 and 6.2. Electricity shortages and an unreliable system of rotating water supply in canals (the turn system) also give farmers incentives to keep their rice fields continuously flooded to the extent that they can.

Photo 6.1 Typical flood irrigation ecosystem in a delta

Photo 6.2 Conventional flooded rice field

Until recently, this profligate use of water by rice has been taken for granted, justified with the belief that it is beneficial for rice production. But there is a growing awareness among the public that irrigated rice production is the largest source of consumption for fresh water, and any reduction in water demand for rice farming will have far-reaching significance. Even if freshwater availability remains constant, which is unlikely, it can be expected that water availability per capita will decrease progressively until population stabilizes, possibly in the 2060s. Further, competing and increasing demands for water from the industrial and urban sectors will make it imperative for agriculture in general, and for rice production in particular, to become more water-saving in its production methods, quite apart from responding to continuing population growth.

The predicted climate changes in the decades ahead are likely to further accentuate the impending water crisis. These wake-up calls imply compulsory changes in the current practices adopted for rice production. To quote from the Prime Minister Dr. Man Mohan Singh's inaugural address to International Rice Congress held at New Delhi in October, 2006: “Rice grown under irrigated condition is facing the threat of water shortage. This is forcing a paradigm shift towards maximizing output per unit of water instead of per unit of land”.

Needed increases in rice production are thus constrained not only by paucity of land for cultivation, but also by water scarcity, which is common in areas where the conventional water-intensive method of irrigated rice cultivation through inundation has prevailed. The future of the country's rice production will depend heavily on developing and adopting strategies and practices that will use irrigation water more efficiently at farm level.

As mentioned earlier, most of the global rice cultivation is carried out on irrigated land. In India, the total irrigated rice area in 2006-2007 was around 24.87 million hectares. This is about 57 percent of the country's total area under rice crop. Under such circumstances, the steady decline in the availability of fresh water (Table 6.5) is bound to have an impact on rice production.

In the world's 'rice bowls', particularly in China and India, acute water scarcity combined with competing demands on freshwater sources has raised the spectre of currently productive agricultural areas becoming desiccated and devastated, of rice bowls becoming dust bowls, triggering conflict.

Table 6.5
Declining and estimated decline in per capita freshwater availability in India

Year	Per capita fresh water availability in india (m³)
1951	5,410
1991	2309
2001	1,902
2025	1,401
2050	1,191

Source: Rakesh Sharma et al. (2005)

The FAO has forecast that by 2030, the global harvested area under rice will increase by 11 percent, with South Asia accounting for almost 75 percent of that increase. This corresponds to an increase of over 24 per cent in South Asia's current harvested area. It is not easy to see where this increase will come from in South Asia as arable area has been rather fully developed. But one must ask pointedly: if the current methods of production remain unchanged, where will the water for such an area increase come from? In this scenario of deepening water crisis and rice-yield stagnation, it is imperative that new cost-effective methods that will use water more effectively be urgently investigated and practiced.

There is a pressing need to adopt alternate, eco-friendly and pro-people production methods, that make effective use of water, while raising production. Given the looming hydrological poverty, it is necessary to reduce the water consumption for irrigated rice cultivation.

6.3 Water-saving Practices for Rice

It is instructive to note that 100 years ago it was recognized by a farmer in Tamil Nadu that rice does not require full and continuous flooding. A farmer named Vaidyalingam Pillai (1911) followed a water management regime of shallow flooding of only 2.5 cm during the first week after planting; 4 cm during 2-3 weeks, and 5 cm afterwards. More than 5 cm flooding was not provided. The fields were irrigated every 4-5 days. This gaja planting method as Vaidyalingam Pillai called it contradicted the accepted adage among Tamil farmers: 'neeruyara nelluyarum' (paddy yield will increase in accordance with flood water depth), and it went against the Tanjore district farmers' habit of flooding their fields to the top of their bunds (Thiyagarajan and Gujja, 2008). He concluded that more flooding lowers rice plants' tillering, despite the belief of'experienced people that more water will increase their yield. He invited the opinion of experts on this departure from common practice once they saw his results.

The importance of alternate wetting and drying of paddy fields has been recognized 100 years ago. Dharmarangaraju (1913) made the following points with regard to irrigation of paddy rice:

(1) Air in the soil is as important as water, and water and air should alternately enter, drain, and leave the soil;

(2) There should be optimum warmth in the soil for proper growth of the crop, for which there should not be water in the soil all the time;

(3 Experiments conducted from 1872 at Saidapet Government Farm have shown that farmers use excessive water for their irrigation;

(4) Water was being used at 5 cm depth for the first 30 days from planting, and at 10 cm depth afterwards; this amounted to 840 cm depth for kuruvai (120-day crop) and 1,440 cm depth for the long-duration samba (180-day) crop.

(5) Experiments conducted in South Arcot and Krishna districts had shown that 60 to 210 cm of water is sufficient for wetland crop;

(6) Yield increases were proportionate to reduced water supply;

(7) With the reduced irrigation, the water saved can be used for 5 times more area from available water sources; and

(8) It is incorrect that rice requires standing water.

The advocacies of Vaidyalingam Pillai and Dharmarangaraju a century ago show a great conceptual breakthrough, proposed at a time when there were no conflicts about sharing river water, and when the general assumption was that the more paddies are flooded with water, the higher would be their yields. Even today, when we have so much pressure on the availability of water for irrigating rice, and conventional flooding is still practiced, we are surprised that reducing water supply to rice had been advocated already in the early 20th Century as a way to raise the productivity of irrigated rice cultivation.

Currently discussed water-saving practices in rice cultivation are: (1) alternate wet and drying (AWD) method, (2) aerobic rice, (3) resource-conserving technologies, and (4) the System of Rice Intensification. We will consider them below in turn.

Alternate Wet and Drying (AWD)

Under certain conditions, allowing the soil to dry out for a few days before reflooding can be beneficial to crop growth. In certain soils that are high in organic matter, toxic substances can be formed during flooding that can best be removed (vented) from the soil through intermittent soil drying.

Intermittent soil drying also promotes stronger deeper root growth which can help plants resist lodging better, in the case of strong winds later in the season, and it gives them more capacity to resist subsequent water stress and drought. Intermittent soil drying can also help control certain pests or diseases that require standing water for their spread or survival, such as the golden apple snail (http://irri.org/knowledge/irri-training/knowledge-bank).

AWD is a water-saving technology that lowland (paddy) rice farmers can apply to reduce their water use in irrigated fields. In AWD, irrigation water is applied to flood the field for a certain number of days after the disappearance of ponded water. The paddy is left to dry out as the water percolates through the soil. Hence, the field is alternately flooded and non-flooded. The number of days of non-floodedsoil in AWD between irrigations can vary from 1 day to more than 10 days.

A practical way to implement AWD is to monitor the depth of ponded water on the field using a 'field water tube'. After irrigation, the depth of ponded water will gradually decrease. When the ponded water has dropped to 15 cm below the surface of the soil, irrigation should be applied to re-flood the field with 5 cm of ponded water. From one week before to one week after flowering, ponded water should always be kept at 5 cm depth. After flowering, during grain filling and ripening, the water level can drop again to 15 cm below the surface before re-irrigation.

AWD can be started a few days after transplanting (or with a 10-cm tall crop in direct-seeding). When there is significant weeds pressure, AWD can be postponed for 2-3 weeks until the weeds have been suppressed by the ponded water. Local fertilizer recommendations as for floodedrice can be used. Fertilizer N should preferably be applied on the dry soil just before irrigation. (http://www.knowledgebank.irri.org/factsheetsPDFs/watermanagement)

Aerobic Rice

Aerobic rice is grown like an upland crop such as wheat, in soil that is not puddled, flooded, or saturated. The soil is therefore "aerobic," i.e., with oxygen, throughout the growing season, as compared to traditional flooded fields, which are anaerobic, i.e., unsupplied with oxygen (http://beta.irri.org/networks15). Aerobic rice is a production system in which especially developed "aerobic rice" varieties are grown in well-drained, non-puddled, and unsaturated soils (Photo 6.3). With appropriate management, the system aims for yields of at least 4-6 t ha^{-1}.

The usual establishment method is dry direct-seeding. Aerobic rice can be rainfed or irrigated. Irrigation can be applied through flash-flooding, furrow irrigation (or raised beds), or sprinklers. Unlike flooded rice, the irrigation - when applied - is not intended to flood the soil, but just to bring the soil water content in the root zone up to field capacity. Seed is dry-seeded manually or mechanically at 2-3 cm depth in rows spaced 25-30 cm at a seeding rate of 80 kg ha^{-1}. Aerobic rice can save as much as 50% of irrigation water in comparison with lowland rice. Weed infestation will have to be managed appropriately.

Photo 6.3 Aerobic rice, Karnataka

Resource-Conserving Technologies (RCTS)

Irrigated rice-wheat systems are practiced in the states of Punjab, Haryana, and parts of Uttar Pradesh and in Punjab (Pakistan). Rice is usually grown in the wet summer season (May-June to October-November) and wheat in the dry winter season (November-December to February-March). The soils and crop management undergo drastic changes during the wet season rice to upland wheat in winter season.

Resource-conserving technologies have been adopted in the rice-wheat rotational cropping system which include :

- Non-puddled transplanted or direct-seeded rice alternated with wheat planted with zero-till or reduced tillage;
- Permanent raised-bed planting system; and
- Surface seeding of wheat and other crops

In the permanent-bed planted rice-wheat system, the savings in irrigation water are around 35-40% (Gupta et al. 2002).

6.4 SRI Water Management

The irrigation regime in SRI is to provide the growing plants with sufficient but never excess water (le minimum de l'eau, in Fr. de Laulanié's words), so that the roots do not suffocate and degenerate (Uphoff, 2008). SRI offers great scope not only to overcome the water crisis, while at the same time increasing rice production and enhancing the livelihood of rice farmers.

Soil should be mostly aerobic most of time, and not continuously saturated so as to benefit the growth and functioning of both plant roots and aerobic soil biota. Fr. de Laulanié's recommendation was to apply a small amount of water daily, preferably in the late afternoon or evening, just a few centimeters, and to let it sink into the soil overnight, draining any standing water the next morning. This had the advantage of 'insulating' the field during the colder night hours, conserving warmth in the soil which would otherwise radiate away, and of exposing the soil during the day to sunlight and air. A layer of standing water on the field would reflect much solar energy again from the soil (Uphoff, 2008).

This latter consideration will be more important in cooler climates, but not in tropical zones where soil temperature will be high in any case. Farmers who have labour constraints may find this method difficult to practice as it requires daily water management. It is more precise and can give higher yields, but farmers' labour may have opportunity costs that will make it reasonable to economize on labor time for water management with less precise and frequent applications.

Many SRI farmers now practice alternate wetting and drying (AWD), flooding their paddies for a few days (the number is quite variable, depending mostly on soil characteristics and weather), and then letting them remain dry for a few days (also a variable number) after the water has percolated into the soil. This requires less management effort from the farmer and produces reasonably good results with less labour input.

If farmers are carefully observing their plants' growth and status, they can adjust their amounts and timing of water with practice to suit their plants' needs best. This strategy of water management is not advisable where farmers have heavy clay soils, that crack seriously when water content falls below a certain level and the soil becomes very hard. For such soils, small daily applications will

Photo 6.4 Shallow irrigation in flat field

Photo 6.5 Irrigation to keep the soil moist in raised bed

be needed for SRI methods to succeed, maintaining sufficient soil moisture to avoid hardening, but the time invested will be repaid.

In Tamil Nadu, the water management for SRI is prescribed based on field experimentation. Up to panicle initiation stage, it is recommended to irrigate the field to 2.5 cm after the previously irrigated water disappears and hairline cracks develop. After panicle initiation, irrigation is done to 2.5 cm depth one day after the previously ponded water disappears from the surface. At the hairline cracking stage, soil will not be dry, but it will still be moist (Photos 6.4 to 6.7).

Irrigation intervals vary with soil texture. Fine-textured clayey soils with higher field capacity need irrigation at longer intervals, while coarse-textured light soils with lower water-holding capacity require irrigation at closer intervals, consuming in the process more quantity of irrigation water.

Such shallow irrigation can save water up to 40% (Table 6.6), and there will not be any yield loss due to this. The data from the experiment conducted in DRR, Hyderabad showed 22-29% saving of water (Mahender Kumar et al. 2007).

Photo 6.6 Field to be irrigated

Photo 6.7 Hairline cracks and weeder-made depressions

Table 6.6
Research finding on SRI water management (Coimbatore, 2001)

	Recommended practice	SRI
Irrigated water (m3 ha^{-1})	16,634	8,419.0
% water saved	-	49.4

Matsushima (1980) emphasized managing water temperature during the rooting period (keeping it below 35ºC) as one of the important management practices for high yields. If the temperature is higher than 35ºC, he advocated exposing the ground surface to the air so that the soil loses the latent heat of evaporation and the soil becomes cooler than when it is covered with water. According to him, exposing the paddy soil to the air prevents various diseases and root rot induced by the excessive reductive conditions of the soil.

Exposing the soil to the air is repeatedly done in the SRI irrigation practice, and thus it inadvertently helps in other ways for better crop growth. SRI-practicing farmers feel that it also leads to the venting of unfavourable gases from the soil, although this remains to be studied. Matsushima's contention that optimum oxidizing conditions which characterize good soil conditions could be achieved by intermittent irrigation is fulfilled in SRI.

Apart from getting higher yields and using less water with SRI water management, there are benefits from fuel savings where groundwater must be pumped and in avoiding water conflicts among farmers relying on the same source of water.

Thus far, SRI farmers using the recommended irrigation methods have not observed reduced grain yields. Instead, maintaining unflooded soil conditions appears to favour increases in grain yields.

A genuine apprehension of the farmers would be that the limited irrigation might lead to weed infestation. Following SRI recommendations, weeder operations should commence 10-12 days after planting and be done every 10-12 days thereafter, so that weeds do not have the opportunity to come up. The active soil aeration that this achieves is also a benefit for the growing plants in addition to removing weeds. Churning them into the soil also enhances soil organic matter as a form of green manure. This is discussed separately in Chapter 8.

The important point that farmers should remember is that their paddy rice does not require flood water, and it is enough to keep the soil moist. Farmers using groundwater will realize savings of water, time and electricity from SRI practice in irrigation. If SRI is adopted in an entire command area, the water that is saved will be sufficient for use in other areas or for other purposes.

6.5 Water Productivity

The efficiency with which crops utilize water for their growth, and how differences in the supplying water to the crops can affect the efficiency of its utilization, can be ascertained by calculating various parameters like water use efficiency and water productivity.

Water productivity of rice ranges from 0.15 to 0.60 kg m-3, while that of other cereals ranges from 0.2 to 2.4 kg m-3 (Cai and Rosegrant, 2003). Inefficient structures and operation of irrigation systems in many cases and ensuing suboptimal water management have led to low water productivity for many crops.

Globally, the additional amount of water that will be needed in the future to support agriculture directly will depend on the gains that can be made in water productivity. If there are no gains in WP, the current average annual amount of agricultural evapotranspiration, currently 7,130 cubic kilometres, will need

Water use efficiency (WUE) :

$$\frac{\text{total biomass or grain production}}{\text{amount of water (delivered or depleted or transpired)}}$$

Water productivity (WP) :

$$\frac{\text{net benefits (grain yield or value of output)}}{\text{amount of water used}}$$

to nearly double in the next 50 years. With appropriate water-saving practices being followed, this needed increase could be held down to 20-30% (Comprehensive Assessment of Water Management in Agriculture, 2007).

Under field conditions, lack of moisture and low fertility are the most important factors which limit yield and hence contribute to less efficient water use by crops.Water productivity can be increased through biological water-saving (by exploiting the genetic and physiological potential of the plants) and by physical water-saving through means such as:

- Improved varieties (e.g.,cultivars with fast-growing roots)
- Better methods of irrigation
- Water-saving cultivation practices
- Better soil management (soil health improvement for water absorption and retention)
- Improved soil-water management practices (e.g., no-tillage, mulch applications)
- Introducing supplemental irrigation for stress situations (e.g., from groundwater)

Developing varieties for drought tolerance and suitable for aerobic rice production are under progress. Transforming the C3 rice plant into a C4 species by genetic engineering of photosynthetic enzymes and making required changes in anatomic structures such as stomata is another approach, still uncertain and certainly costly.

Furrow irrigation, raised-bed irrigation, and micro-irrigation methods of irrigation are being tried in rice cultivation (Photo 6.8). Improving soil health to rectify soil conditions, increasing water absorption and retention, and enhancing soil fertility and nutrient supply can greatly help to increase yields, and thus WP. Effective tillage (e.g., leveling) and innovative mulching approaches (e.g., polythene mulching) can also contribute to reduction of water use.

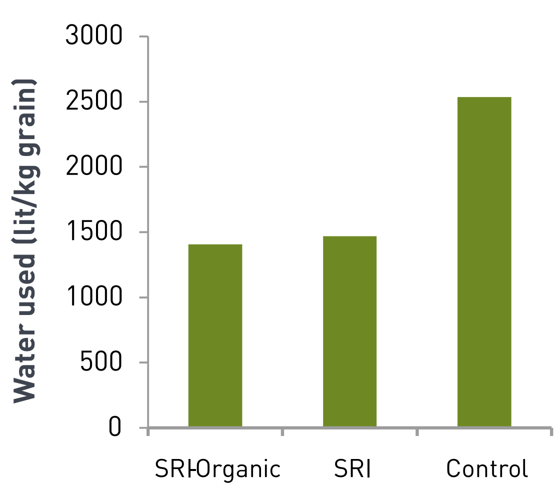
Photo 6.8 Sprinkler irrigation being developed for rice at North Eastern Complex, ICAR,Patna

Experimental evidence has shown the benefits of SRI type of irrigation. Sandhu et al. (1980) and Li et al. (2005) found no adverse effect on rice yields with intermittent irrigation at 1-5 days after disappearance of standing water, even without the other agronomic changes recommended for SRI practice. Just intermittent irrigation could save 25-50% of water compared to continuous submergence without yield loss.

Increased water productivity to the extent of 96% due to water-saving irrigation without detrimental effect on grain yield has been reported by Thiyagarajan et al. (2002). Ceesay et al. (2006) observed nearly three times higher grain yield with SRI practice (7.3 t ha–1) compared with continuous flooding (2.5 t ha–1). Ceesay et al. reported a six-fold increase in water productivity, i.e. paddy rice yield per unit volume of water. More details on the effects of SRI can be seen in Chapter 10.

Thakur et al. (2011) found that 1,463 litres of water were required to produce 1 kg of rice with SRI management, while 2,778 litres of water were needed under standard management practice. Water saving was to the extent of 22.2%, due mostly to reduction in seepage and percolation losses. Lin et al. (2011) studied the effect of increasing the proportion organic nutrients in soil fertilization and found that aerobic irrigation increased water-use efficiency, and this was highest when there was 50% organic fertilization, matched with equal nutrient value of synthetic fertilizer, rather than 25% or 100% organic fertilization.

In a systematically conducted experiment at Hyderabad in the rabi season of 2009-2010, SRI crops under organic and inorganic nutrient management resulted in 8.1 and 8.2 t ha–1 grain yield with 12.6 and 13.7% yield increase over the control plots, respectively (Gujja and Thiyagarajan, 2010). Careful measurement of water use has showed that water productivity is higher under SRI, and water savings reached 37.5% and 34.2% under SRI-organic and SRI methods, respectively (Fig. 6.2 and 6.3).



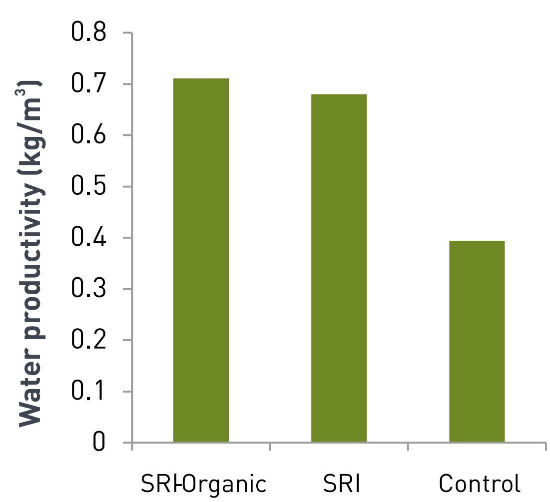


Figure 6.2 and 6.3 Water (irrigation and rainfall) used and water productivity in SRI and control rice crops, rabi 2009-2010, ICRISAT, Hyderabad. (Gujja and Thiyagarajan, 2010).

6.6 Water Management in Rainfed SRI

In areas where transplanting is possible with rain water, normal SRI with transplanting is practiced with benefits similar to, if not equal to, irrigated rice production with SRI management. The two issues associated with water management in this situation are: (1) to control excess water when there is heavy downpour, and to keep it from harming the crop; and (2) manage drought stresses when there is not sufficient rain. SRI management for plants, soil, water and nutrients appears to help plants in rainfed areas to tolerate water-stress periods as it promotes deeper root growth and also enhances the life in the soil.

In an observation at Sarvar in Gujarat state, during a dry spell for 10 days starting 5days after transplanting, major losses occurred in the control plots, but an increase in biomass was observed in SRI. This was attributed to better root growth in the SRI plants and to organic manure application to the soil. The yield increase was to the extent of 83% (Patwardhan and Patel, 2008). Transplanting timing is affected if there is no timely rainfall (Dutta and Pati, 2008). Application of SRI principles in rainfed rice has been successful in Cambodia and Myanmar (Uphoff, 2008; Kabir and Uphoff, 2007).

In a study conducted in Philippines, mulching with gliricidia cuttings was tried to conserve moisture in rainfed SRI (http://ciifad.cornell.edu/sri/countries/philippines/binuprst.pdf). Trials with an indigenous variety known for its drought tolerance, using five different spacings, gave yields averaging 7 t ha^{-1}, without irrigation.

With climate change, increasing variability of rainfall, and the growing competition for water and land, SRI offers a new opportunity for increasing the crop produced per drop of water and for reducing overall agricultural water demand if the new water management practices are used more widely. This is important because the agricultural sector in many parts of the world accounts for the largest share of water use (World Bank Institute, 2008).

6.7 Summary

Water-saving with SRI cultivation practices is one of the best opportunities that we have in terms of improving national water security. What is important is to educate the farmers to the fact that better rice production does not require flooding; indeed, rice does not benefit from this if the other plant, soil and nutrient practices of SRI are followed, favouring the growth of plants with deep, vigorous root systems accompanied by biodiverse populations of aerobic soil biota. It is also necessary that water delivery systems ensure proper drainage facilities which can help keep the soil in SRI fields mostly aerobic.

7 NUTRIENT MANAGEMENT

Like any other crop, rice also requires all the sixteen essential elements that plants need for growth and completion of their life cycle. The essential nutrients are classified into major nutrients (macronutrients) required in large amounts by the plants, and those (micronutrients) that are required only in trace amounts by the plants. However, all are equally important because each plays a role in the growth and development of plants. Of the nine major elements, carbon is derived from the atmosphere, and hydrogen and oxygen are derived from water, and thus these are not considered in nutrient management discussions.

Since crops require mineral nutrients, the supply must be adequate for the targeted yield. As the natural nutrient sources provide most but not necessarily all of the crop's requirements, additional nutrients often are required. The concept of soil fertilization in its modern comprehensive form and on the basis of targeted high soil fertility has proved to be a powerful tool for enormous yield increases in areas of intensive agriculture.

In many situations, the use of fertilizer is severely limited by water shortages and/or economic constraints. Cropping under such low-yielding conditions must, therefore, rely on the 'capital' of farm nutrient resources. This makes it necessary to manage more effectively the nutrient flows and cycles within a farm (Figure 7.1). Furthermore, the nutrients exported from the farms to the cities in the form of food should be recycled, i.e., industrial food processing and communal waste products should be used as a cheap nutrient source according to recommendations.

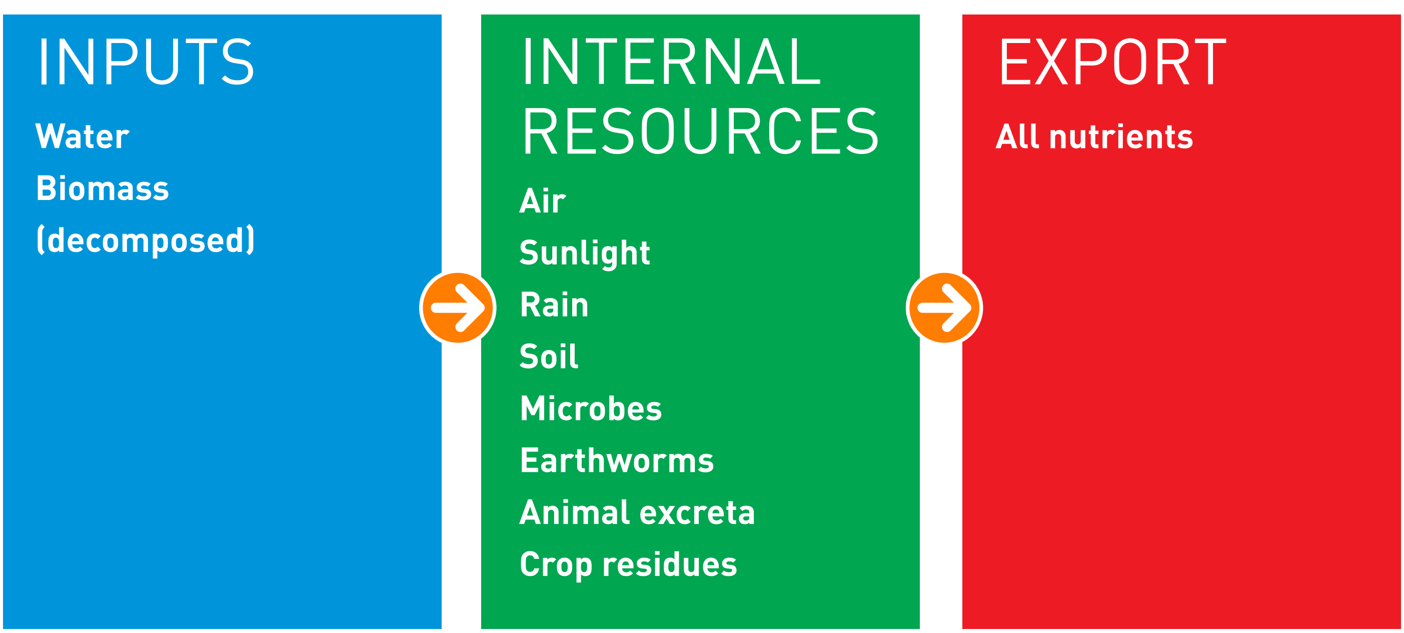


Figure 7.1 Nutrient balance in a closed farm

7.1 Soil Health

Soil is a dynamic, living, natural body that is vital to the functions of terrestrial ecosystems and represents a flowing, unique balance between the living and the dead. The number of living organisms in a teaspoon of fertile soil (10g) can exceed nine billion, more than the human population of the earth (http://www.bibalex.org/supercourse/lecture/lec2871/003.htm).

Soil health is judged by soil physical, chemical, and biological properties. Topsoil can be quickly lost through erosion or degradation, whereas it takes years, decades, centuries and millennia to build up soil under natural conditions. Plants themselves, through root exudation, contribute to enhancing the soil's fertility, and soil amendments of decomposed biomass in almost any form can have a positive effect on the build-up of soil resources.

Topsoil is a non-renewable resource within human life spans. The most important step for soil management is to know the soil's status, often characterized in terms of soil health. This is a figurative expression representing the productivity level and the resilience of particular soil for a given crop under a certain set of conditions.

Soil health is defined as the ability of soil to perform or function according to its potential, and this changes over time due to human use and management or to unusual natural events (Mausbach and Tugel, 1995). Soil health can be enhanced by management and land-use decisions that weigh the multiple functions of soil, and it is impaired by decisions which focus only on single functions, such as crop productivity.

Soil health is inseparable from issues of sustainability. Soil organic matter is critical in most soils to maintain the soil structure which provides optimal drainage, water-holding capacity, and aeration for the growth and health of crops and soil biota. Organic matter also contributes significantly to cation exchange capacity (CEC), which enables the soil to buffer and maintain the concentration of many nutrients in solution.

Production systems that rely heavily on inorganic nutrient supplies and neglect soil organic matter contain inherent inefficiencies. Soils which are incapable of storing nutrients require excessive or continuous addition of soluble nutrients for crop growth, to compensate for losses and inefficiencies. Soluble nutrients that are in excess of plant and microbial needs will pass beyond the reach of plant roots, with potential adverse consequences for groundwater quality, compounded by the loss of valuable and possible dwindling nutrient resources.

Soil organisms must be acknowledged as key architects in nutrient turnover, organic matter transformation, and physical engineering of soil structure. The microbial populations of the soil alone encompass an enormous diversity of bacteria, algae, fungi, protozoa, viruses and actinomycetes. While the specific functions and interactions of the majority of these organisms are still not well elucidated, their roles as functional groups in soil health regeneration and maintenance are becoming increasingly known.

Long-term experiments on various cropping systems of different agro-ecological regions and soil types have revealed that the continuous use of inorganic nitrogen fertilizer and its indiscriminate application, ignoring the need for soil organic matter to maintain the soil biota, leads to long-term, and even some short-term, deterioration, affecting yield sustainability due to deficiencies of macro- and micronutrients like S, Mg, Zn, and Mn. Over application of some nutrients which stimulate the growth of plants and/or microorganisms that are favoured depletes the stocks of other nutrients which are needed by all plants and soil organisms.

Just as a healthy person is resistant to stresses and diseases and thus will use drugs sparingly, a healthy soil can suppress soil-borne diseases, reduce pesticide requirements, and buffer plants from water and nutrient stresses (Wolfe, 2006).

7.2 Soil and Plant Testing

Intensive research on nutrient supply to crops has led to better quantitative understanding of the dynamic nature of both the nutrient release from soil as well the demand of the crops during their growth period. This has led to changes in the approaches used for generating fertilizer recommendations.

Soil testing is necessary as most agricultural soils are deficient in one or more nutrients, and poor (deficient) soil leads to poor growth and plant stress. Soil test results also provide vital information for diagnosing soil-related constraints. Soil testing is any measurement of physical and/or chemical and/or biological properties of the soil, but by variable means of determination of the soil productivity that give estimations of available nutrients. It should therefore be more than a soil chemical test in order to be able to interpret the analysis and produce a fertilizer recommendation that will give optimum economic yields.

Standard methods are used for analyzing samples for soil testing. The soils are tested with respect to the following determinations:

- pH, or the soil's reaction indicating acidity or alkalinity of the soil.
- Total soluble salts as indicated by electrical conductivity values which show the degree of salinity.
- Organic carbon, which gives an indirect measure of available nitrogen.
- Other available nutrients, e.g., P, K and other selected nutrients suspected of being in short supply.

The biological properties should also be studied before making fertilizer recommendations, although this is not commonly done. Biological assessments are presently more complicated and more expensive than chemical measures. The soil flora and fauna population play significant roles in maintaining soil health and serve as an important indicator for assessing the soil's health. Physical properties like soil porosity, bulk density, and water-holding capacity also need to be considered when assessing soil health.

Plant analysis indicates whether the plants contain the concentrations of essential nutrients necessary for optimum growth and can help to generate recommendations for correcting nutrient deficiencies before they reach a critical level.

7.3 Fertilizer Recommendations

Modern agriculture has depended heavily on the introduction and use of inorganic fertilizers to supply soil nutrients, particularly the macronutrients of nitrogen, phosphorus and potassium. The advantages of inorganic fertilizers are that they are easier to apply; often not very expensive, especially if subsidized by the government; have more predictable nutrient content; and organic nutrients are sometimes simply not available in sufficient supply. One of the major reasons for the success of Green Revolution in terms of achieving national self-sufficiency in food production was the use of inorganic fertilizers, promoted often by government subsidies.

Soil test-based fertilizer recommendations and generic recommendations are generally available throughout the country, and there are a lot of variations in the rates due to variations in seasons and durations of the crop. It is advisable to adopt a soil test-based fertilizer recommendation so as to adjust with the native fertility of the soil. This will ensure sufficient nutrient supply, but also avoid unnecessary use of external nutrients when there is already sufficient supply available in the soil.

Various decision-support systems and simulation models have been developed to assist farmers. IRRI has developed a Site-Specific Nutrient Management (SSNM) system which takes into account the native capacity of the soil to support a crop. The total fertilizer N needed by rice to achieve a profitable target yield is determined from the anticipated yield gain, applied fertilizer N, and a targeted efficiency of fertilizer N use. Fertilizer N is supplied to match the crop's need for supplemental N, especially at the critical growth stages of active tillering and panicle initiation. Enough amounts of fertilizer P and K are also applied to overcome deficiencies and sustain profitable rice farming (http://beta.irri.org/ssnm/index.php/SSNM-made-sim.html).

7.4 Integrated Nutrient Management (INM)

With the introduction of modern varieties and cropping systems, the annual crop demand for nutrients has increased rapidly, and deficiencies of nutrients have become a constraint in soils that was previously not considered as being a risk. Therefore, a field-specific, integrated nutrient management in intensive cropping systems is essential rather than rely on soil test-based recommendations of inorganic fertilizers alone.

Integrated nutrient management differs from the conventional nutrient management by more explicitly and systematically considering nutrients from different sources, notably organic materials; nutrients carried over from previous cropping seasons; the dynamics, transformation and interaction of nutrients in soil; interactions between and among nutrients; and their availability in the rooting zone and during the growing season in relation to the nutrient demands of the crop. In addition, it integrates the objectives of production, ecology and environment, and is an important part of any sustainable agricultural system.

The appropriate contribution of mineral fertilizers, organic manures, crop residues, compost and/or N-fixing crops varies according to the system of land use and the ecological, social and economic conditions. The above factors all need to be considered when making fertilizer recommendations. For plants to utilize chemical fertilizers effectively, the soil in the root zone must have substantial capacity to retain and provide exchangeable cations. Cation exchange capacity (CEC) is considerably enhanced as the soil organic matter content increases. Utilizing organic means to maintain soil fertility and judiciously adding inorganic nutrients gets best results. Enhancing the soil organic matter content is essential for maintaining soil health.

7.5 Foliar Nutrition

Foliar nutrition has many advantages like easy absorption, acceleration of growth, translocation of metabolites, and ultimately greater yield increase. Higher efficiency of plant uptake of nutrients applied through its foliage compared with soil application has been reported. Foliar nutrition is recommended for several crops to help overcome nutrient deficiencies and also to promote growth. The recommendation for rice suggested in Tamil Nadu is two sprays of a foliar combination that has 2% DAP + 1% MOP + 1% urea, first at panicle initiation, and then at the first flowering stages in addition to the application of recommended doses of N, P, K through the soil.

Panchagavya, an organic preparation using various cows' products, is very popular with organic farmers. In Sanskrit, Panchagavya means the blend of five (pancha) products obtained from the cow. All these five products are individually called Gavya and are thus collectively termed as Panchagavya. This contains ghee, milk, curd, cow dung, and cow's urine.

Panchagavya had reverence in the scripts of Vedas (devine scripts of Indian wisdom) and is part of Vrkshyurveda (Vrksha means plants and ayurveda means health system). The texts on Vrkshayurveda are systematizations of the practices that farmers followed at field level long ago, placed within a theoretical framework. It defined certain plant growth stimulants; among them, Panchagavya was an important one that enhanced the biological efficiency of crop plants and the quality of the resulting grains, fruits and vegetables (http://www.agricultureinformation.com/forums/organic-farming/15995-panchagavya-how-make.html).

7.6 Use Efficiency of Nutrients

In most soils, application of chemical fertilizers is necessary if high-yielding, fertilizer-responsive cultivars of crops are grown with improved cultural practices. There are two reasons for not getting expected yield levels even after the application of chemical fertilizers to crops. Either the recovery of fertilizer nutrients is poor, or the efficiency with which the nutrients are taken up and used for grain production is low.

The factors governing fertilizer efficiency include the selection and adoption of: a) right source, b) right quantity, c) right time, and d) right method of fertilizer application. Among these, the application of the fertilizer nutrients at the right time based on the needs of the crop, the peak period of absorption, and the thoroughness of assimilation of a particular nutrient, have been found much useful to increase the use-efficiency of the applied nutrients without any additional cost for the fertilizer nutrient input.

A large number of experiments have been conducted in India to determine the optimum timing of fertilizer application for different crops, and it is generally agreed that for most crops, fertilizer application at the critical stage(s) of crop growth is necessary for getting highest yields and for improved use-efficiency of fertilizer nutrients. Recovery of the fertilizer nutrients applied at different growth stages may vary widely.

Slow-release fertilizers and fertilizers coated with material like neem cake enhance the efficiency with which the nutrients are utilized by controlling the release of the nutrients and minimizing losses.

7.7 Nitrogen Management

Rice and wheat are highly responsive to nitrogen (N) and are the major consumers of fertilizer N in the country. The efficiency of applied N in Indian soils for rice generally ranges from 25 to 45%, compared to 50 to 60% in upland crops. Several new approaches, theories, concepts, and tools have been employed; and several N management techniques like split application of N, better methods of application, integrated N management, slow/controlled release of N, modified forms of N fertilizers like urea super-granules, exploiting biological N fixation, leaf colour-based N application, etc., have come up for adoption by farmers.

The results of a number of experiments have revealed that rice generally responds significantly up to 120 kg N ha^{-1}, although in some places positive response to higher doses of N has also been reported. Applications in excess of this are largely wasted and have negative environmental impacts on groundwater. G x E interactions (between genetic potentials and environmental factors) have a great role on the response of the crop to N application.

Split application comes out as a key feature of N recommendations. This invariably leads to lower losses of N and better N-use efficiency. Besides being easy to adopt, it also provides a certain flexibility to the farmer in tailoring N applications to crop and weather conditions. Split application at critical stages of crop growth is the single most widely used practice for increasing nitrogen-use efficiency.

The exact schedule of split applications (number and timing of splits) is not the same for all conditions. The number of splits needed usually increases: i) in coarse-textured sandy soils, particularly under flooded /irrigated systems or high rainfall regions; ii) where larger amounts of N are to be applied; and iii) where the crop is of longer duration.

Leaf Colour Chart-Based Nitrogen Application

The leaf color chart (LCC) is an inexpensive and simple tool to monitor leaf greenness and guide the application of fertilizer N to maintain optimal leaf N content, applying N only when there is demand by the crop. Thus, this is a need-based N application and ensures better use-efficiency. A standardized plastic LCC with four panels (Figure 7.2), ranging in color from yellowish green to dark green, has been developed and promoted across Asia.

The threshold value requires calibration for each variety and location. In this approach, a standard level of N at different growth stages of the crop is recommended to be applied at each time of measurement if the observed LCC value falls below the threshold level, and the level of N is a fixed dose for that stage. The total N applied will vary as N is applied only if the LCC value falls below the threshold value.

In Tamil Nadu, LCC-based N application is recommended as part of SRI practice. The procedure for LCC-based N application is as follows:

1. Measure color of the youngest, fully-expanded and healthy leaf from 10 randomly-selected plants.

a) Place the leaf on top of the leaf color chart (LCC). Do not detach the leaf.

b) Repeat leaf color measurements every 10 days, starting from 14 days after transplanting (DAT) or 21 days after seedling emergence, and continuing to panicle emergence.

2. Apply N fertilizer whenever the leaf color is below the critical value.

a) Use a critical value of 3 or 4, depending on the crop establishment method, season, and cultivar.

b) Validate critical value for local conditions.

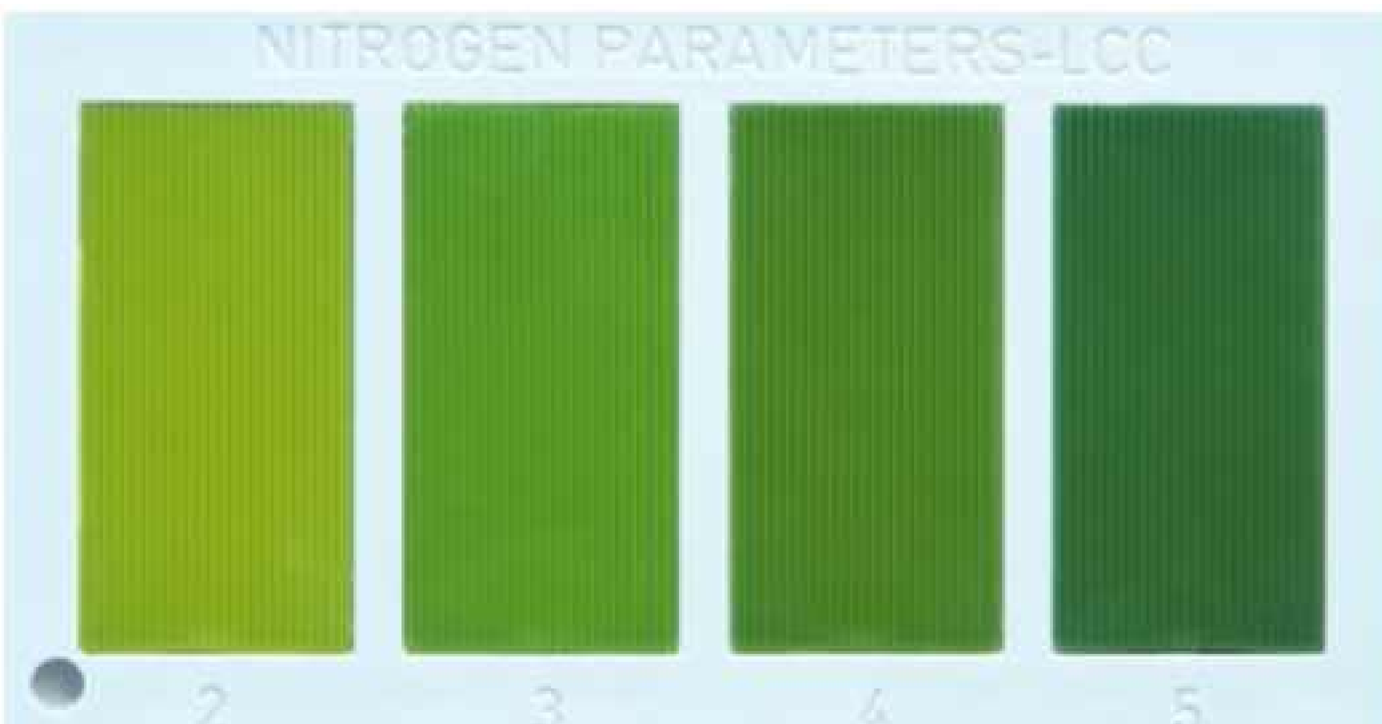


Figure 7.2 Four-panel Leaf Colour Chart

7.8 Organic Manures

Use of fertilizers and chemicals in agricultural production has been regarded as a necessity to produce more food to meet the requirements of a growing population. Introduction of high-yielding varieties has contributed to food security in the country. Yield maximization has been the major objective, and sustainability issues have remained unattended to. The yield plateau in some crops, extensive use of chemicals for some crops, chemical residues reported in the food chain, and environmental hazards have brought up the issue of reverting to older practices of "organic farming" in irrigated agriculture. Organic farming aspires to achieve a complex mix of agronomic, environmental, social, and ethical objectives, which set the target for the development of a farming system in its particular location.

The addition of organic materials in the form of manures and crop residues plays a vital role in restoring and maintaining soil fertility while improving the physical, chemical and biological properties of soil. Organic manures, besides supplying essential nutrients, will add to the favourable conditions for soil microbes by being a source of carbon for them. The role of microbes even if fertilizers are applied should not be ignored. For example, if urea is applied, the nitrogen from it will become available to the plants only if the amide form of nitrogen in urea is converted into an inorganic form (NH4 or NO3) by the microbes nitrosomanas and nitrobacter. It should always be remembered that plants take up nitrogen in inorganic form only, and they do not recognize the source of it, i.e., whether it is from an organic or inorganic source. This said, however, the process of availability and uptake is inherently biological. Large applications of inorganic N can alter the populations of soil biota, including N-fixing microbes, in ways that are not advantageous to soil and plant nutritional processes.

Continuous application of organic matter in the form of compost, farmyard manure, and plant residues is needed to maintain or increase soil organic carbon. Soil organic carbon levels are a good indicator of native fertility. In general, paddy soils are fairly poor in organic carbon (~ 5 g kg-1). Thus, it is essential to use more organic biomass with most soils to achieve and sustain good fertility status.

Utilization of crop residues can reduce the need to use inorganic inputs, recognizing that this would also reduce the pollution of surface and groundwater, in addition to lowering costs of production. In India, nearly 100 to 115 MT of crop residues are either wasted or burnt, depriving arable soils of this restorative input.

Crop residues have been traditionally used to improve and maintain soil productivity. It is estimated that 120 x 106 kg yr-1 rice residue, out of 180 x 106 kg yr-1 (assuming that 1/3of the residue is used as feed for animals and for other purposes), can be returned to the soil to enhance soil quality; this will contribute 2.604 million tonnes of N+P2O5+K2O to the soil, considering the nutrient content in rice straw as 0.61% N, 0.18% P2O5 and 1.38% K2O (Tandon, 1996).

The recycling of crop residues has the advantage of converting a surplus farm waste into useful products for supplementing the nutrient requirement of crops and for saving foreign exchange otherwise spent on fertilizers. Growing green manure crops, their in-situ incorporation, and applying green leaf manures are also recommended practices, but very few farmers adopt these practices.

Many farmers who have previously been applying organic sources of nutrients before using inorganic fertilizers have ignored them completely in recent years, with the result that soil health in terms of organic carbon and microbial activity has been jeopardized. The steady decline in animal population in recent decades has meant reduction in supplies of cattle manure, and farmyard manure has become a difficult resource to obtain.

7.9 Soil Biofertility

The fertility of soil depends not only on its chemical composition, but also on the qualitative and quantitative nature of the microorganisms inhabiting it. Mineral nutrients, organic matter, and biochemical growth factors necessary to meet the microbial nutrient requirements generally exist within appropriate ranges of temperature, moisture and pH for microbial growth. It is stated that one hectare foot (one hectare to a depth of 30 cm) contains 2 to 10 metric tonnes of living microorganisms.

Soil microorganisms play many important roles in natural ecosystems. Without microorganisms, soil would be an inert geological or mineral mass incapable of supporting plant life, and without plant life, the animal life that it sustains would not be possible.

- One of the main activities of microorganisms in nature is to break down complex organic matter into simple chemical compounds, so there is an endless cycle of synthesis and destruction, with a dynamic equilibrium maintained in soil microbial populations.
- Another important role of certain soil microorganisms is fixing atmospheric nitrogen. Approximately 139 million metric tonnes of nitrogen are added to the soil every year by different nitrogen-fixing systems.
- Soil microorganisms play important roles in other natural cycles, such as transformations of phosphorus, sulphur, iron and other minerals in their respective cycles, and for the availability of other minor elements.
- Also, most soils contain microbial populations with the necessary genotypic capacity to catalyze all requisite reactions for ecosystem development.

Beneficial activities of microorganisms in the soil

- Decomposition of plant residues and organic materials leads to humus synthesis and to mineralization of organic nitrogen, sulphur, and phosphorus.
- Increasing plant nutrient availability (P, S, Mn, Fe, Zn and Cu) through symbiotic mycorrhizal associations, production of organic chelating agents, oxidation-reduction reactions, and phosphorus solubilisation.
- Biological nitrogen fixation by free-living bacteria in the root zones of gramineae plant species and cyanobacteria, associative microorganisms, and symbiotic bacteria with legume and non-legume plants.
- Promoting plant growth through the production of plant growth hormones, protection against root pathogens and pseudopathogens, and enhanced nutrient-use efficiency.
- Controlling deleterious microorganisms and plants (plant diseases, soil nematodes and insects, weeds).
- Biodegrading synthetic pesticides or other soil contaminants.
- Enhancing drought-tolerance of plants.
- Improving soil aggregation.

The use of azolla, blue green algae (BGA), Azospirillum and phosphobacteria in rice crop production is becoming well-recognized. There have been new research focuses on developing microbial consortia as well as bioinoculants for targeting micronutrients.

Earthworms are ubiquitous in most soils and have become unwitting symbols of a healthy, living soil. They can contribute in several ways to soil health. Most notably, earthworm burrows can occupy as much as 1% of the soil volume aiding in infiltration and flow-through of water, as well as providing pathways for root exploration and faunal habitat. Their feeding habits can help homogenize the topsoil and, in the case of surface feeders, incorporate large amounts of surface litter into deeper soil levels. Their digestive process releases nutrients and fragments of plant residues, leaving behind fertile casts and mucus burrow linings. Vermicomposting has become very popular in mobilizing organic manures.

Other soil organisms such as termites and ants, mites, spiders, collembola etc. also play important roles in soil food webs, mobilizing, storing and releasing nutrients through a complex set of inter-species relationships.

Soil biological fertility has been gaining attention recently, and the soil biota are now better recognized as the key drivers of soil fertility and productivity that they are (Thies, 2006). Understanding the operative relationships between soil biodiversity and fertility could allow ecosystem managers to encourage the presence of organisms that are beneficial to soil systems intended for crop and animal production, as well as to overall ecosystem health (Thies and Grossman, 2006).

7.10 Nutrient Deficiency Symptoms in Rice

Symptoms of nutrient deficiency or toxicity are not always readily apparent in a growing crop. Often, more than one nutrient or growing condition may be involved. In many field situations, when a deficiency is identified, it may be too late to introduce treatments to correct the problem in the current crop.

Nitrogen, phosphorus, potassium, and magnesium are mobile nutrients, and deficiency symptoms appear in the oldest (lower) leaves first as the nutrient gets moved to youngest leaf. Calcium, iron, zinc, manganese, and sulphur are immobile nutrients, and their deficiency symptoms appear in the youngest (upper) leaves first as the nutrient becomes part of plant compounds. The functions and deficiency symptoms of the most important nutrients for rice are presented in Table 1.

Table 7.1 Functions and deficiency symptoms of important nutrients in rice

Nutrient	Functions	Deficiency symptom	Effect of deficiency
Nitrogen	• Essential component of amino acids, nucleotides and chlorophyll • Contribute to height • Number of tillers and spikelets • Size of leaves and grains • Spikelet fertility • Protein content of grains	• Old leaves, and sometimes all leaves, become light green and chlorotic at their tips. • Except for young leaves, which are greener, deficient leaves are narrow, short, erect, and lemon-yellowish. • Deficiency often occurs at critical growth stages such as tillering and panicle initiation, when the demand for N is largest.	• Stunted yellowish plants • Poor tillering • Leaves die under severe stress. • Smaller leaves • Entire field may appear yellowish. • Early maturity or shortened growth duration

Nutrient	Functions	Deficiency symptom	Effect of deficiency
Phosphorus	• Root development • Earlier flowering and ripening • Active tillering • Grain development • Food value of grain • Playing an important role in the formation of plant hormones and maintenance of membrane integrity • Acting as an essential constituent of adenosine triphosphate (ATP), nucleotides, nucleic acids, and phospholipids	• Stunted, dark green plants with erect leaves. • Stems are thin and spindly • Young leaves may appear to be healthy, but older leaves turn brown and die. • Red and purple colors may develop in leaves if the variety has a tendency to produce anthocyanin. • Leaves appear pale green when N and P deficiency occur simultaneously.	• Plant development is retarded. • Reduced tillering • The number of leaves, panicles, and grains per panicle may also be reduced.
Potassium	• Playing an essential function in osmoregulation, enzyme activation, regulation of cellular pH, cellular cation-anion balance, regulation of transpiration by stomata, and transport of photosynthetic products • Tillering promotion • Size and weight of grains • Tolerance to adverse climatic conditions, lodging, insect pests, and diseases. • Strengthening straw and stems of the rice plant	• Dark green plants with yellowish-brown leaf margins, or dark brown necrotic spots first appear on the tips of older leaves. • Under severe K deficiency, leaf tips are yellowish-brown. • Symptoms appear first on older leaves, then along the leaf edge, and finally on the leaf base. • Upper leaves are short, droopy, and "dirty" dark green. • Older leaves change from yellow to brown and, if the deficiency is not corrected, discoloration gradually appears on younger leaves. • Leaf symptoms of K deficiency are similar to those of tungro virus disease. Unlike K deficiency, however, tungro occurs as patches within a field, affecting single hills rather than the whole field.	• Response to N and P is constrained by insufficient K. • Effects on the number of spikelets per panicle, percentage of filled grains, and grain weight.

Nutrient	Functions	Deficiency symptom	Effect of deficiency
Zinc	• Playing an essential role in the following biochemical processes: auxin metabolism, nitrogen metabolism, cytochrome and nucleotide synthesis, chlorophyll production, and enzyme activation • Acting as an essential component in the cellular membrane as well as being present in some essential enzymes • Activation of many enzymatic reactions	• More common on young or middle-aged leaves. • Dusty brown spots appear on upper leaves of stunted plants, sometimes two to four weeks after transplanting, • Midribs near the leaf base of younger leaves become chlorotic; leaves lose turgor and turn brown as blotches appear on the lower leaves	• Under severe deficiency, tillering decreases • Time to crop maturity may be increased. • Growth may be greatly reduced • 2-4 weeks after transplanting, uneven plant growth and patches of poorly established hills in the field • Increased spikelet sterility
Iron	• Formation of chlorophyll • Inhibition of K absorption • Electron transport in photosynthesis • Constituent of components for photosynthesis • Electron acceptor in redox reactions	• Inter-veinal yellowing and chlorosis of emerging leaves. • All leaves become chlorotic and turn whitish under severe deficiency	• Decreased dry matter production • Reduced chlorophyll concentration in leaves • Reduced activity of enzymes involved in sugar metabolism.

Sources:
http://www.ipni.net/ppiweb/bcropint.nsf/$webindex/39AB5958BED4B2BC85256BDC00738F2F/$file/BCI-RICEp23.pdf; http://www.knowledgebank.irri.org/ericeproduction/IV.1_Essential_nutrients.htm

7.11 Nutrient Management In SRI

So far, no specific nutrient management recommendations have been made for SRI crops. SRI is not necessarily an 'organic' management strategy. Fr. de Laulanié developed the first version of SRI methods during the 1980s relying on chemical fertilizer, since that was understood to be the way that yields could be best enhanced, especially on Madagascar soils which were judged to be quite deficient by standard soil chemistry analyses. When the government's subsidy for fertilizer was removed in the late 1980s, he switched to using compost, and found that SRI results became even better. He discovered empirically the merit of the advice from organic farmers: Don't feed the plants - feed the soil, and the soil will feed the plants.

There can be soils where limited or no availability of chemical nutrients will be constraining. Where there are deficits that cannot be filled by soil reserves or biomass amendments, inorganic fertilization may be necessary. In fact, rice plants will not take up nutrients in excess of their internal needs for plant growth and maintenance. It is a fact that plants have been growing on the earth's surface for over 400 million years without exhausting their supply of nutrients. Even 99% recycling of nutrients would not have sustained continued fertility for this long unless there were endogenous processes in plants and in soil systems that continually replenish nutrient supplies, not relying upon man-made inputs (Uphoff, 2008).

The main function of compost is not so much to supply the plants directly with nutrients (NPK), as to enhance the structure and functioning of soil systems. When soils are full of life, they can mobilize large amounts of nutrients – and particularly micronutrients, which are essential to plant growth and health but which are not provided in NPK fertilizer. Moreover, they can facilitate many beneficial processes in the soil.

Organic manures are recommended in SRI cultivation since they are found to give better crop responses. Enrichment of the soil for nutrient supply with tank silt (40–50 t ha^{-1}), FYM/compost (15 t ha^{-1}), and/or incorporation of 45-60 day-old green manures grown in situ such as sunnhemp/dhaincha (Photo 7.1) are ideal for basal incorporation.

Since not all rice farmers are in a position to adopt organic farming methods, Integrated Nutrient Management (INM) is generally recommended for SRI. INM is not merely application of fertilizers along with organic manures. It includes the application of available organic sources like cattle manure, poultry manure, vermicompost, green manures, green leaf manures, biofertilizers, and supplementing with fertilizers in adequate splits to meet the nutrient demands of the crop at different growth stages.

Mobilizing organic sources is not an easy task if every rice farmer wants to use more of them. One easy solution could be growing gliricidia on the paddy field bunds and fences (Photo 7.2). Gliricidia (Gliricidia sepium or Gliricidia maculata) is a fast-growing, tropical leguminous tree that adapts very well in a wide range of soils, ranging from eroded acidic soils (pH 4.5-6.2), fertile sandy soils, heavy clay, and calcareous limestone, to alkaline soils. Gliricidia tolerates fire, and the tree quickly re-sprouts with the onset of rain.

Growing gliricidia plants on farm bunds serves the dual purpose of producing green leaf manure, rich in N, under field conditions, and they also help in conserving soil through reduced soil erosion. This legume is root-nodulating, N-fixing, and multipurpose, tolerant to pruning. Gliricidia contains 2.4% nitrogen, 0.1% phosphorus, 1.8% potassium, and 1.2% calcium. If stem cuttings are planted, they root and sprout, becoming a regular source of green manure after three years. From well-grown trees, 100–200 kg of green leaves will become available.

Gliricidia was recommended to the farmers of Tamil Nadu in the 1970s, and serious steps were taken to popularize it. But, it became 'history' as farmers have forgotten about it. Sri Lankan farmers are growing gliricidia on their field bunds, however, and are using the green manure (Photo 7.3). Many farmers are also recycling the rice straw. Straw should be heaped and some FYM should be sprinkled on it to facilitate decomposition (Photo 7.4).

Photo 7.1 Sunnhemp crop

Photo 7.2 Gliricidia on field bunds

Experiments conducted at the China National Rice Research Institute, Hangzhou, showed that the highest yield in SRI was obtained with equal proportions of organic and inorganic nutrient applications rather than a 25:75 ratio or 100 % organic (Lin et al. 2011).

The soil environment created by SRI's wider spacing of plants, its unflooded water regime, and the churning up of the soil by weeder use are found to encourage a different microbial and nutrient dynamics in the soil. The effect of combined inoculation of Azospirillum and Trichoderma harzianum has been found to be more pronounced in SRI (Ravi et al. 2007).

Use of just chemical fertilizers can be effective for SRI, and organic SRI farmers do not use chemical fertilizers. The recommended doses of fertilizers for a conventional rice crop specific to the region may be adopted until SRI-specific recommendations are generated.

In a Participatory Technology Development Study in Kunduz river basin of Afghanistan, Thomas and Ramzi (2011) found that the grain yields under SRI were 66 % higher than with traditional methods, despite using much less fertilizer or not using fertilizer at all.

Ceesay et al. (2011) did not find much effect on the yield of SRI crop by increasing the nitrogen doses by 2 to 3 times (Table 7.2).

Photo 7.3. Gliricidia loppings applied in the field

Photo 7.4. Rice straw recycled

Table 7.2 Grain yield and water productivity under different fertilizer doses

Treatment	Grain yield (t ha^{-1})	Water productivity (kg grain kg^{-1} total water input)
Continuous flooding with recommended fertilizers (70-30-30 NPK) with local practices	2.5	0.14
SRI with recommended fertilizers (70-30-30 NPK)	7.6	0.76
SRI with higher N (140-30-30 NPK)	7.9	0.79
SRI with very high N (280-30-30 NPK)	8.0	0.81

Source: Ceesay et al. (2011).

7.12 Nutrient Removal by SRI Crop

Experiments conducted at Coimbatore have shown that under the same nutrient application level, SRI plants take up more nutrients. Similar observations were made by Barison and Uphoff (2011), with the further observation that SRI phenotypes produce more grain weight per unit of nutrient taken up. This can mean that nutrient recovery by the plant is greater in SRI crops or because the SRI plants' extensive root systems remove more nutrients from the soil than are supplied externally.

One of the concerns in SRI nutrient management is whether there is depletion of nutrients from the soil because of the higher plant growth and grain yield associated with higher nutrient uptake. Only long-term experiments can resolve this issue. But, some of the experiments conducted so far have not shown that the available nutrient status was reduced after the SRI crop. The delayed senescence and the higher LAI present higher N in the leaves after flowering in SRI plants and also probably there is lesser translocation of N from the leaves to the grains to facilitate greater carbohydrate synthesis.

Studies carried out by the Directorate of Rice Research (DRR), Hyderabad, for two seasons showed that even though SRI resulted in higher productivity, the nutrient uptake was similar with marginally higher nutrient-use efficiency (8, 8 and 12% of N, P and K) without depleting the available nutrients compared to transplanting (Mahender Kumar et. al. 2009). Incorporation of weed biomass and higher root and stubble biomass from the SRI crop probably enhance the nutrient availability in the soil.

Studies by Barison and Uphoff (2011) showed that there were no substantial differences in the nutrients accumulated by the SRI rice plants compared to those conventionally grown, but there have not been any significant dilution of plant nutrients within the plant by the higher yield obtained with SRI. There were similar P levels measured in the soil of plots where both SRI and conventional rice were grown, yet 66% more P was accumulated in the above-ground biomass of SRI plants.

A non-farm survey indicated a doubling of N uptake by plants grown with SRI methods in comparison to conventional methods, eventhough the SRI and conventional plots had similar soil fertility in terms of chemical availability. The higher uptake of N by SRI plants suggests possibly greater activity of nitrogen-fixing bacteria living as endophytes within roots, or by free-living microbes within the rhizosphere, or possibly even within the phyllosphere (Chi et al. 2005).

While admitting that there is not a satisfactory scientific basis at present to account for all of the nutrient relationships with SRI, Uphoff has proposed some hypotheses on the nutrient uptake of rice under SRI as follows:

- Rice plant growth - rather than being just the result of the uptake of nitrogen (N) - is also a cause for such uptake, especially the rapid growth that can be induced by SRI management practices. SRI's promotion of the rapid growth of roots and tillers promotes and accelerates the uptake of N by rice plant roots.
- SRI methods maintain effective nutrient uptake by roots within a healthy rice rhizosphere for a longer period than with traditional rice cultivation methods.
- SRI methods by producing a much greater root system that can explore a greater volume of soil enable the rice plant to extract more, though often minor quantities, of the trace elements needed for best and healthiest growth.
- The SRI soil management practices, combining aerobic and anaerobic soil conditions,

would enhance N availability, either through greater biological nitrogen fixation or through more diverse forms of N being made available to the plant root with aerobic soil conditions.

- Mechanical (rotary) weeding aerates the soil as well as removes weeds, thereby improving soil oxygen status, stimulating faster decomposition of organic matter, and hence supplying N and other nutrients in better synchrony with plant demands than in the traditional rice system

These are all plausible explanations, but there needs to be systemative evaluation and basic research done to get a grip on the causal mechanisms involved in the repeatedly observed superior crop performance of SRI rice.

7.13 Summary

The SRI management practices of lower planting density, inter-cultivation, applying more organic manures, and limited irrigation create a different kind of nutrient dynamics in the soil which is not sufficiently understood. Since the grain yields in SRI are higher, it is easy to assume that nutrient mining is taking place; but this assumption is based on the knowledge gained from study of non-SRI rice-growing practices. The behavior of the rice plants under SRI management is quite different, exhibiting very different growth responses.

It is probable that the efficiency of the SRI crops to utilize nutrients is higher than with non-SRI crops. Physiological studies have shown that SRI plants have longer periods of photosynthesis and higher photosynthetic efficiency, and there is better light utilization besides prolonged and better root activity, making the plants healthier than with non-SRI crop (see Chapter 10). All these might help SRI plants to produce 'more with less.'

The nutrient management in SRI is particularly focused on supplying more organic manures to build up soil fertility and the life in the soil. It is no wonder that many organic rice growers have embraced SRI immediately. SRI is making more farmers realize the importance of soil health by applying more organic matter to sustain the structure and functioning of soil systems.

8 INTERCULTIVATION

Intercultivation is an operation for soil cultivation that is performed in the standing crop, between plants, with hand tools or possibly mechanized implements. This provides the crop with a better opportunity to establish itself better and to grow more vigorously upto the time of maturity. This results from good soil aeration and better development of root systems. The intercultivation operation is most obviously seen as necessary to help control the growth of weeds, but it may also serve as a moisture-conservation measure by closing cracks in the soil. Active soil aeration is a function usually overlooked when intercultivation is referred to as 'weeding.'

The tools best used for intercultivation depend upon the nature of the crop, the soil characteristics, and the water regime. Hand hoes, harrows, and spades can be used in small landholdings whether the crop is broadcast or line-sown. Partially mechanized rotary hoes, cono-weeders, etc. are used in line-sown crops. Bullock-drawn implements like the desi plough are usually used in rainfed environments. Motorized intercultivators and implements attached to mini-tractors or regular tractors are also used to some extent.

In contemporary rice culture, intercultivation is not considered as a very important agronomic practice. However, it has been practiced to some extent in the past, primarily as a weed control measure. With SRI, where weeds are not controlled by flooding, it assumes great importance, but as noted above, the soil aeration through intercultivation is an even greater contribution to SRI performance than is its weed control.

8.1 Weed Management in Rice

Weeds compete with rice plants for moisture, nutrients, and light, and they also crowd the plants physically. If weeds are allowed to grow unrestricted, they can reduce the yield of wetland rice by up to 36%, and of dry land rice by as much as 84% (Matsunaka, 1983). The best method of weed control depends upon the type of rice culture. Reductions in labour availability have pushed a transition from traditional hand weeding to rotary weeders, and then to herbicides as the primary means of weed control.

Weed control methods in irrigated wetlands include cultural, manual, mechanical weeding, spraying, and biological control techniques (Nyarko and Datta, 1991). Flooding is the most extensively adopted ecological method for controlling weeds in irrigated rice, and in fact this is the principal reason for submerging rice fields. The weeds that survive flooding can be pulled out by hand, or if the rice has been planted in rows, mechanical weeders are used. In some places, lowland rice farmers trample weeds into the soil instead of hand pulling (Nyarko and Datta, 1991)

In dry-seeded wetland culture, most farmers practice only hand weeding, from once to three times. Sometimes the second or third weeding is done after the rice is flooded. Rotary weeders and herbicides are not used. Hand weeding is still the only effective method to control weeds in dryland rice, although bullock-drawn harrows are used in some places. No rotary weeders or chemical means are used. For hand-weeding, besides ordinary khurpies (an indigenous digging tool) and hand-hoes, certain special forms of weeders such as Eureka Weeder, Hazeltine Weeder, and Excelsior Weeder have been found very useful. Bullock-hoes were also used a century ago (Mukerji, 1907).

For rice cultivation, hand weeding usually takes around 120 hours ha^{-1}; mechanical weeding requires around 50-70 hours ha^{-1}. Hand weeding is most useful for removing annual weeds and certain perennial weeds that do not regenerate from underground parts. It is a practical method of removing weeds within rows and hills where a cultivating implement cannot be used; but it requires more labour than other direct weed control methods (IRRI, 2009)

In India, under lowland conditions, it takes about 200-250 hours ha^{-1} to do hand weeding, depending on the degree of weed infestation. In row-seeded or transplanted rice, where weeds can be controlled by the use of mechanical weeders, it can take 50-60 hours ha^{-1}, depending upon weed infestation and soil conditions (Parthasarathi and Negi, 1977).

Hand weeding of young weeds when the rice crop is still in its two-leaf to three-leaf growth stages is extremely difficult. Therefore, hand weeding is generally delayed until weeds are large enough to be grasped easily. This method requires adequate soil moisture to ensure that weeds can be easily pulled up. After such weeding, the weeds usually have to be removed from the field to stop them from regenerating when left sitting in the field water. This exports nutrients from the soil.

8.2 Mechanical Weeding

The rotary weeder was apparently first developed by a Japanese farmer in 1892. The single-row rotary weeder has been reported to require 80-90 labour hours to weed 1 ha, and it is difficult to use because it must be moved back and forth (Nyarko and Datta, 1991). IRRI developed a push-type cono-weeder that uses a conical-shaped rotor to uproot and bury weeds. Compared to the conventional push-pull rotary weeder, the single-row cono-weeder is about twice as fast (40-50 labour hours ha^{-1}), and the two-row cono-weeder is 3-4 times faster (25-35 labour hours ha^{-1}).

However, mechanical weeding may be less effective than hand weeding because weeds within the crop rows are not removed. Competition from those weeds that survive can impede crop growth and yield. The challenges for mechanical weeding are that: (a) it requires row-planted crops, and (b) it is very difficult if the soil surface is dry, or if the soil sets hard (IRRI, 2009). If the soil is too dry, the weeder rolls over the soil surface without burying the weeds. The conoweeder is also ineffective in standing water (Nyarko and Datta, 1991).

The push-type rotary weeder mixes weeds with mud between rows and has been the most successful tool. A comparative study on different methods of weeding as showed that the labour for two rotary weedings (115 hours ha^{-1}) is about half that for two hand weedings (202 hours ha^{-1}). However, grain yield was lower, and the reason for this could be due to the inability of rotary weeding to remove weeds within or close to rice hills (De Datta, 1981).

Human-powered rotary weeding combined with other methods of weed control has been reported to be widely used in some provinces in the Philippines, and some modifications of this basic device have been used in many countries in South and Southeast Asia (Photos 8.1 and 8.2). Gasoline-powered small weeders have also been popular in Japan (Nyarko and Datta, 1991). Power weeders were developed in the early 1970s both in India and Philippines.

It may be noted that the weeders used earlier were meant for control of weeds. Rotary weeders did not become used widely in India despite being recommended (Ramaiah, 1954). When Venkatasubramanian (1958) compared the system of bulk planting plus hand weeding, with line planting (25 cm row spacing) plus use of rotary weeder, and intercultivation, it was found that the rotary weeder was more economical (Table 8.2).

The IRRI Rice Fact Sheet (2003) on mechanical weed control has recognized the fact that soil-stirring seems to increase root and shoot growth, tillering, and grain yield. Use of a weeder in rice cultivation is, however, not mentioned in the recent Handbook of Agriculture produced by the Indian Council of Agriculture (ICAR, 2010).

8.3 History of Intercultivation in Rice

Stirring the soil once in a fortnight until the rice plants are about 1-½ feet height had been emphasized a century ago by Mukerji (1907). It is fascinating that the importance of intercultivation was recognized so long before now (Thiyagarajan and Gujja, 2009). Vaidyalingam Pillai (1911) advocated shallow digging of the inter-row spaces with a spade 20 days after transplanting, and again at 40-45 days after transplanting. He recommended removing soil from around each hill to place manure near the plant root zone. For his first crop of gaja planting, each hill was pressed with the foot.

The shallow digging of inter-row spaces and pressing each hill with the foot represent a conceptual advance as these practices aimed not only at weed control but also introduced the practice of disturbing the soil – similar to the intercultivation with a mechanical weeder that is recommended in SRI today. These practices indicate some understanding on the farmer's part that disturbance to the soil around the hills has beneficial effects. No modern rice cultivation methodology seems to have promoted this concept except SRI, which underscores the importance of active soil aeration.

In describing the practices of stable and high-yielding rice cultivation, Matsushima (1980) endorsed inter-tillage after the roots of the transplanted seedlings are reestablished, and he favoured the practice of removing the soil around the base of the plant hill by hand, to make the hill spread out and promote tillering. Matsushima found these practices difficult, however, so did not strongly urge them.

Seko and Kuki (1956) studied the effects of intercultivation in paddy fields for four years (1949-1952) and reported that:

(a) cultivating the soil depressed the growth of rice temporarily, but after 1-2 weeks the growth became more vigorous; however, they found no significant difference in yield;

(b) cultivating the soil caused some negative effects on growth and yield under adverse environmental conditions such as low air temperature and insufficient sunshine;

(c) by cultivating soil, the roots of the rice plants in the shallow part of the soil were cut or stirred; when new roots grow, the number of total roots and weight became greater than in non-cultivated soil; further, those roots which had been cut elongated rapidly;

(d) redox potential was high after intercultivation, but it became lower than non-cultivated soil after 3-4 days; and

(e) the NH4-N content of the soil increased due to mixing up of the oxidized uppermost layer into the reduced lower layer.

Seko and Kuki (1956) concluded that in intercultivation, weeding should be considered a more important purpose than cultivating the soil, and it is enough to operate the weeder to control the younger weeds and to mix in the top-dressed fertilizer. They wrote that it is unnecessary to repeat cultivating the soil several times successively. This conclusion is now challenged by SRI.

Reviewing the theories on intercultivation, Nojima (1960) mentioned that the following theories have been believed since the 17th century:

(a) A kind of physico-chemical change occurs in the soil which causes decomposition of organic matter in the soil and thus increases the supply of nutrients;

(b) Intercultivation decreases the amount of toxic gases in the soil and increases the amount of useful oxygen accessible there at the same time;

(c) Cutting of roots promotes the growth rate of plants; and

(d) The cumulative effect of all these processes is that the final yield is increased to a great extent.

These conclusions differ from those of Seko and Kuki (1956) and are close to the thinking with SRI. But Nojima himself did not recommend frequent weeding up to the time of canopy closure.

8.4 Intercultivation In SRI

Intercultivation of the rice crop has become usually uncommon in irrigated rice environments, as noted above. However, the introduction of the System of Rice Intensification (SRI) has brought a new dimension in the agronomy of rice cultivation wherein intercultivation with a weeder is one of the six principles which have a significant beneficial influence on the growth of the rice crop. The differences in weed management in conventional and SRI methods of cultivation are presented in Table 8.1.

In SRI, the intercultivation with a mechanical weeder is done at 10-12 day intervals from planting, moving between the square-planted hills in both directions (Photo 8.1). This operation not only incorporates the weeds into the soil, to decompose and return nutrients to it; it also mixes and aerates the wet soil (Photo 8.2). Mechanized inter-row cultivation has the advantage that it aerates the soil, which appears to help crop growth (IRRI, 2009).

Table 8.1
Weed control methods in conventional and SRI cultivation

Method of cultivation	Weed control method
Conventional planting	Recommendation in Tamil Nadu, India : Hand weeding twice, at 15 and 35 DAT, or use. of a herbicide at 3-7 DAT, plus one hand weeding at 35 DAT Recommendation in Handbook of Agriculture, ICAR (2010): Hand weeding 2-3 times at 20-day intervals from 20 DAT. If weed problem is acute, herbicide plus need-based hand weeding 20 days later. IRRI Rice Fact Sheet (2003): Hand weeding at 20-22 and 30-32 DAT, repeated once or twice more at 40-42 and 50-52 DAT; or Mechanical control with rotary hoe at 10-12 or 20-22 DAT, and repeat its use once or twice at 30-32 and 40-42 DAT.
System of Rice Intensification	Intercultivation with a weeder at 10-day intervals, from 10-12 days after planting until the canopy closes, upto 4 times (10-12 DAT, 20-22 DAT, 30-32 DAT, 40-42 DAT). Cultivate between the hills in two directions, perpendicularly, and remove the remaining weeds close to the plants, if any, by hand

Photo 8.1 Intercultivation by conoweeder

Photo 8.2 Intercultivation by rotary weeder

The conclusions of Seko and Kuki (1956) and Nojima (1960) that intercultivation has no specific effect on the rice crop other than weed control, was probably due to the climatic conditions of Japan, or perhaps because in their studies, the intercultivation operation was carried out within a month after planting. In SRI, the practice of intercultivation is recommended to be followed until the canopy closes, and more importantly, whether there are weeds or not; the principle is to intercultivate the soil as active soil aeration, not just to remove weeds. The experience in India is that farmers see dramatic increases in the growth of their plants after intercultivation, especially the first weeding/soil aeration after planting.

The intercultivation operation in SRI, if done several times, can add 1 to 3 tha-1 yield without other soil amendments, by inducing better soil health and more nutrient cycling and solubilization through microbial activity (Uphoff, 2008). This practice adds active soil aeration to the passive soil aeration that results from SRI water management practices (no continuous flooding). The growth of phosphobacteria and possibly of N-fixing bacteria can be enhanced by alternatively wetting and drying the soil (Uphoff et al. 2009). There is enough experimental evidence and farmers' experience in India to say that over and above weed control, intercultivation has significant benefits (more details in Chapter 10).

It is important that mechanical weeding should be supplemented by hand pulling of weeds that are close to the rice plants and are not removed by the weeder; the time required for weeding by this combination is less than for hand pulling alone (Nyarko and Datta, 1991). The study by Ramamoorthy (2004) has showed how this can affect the tillering of the particular hill with unremoved weeds (Photo 8.3).

Photo 8.3 Weeds growing within the hill (right side) and not removed by weeder. Both are SRI plants

Nyarko and Datta (1991) emphasized that to achieve the best results in transplanted rice, a weeder should be run in two directions, at right angles to each other. This view, which could not be implemented in simple line-planted crops (whether by labour or machine) has been made possible in SRI where square planting is recommended.

According to Nyarko and Datta (1991), some farmers did not use rotary weeders for these reasons:

(1) Using a rotary weeder is inconvenient if the dominant weeds are creeping grasses or sedges;

(2) If weeding is done late, rotary weeders cannot control weeds as well as hand weeding can;

(3) If puddling is not done properly, the soil can become too hard and too shallow for a rotary weeder to push the weeds into the mud (this is particularly true for newly-established paddy fields);

(4) In many cases, the available rotary weeders do not fit the system; for example, the desirable plant spacing and the width of the available rotary weeders are not compatible; and

(5) Small farm sizes may make using a rotary weeder uneconomical.

All the above reasons apply to the present situations except for the last (5), which is not true. We find that marginal farmers are able to do the intercultivation operation without depending upon outside labourers. Especially farmers with small landholdings benefit from the cost-effective yield increase the intercultivation can give. Having a small field is no barrier to weeder use.

8.5 Types of Weeders used in SRI

When weeders were used for weeding purposes only, four decades ago, besides the single-row model, there were two-row models, animal-drawn three-row models, and tractor-powered weeders also available (Photo 8.4 to 8.6) (Stout, 1966). However, the use of these weeders had become extinct and was dormant until the introduction of SRI.

When SRI was first introduced in Madagascar, the rotary hoe was being recommended. It was also called as the Japanese weeder. In China, it is called a 'wolf-fang' weeder because of the sharply-pointed 'teeth.' In India, when SRI was introduced, two types of weeders were being recommended: the conoweeder, and the rotary weeder (Photo 8.7). The conoweeder has hollow cones with tooth bars that churn the soil and remove weeds. It moves more easily over the surface of the soil. A conoweeder weighs about 7.5 kg and can be operated only by men labourers. A rotary weeder, being lighter (about 2 kg), can be operated by women labourers also.

The efficiency of rotary weeders has been improved by providing ball bearings in their assembly as introduced by an Andhra Pradesh farmer, which makes them easier to push. A large number of weeder designs have been evaluated and publicized by WASSAN (Watershed Support Services and Activities Network) in Hyderabad under the guidance of the farmer Kishan Rao. The Mandava weeder, named after the Mandava village of Kishan Rao, is now being extensively used by farmers in several states.

Several alternative designs in the hand-operated weeder for SRI have come out in the last five years to save labour, time and energy, and also to suit particular types of soil. One of the significant impacts of SRI is the tendency of some farmers to modify their weeder design and construction to suit their conditions and convenience. Some manufacturers also have modified versions (Photos 8.7 to 8.16).

Photo 8.4 Japanese rotary weeder used in 1960s

Photo 8.5 Vertical axis weeder used in 1960s.

Photo 8.6 Motorized weeder used in 1960s.

Photo 8.7 Rotary, cono and drum weeders

Photo 8.8 Single-row Mandava weeder

Photo 8.9 Two-row Mandava weeder

Photo 8.10 Pulling and pushing type of three-row weeder (Madagascar)

Photo 8.11 Simple weeder designed by Nong Sovann (Cambodia) with wooden axle, large nails, rake, and metal rods, costing less than USD 3.

Photo 8.12 Roller weeder (Madagascar)

Photo 8.13 Indigenous weeder (Tripura)

Photo 8.14 Super-simple weeder (Nepal) made from nails and wood, used like a broom, constructed for about USD 0.25.

Photo 8.15 Gauge wheel-type weeder developed by a farmer (Tamil Nadu)

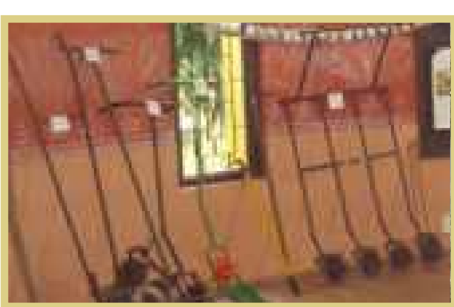


Photo 8.16 Weeder exhibition at SAMBHAV, Odisha

A workshop was held in farmers' fields in Andhra Pradesh in 2005 where different kinds of weeders were demonstrated and evaluated by farmers and manufacturers. (http://www.wassan.org/sri/documents/SRI_Implements_Ravindra.pdf) (Shambu Prasad et al. 2008). A compendium on weeders has been published by WASSAN showing a great variety of weeders (http://wassan.org/sri/documents/Weeders_Manual_Book.pdf).

Most of the farmers practicing SRI in larger areas emphasize the need for a motorized weeder. Some farmers, researchers and private companies are attempting to develop such motorized weeders (Photos 8.17 to 8.20). In scaling-up activities for SRI, weeders are often supplied at a subsidized price by state governments.

Photo 8.17 Single-row motorized weeder (private)

Photo 8.18 Motorized weeder developed by S. Ariyaratna (Sri Lanka)

Photo 8.19 Three-row motorized weeder (TNAU)

Photo 8.20 Two-row motorized weeder (private)

One of the farmers in Tamil Nadu modified the conoweeder to have a ridger attachment for creating furrows in between the rows and ridges along the rows. His vision was that this will also help in preventing the mortality of the plants during monsoon rains (Photos 8.21 &8.22).

Photo 8.21 Small ridger attached to conoweeder

Photo 8.22 Ridges and furrows made by the modified weeder

8.6 Labour Requirements for Intercultivation

Studies conducted in Madagascar (Barison, 2003) calculated that the labour requirement for weeding was 41.13 man days ha^{-1} and 62.13 man days ha^{-1} for conventional and SRI method of cultivation, which were 21% and 25% of total labour use.

Such a high requirement of labour for SRI weeding reported from Madagascar has not been observed in India. Intercultivation with a weeder for four times plus removal of left-out weeds requires 38 labourers per ha, while conventional weeding with women

Table 8.2 Cost of weeding and intercultivation in Tamil Nadu with conventional weeding and mechanized hand weeding over years and locations

Method of weeding	Type of labour	Wages/ labour day)	Labourer requirement / acre	Cost of ? weeding (Rs/acre)
Rice Research Station, Tirur, Tamil Nadu, 1958 (Venkatasubramanian, 1958)				
Conventional random planting (hand weeding twice)	Women	56 naya paise	14	7.84
Line-planted (rotary weeder three times)	Men	87 naya paise	6	5.22
Farmer's field, Tirunelveli, Tamil Nadu, 2003 (Thiyagarajan et al. 2005)				
Conventional random planting (hand weeding twice)	Women	Rs.40	32	1,280
SRI –square-planted (conoweeder 4 times plus hand weeding of left-out weeds)	Men	Rs.40	15	600
Regional Research Station, Paiyur, Tamil Nadu, 2005-2008 (six-season average) (Vijayabhaskaran and Mani, 2008)				
Conventional random planting (herbicide followed by hand weeding once at 45 DAT)	Men and women	Rs. 92	15	1,380
Square-planted (conoweeder three times, plus hand weeding of left-out weeds)	Men and women	Rs.92	10	920
V.K.V. Ravichandran, Farmer, Nannilam Tamil Nadu, 2009 (personal communication)				
Conventional random planting (hand weeding thrice)	Women	Rs.80	30	2,400
SRI- square-planting (conoweeder three times, plus hand weeding of left-out weeds)	Men Women	Rs.150 Rs.80	9 6	1,350 480

labourers for two times at 15 and 35 DAT consumes 80 labourers per ha. The cost for the conventional method of weeding was Rs. 3,200 per ha, and for SRI it was Rs. 1,520 per ha (Thiyagarajan et al. 2005). The number of labourers required for hand weeding or using a weeder will vary with location and season, to be sure. Table 8.2 shows such variations, indicating the labour cost and efficiency. The four different comparisons when aggregated show the rotary or conoweeder reducing farmers' weeding costs by about one-third.

A survey with farmers showed that SRI farmers had a 43 % reduction in their overall labour costs (Ravindra and Bhagya Laxmi, 2011).

Using a mechanical weeder 3-4 times in a crop season as recommended, faces problems which are mostly associated with labour availability. If a single labourer does the operation on one hectare of SRI crop with 25 x 25 cm spacing, he will have to walk 40 km to use the weeder in one direction, and 80 km in both directions. This is a mathematical projection if weeding is carried out by one person. (The same calculation could be applied for several operations in conventional cultivation). If 10 people do this work, each will just walk 8 km per time (both directions). The weeding operation is one of the major difficult parts in SRI, and we see a lot of variations in its adoption, like doing one direction only, 1 to 4 times; or doing both directions 1 to 4 times. It is important to do the first intercultivation before 15 days after transplanting for maximum benefits.

In using the weeder, there exist a lot of variations in the acceptance itself. Some labourers do not complain, while others resist, saying that they experience shoulder pain, especially when using the conoweeder. Some are enthusiastic about the new technology, saying it eases their work. The mindset of the labourer greatly influences the efficiency of weeder use. Sometimes, in some soil types, the weeder gets stuck often, increasing the frustration of the labourer. This is one of the reasons why many SRI-practicing farmers are asking now for a power-operated weeder.

One of the significant changes brought about by weeder use is the shift in employing women labourers for hand weeding, completely eliminating their role in most places, because 'mechanical work' is considered to be 'men's labour.' In some places, weeding operations have been taken over completely by men, releasing women from this part of the crop cycle. Whether this is something good or bad for women depends on whether the work of hand weeding is considered as laborious and even drudgery, or as desirable source of income. Where lighter-version weeders like the rotary weeder are available and appropriately designed, women do not hesitate to use them.

Experiments at ANGRAU on the physiological work load of women when using the manual conoweeder in SRI cultivation, in comparison to conventional methods of (hand) weed control, has revealed that conoweeders can increase the productivity of women's labour in weeding by two times and can save 76% of women's time through the improvement brought in their pace of performance (Aum Sarma, 2006).

On average, the number of labourers required to cover an acre in both directions may vary from 3 to 5. There are a few cases of higher labour requirement for weeder use also, but this is not the common experience. Some other labour-related issues on weeder use are:

- In labour-scarce areas, higher wages may be demanded for performing weeding.
- Groups of labourers often join together and go for contract weeding operations, moving from field to field together for a fixed payment.
- Most marginal farmers do their SRI weeding operation entirely by family labour,

completely eliminating their weeding cost. But they cover the paddy area by taking more time, 2-3 days per acre.

- Instances of a farmer doing the weeding operation all by himself have also been reported.
- Since the weeding requirement is common to all farmers with either conventional or SRI cultivation, availability of labour determines the timeliness of weeding and the avoidance of loss of yield. Some SRI farmers have reported that this problem is mitigated by use of mechanical weeders.
- There are several instances where no labour-related problems were encountered in any of the SRI operations.

8.7 Reducing the Drudgery of Weeder Operation

Weeder operation is reported to be one of the difficult practices in SRI mainly due to the drudgery involved in using hand-operated weeders. Some of the suggestions for reducing the drudgery of weeder use are:

- Modifying the weeder design with ball bearings to reduce friction, as done by an Andhra Pradesh farmer.
- Having a wooden handle for the weeder (especially rotary weeder) to reduce the weight of the weeder.
- Having a set of (say, 10) trained labourers for doing weeding in a village and employing them by contract. With experience and cooperation, they can make the operation more efficient.
- Instead of using the weeder in both directions at 10-day intervals, use it in one direction the first time, and then in the opposite direction after seven days, and repeat this several times.
- For some soils, depending upon their clay content, the most suitable weeder should be chosen or the weeder design should be modified to suit the soils.
- Use of a motorized weeder. There are efforts going in India, Malaysia, Philippines and other countries to design and build such weeders well-suited to SRI cultivation. It is expected that within a year or two, appropriate motorized weeders will become available, which will make SRI adoption much easier and more attractive.

8.8 Issues Related to Intercultivation in SRI

Most of the SRI farmers in Odisha adopt this method of weed management to increase productivity. However, access to appropriate weeders is still a major challenge, and the current supply of a single category of weeder for use on all types of soil is a problem (Shambu Prasad et al. 2008)

Weeder operation in both directions will not be difficult if planting is done properly in squares. If a marker is used, either a rake-marker or a roller-marker, geometric spacing is easily facilitated; if ropes are used, some care is needed by the labourers to align the lines properly in both directions.

Procurement and supply of weeders at the time of requirement is crucial in the initial stage of SRI promotion. Several NGOs have contributed significantly by procuring the weeders from outside and supplying them to local farmers. In the TN-IAMWARM project of Tamil Nadu, special training is being organized for village artisans to manufacture weeders locally and also to make markers.

The following points summarize the issues related to the intercultivation in SRI:

- First use of the weeder at 10-12 days after transplanting is crucial in SRI and should not be missed.
- Herbicides are not recommended in SRI because they do not contribute to soil aeration, which a mechanical weeder does. Moreover, they can adversely affect the soil biota, which is important for nutrient mobilization and for achieving 'the SRI effect.'
- Some water should be there on the field while using the weeder to make pushing the weeder and moving the soil easier.
- It is important to remove left-out weeds by hand. The labour for this hand weeding should be minimal.
- Some earthing up around plant culms takes place when the weeder is used. This makes the plants to produce new roots which increase root capacity and activity.
- If a weeder is used after a top dressing of urea, this will incorporate the fertilizer and increase its use-efficiency.
- The suitability of different types of weeder is site-specific and depends upon soil conditions and labourers' mindset.
- It would be ideal to manufacture the weeder by ironsmiths in the nearby area to get suitable models appropriate to local conditions.
- Rather than distribute standard models free to farmers, some arrangements would be preferable for small down payments to give farmers access to a weeder, and then they can pay the remainder at harvest time, when money is in hand. Farmers can earn from their SRI harvest many times more than the cost of the weeder, and this way, they are able to assess appropriate designs and quality construction from manufacturers, buying weeders that are best suited to their needs.

The benefits of intercultivation in SRI are reviewed in Chapter 11.

8.9 Intercultivation in Dryland SRI

Applying SRI principles and practices in rainfed rice cultivation is being taken up in some parts of India, where line sowing with wider spacing to facilitate weeder use is practiced. The practices are still to be standardized. The AME Foundation working with rainfed rice farmers in the Dharwad area of Karnataka is helping them to adopt some of the SRI principles. In the conventional system, farmers do intercultivation with a simple bullock-drawn implement (Photos 8.23 and 8.24). A bullock-drawn three-row weeder (Photo 8.25) and a cycle-wheel intercultivator are being tried now (Photo 8.26).

Photo 8.23 Intercultivator in conventional rainfed rice

Photo 8.24 Bullock-drawn wooden harrow

Photo 8.25 Three-row weeder

Photo 8.26 Cycle weeder

8.10 Summary

Intercultivation with mechanical weeders in SRI not only plays a role in the control of weeds but also has been found to have a beneficial effect on the growth of the crop. With appropriate models and skills, farmers can greatly reduce their cost of weeding also. Some of the constraints in using the weeder are associated with availability of weeders for which some policy support from extension agencies is needed. The labour mindset which is often negative can be sorted out through education and training.

9 PESTS AND DISEASES IN SRI

Insect pests attack all portions of the rice plant and at all stages of plant growth. Feeding guilds consist of: (1) root feeders, (2) stem borers, (3) leafhoppers and plant hoppers, (4) defoliators, and (5) grain-sucking insects.

The incidence of pests and diseases in SRI crop appears to be influenced by the micro-environment created for plants, starting with younger seedlings, more widely spaced, with less water standing in the field, and later on, having profuse vegetative growth and doing intercultivation at regular intervals. The resulting rice plants themselves appear to be stronger and more resistant to chewing and sucking insects, perhaps because of the roots' greater silicon uptake under aerobic soil conditions. The resistance of a rice crop grown under SRI management to pests and diseases has been frequently reported by farmers and has also been studied experimentally to some extent. However, the interaction of pathogens with SRI crops is yet to be studied in detail.

9.1 Insect Pests

The incidence of different insect pests like thrips, whorl maggot, leaf hoppers, plant hoppers, gall midge, stem borer, and leaffolder in SRI crops has been studied to some extent.

9.1.1 Thrips

Usually, thrips (S. biformis) are a major problem at seedling stage, both in the nursery and in transplanted fields. David et al. (2005) in their study of comparative pest incidence in nurseries found that nursery seedlings conventionally grown supported over 10 times more population of thrips, with four times more damage, than was seen with seedlings under SRI nursery management (Table 9.1). Shorter nursery duration may enable them to escape infestation as observed with S. mauritia, or with less severe damage due to S. biformis.

Table 9.1 Pest abundance in nursery

Insects and their damage / population	SRI cultivation (Mean ± SE)	Conventional cultivation (Mean ± SE)	t value	SRI as % of conventional
Cut worm (% damaged leaves per seedling)	0.0 ± 0.0 (0.0)	20.4 ± 4.8 (19.1)	16.1**	0%
Thrips (per seedling)	0.5 ± 0.2 (0.9)	6.1 ± 0.5 (2.5)	19.3**	8.2%
Green leaf hopper (per seedling)	0.1 ± 0.0 (0.8)	0.4 ± 0.1 (0.9)	14.8**	25.0%
BPH (per seedling)	0.0 ± 0.0 (0.0)	0.2 ± 0.0 (0.8)	11.5**	0%
Whorl maggot (% damaged leaves per seedling)	0.8 ± 0.2 (0.9)	9.3 ± 2.6 (9.1)	12.5**	8.6%

Figures in parentheses are transformed values.
**Significant difference ((P<0.001)
Source: David et al. 2005

Different irrigation practices may also lessen the thrips problems in the nursery. Being much smaller, SRI seedlings may be submerged even by a thin film of water on the soil that will dislodge thrips (Reissig et al. 1986). Sprinkling of water with a can may also get rid of thrips as they are easily washed away by rainfall. At the vegetative stage, closer spacing and heavy irrigation of plants would encourage thrips populations (Venugopal Rao et al. 1982). SRI management is different in that it is characterized by wider spacing and alternate wetting and drying (Table 9.2).

Table 9.2 Pest abundance in main field of conventional and SRI crops

Insects and their damage / population	SRI cultivation (Mean ± SE)	Conventional cultivation (Mean ± SE)	t value	SRI as % of conventional
Whorl maggot (% damaged leaves per hill)	17.9 ± 1.9 (18.0)	23.2 ± 2.0 (19.1)	6.6**	77.2%
Thrips (per hill)	6.6 ± 0.1 (2.2)	20.2 ± 2.0 (4.1)	12.2**	32.7%
Green leaf hopper (per hill)	0.6 ± 0.1 (1.0)	1.1 ± 0.2 (1.2)	10.7**	54.5%
BPH (per hill)	1.1 ± 0.2 (1.2)	2.7 ± 0.2 (1.8)	14.4**	40.7%
Whorl maggot (% truncated leaves per hill)	5.6 ± 1.8 (5.9)	8.8 ± 1.4 (9.1)	4.5**	63.6%
Gall midge (% silver shoot per hill)	5.0 ± 1.2 (6.8)	11.0 ± 1.5 (19.1)	9.3**	45.5%
Stem borers (deadheart/white ear per hill)	11.7 ± 1.3 (15.5)	7.3 ± 1.0 (10.0)	10.1**	160.3%
Leaffolder (scraped leaves per hill)	20.3 ± 1.6 (21.7)	6.5 ± 1.0 (11.8)	15.4**	312.3%
Earhead bug (no. per hill)	0.9 ± 0.1 (1.1)	0.9 ± 0.1 (1.1)	0.4NS	No change
Figures in parenthesis are transformed values. ** significant difference (P<0.001)NS : not significant				

Source: David et al. 2005

9.1.2 Whorl Maggot

Adult whorl maggot (H.philippina) is able to locate rice plants only by the reflected sunlight from the water surface (Reissig et al. 1986). Even though conventional nursery beds are alternately flooded and drained at early stages, the seedlings along the edges are always nearer to stagnant water in furrows. This results in more egg-laying (oviposition) on them. The modified SRI mat nursery is probably less attractive to these flies as they are not attracted to direct-seeded fields or to seed beds. .Thus, SRI seedlings may carry on them fewer eggs or maggots than do those from a conventional nursery (David et al. (2005).

Adult flies continue to lay eggs on transplanted seedlings, and larval feeding on the growing point of shoots results in severe stunting and poor establishment of seedlings. The flies prefer to lay eggs on plants in flooded plots during the first 3-4 weeks after transplanting compared with rice plants growing in saturated but unflooded fields as with SRI. Maggot infestation has been reported to be reduced with an increase in plant density, which is much less when maggot attacks.

Further, SRI seedlings are one week younger than conventional ones at the time of planting. This could cause them to be more susceptible to H. philippina. More flies could be sighted on conventional seedlings mostly because of the differences in irrigation practice between the two systems after the initial draining of water. The weeding method may also contribute to the incidence of fewer adults on SRI plants. The rotary weeder utilized at 12-15 DAT, triggers root growth and tillering. This is not done in conventional fields which are flooded to assist easy hand weeding. This could help the flies easily locate the plants for oviposition. In SRI, the rotary weeder even causes the water film to disappear, probably making the seedlings, though smaller, less recognizable to the flies after weeding (David et al. 2005).

Padmavathi et al. (2007) observed that SRI plants had more leaves damaged by whorl maggot as compared to conventional methods, however. So, more research on this is needed.

9.1.3 Hoppers

In general, leafhoppers (family Cicadellidae) attack all aerial parts of the plant, whereas planthoppers (family Delphacidae) attack the basal portions (stems). Both leafhoppers and planthoppers (order Hemiptera) are sucking insects which remove plant sap from the xylem and phloem tissues of the plant. Severely damaged plants dry up and take on the brownish appearance of plants that have been damaged by fire. Hence, hopper damage is commonly called "hopper burn". These insects are severe pests in many Asian countries where they not only cause direct damage, by removing plant sap, but are also vectors of serious rice diseases, such as the rice tungro virus transmitted by the green leafhopper (Nephotettix virescens) and the grassy stunt virus transmitted by the brown planthopper (Nilaparvata lugens) (http://ipmworld.umn.edu/chapters/heinrich.htm).

SRI practices have an in-built mechanism to suppress brown planthopper (BPH) as well as green leafhopper (GLH) populations. Several factors lead to the abundance of Nephotettix spp. and N. lugens. Dense planting, continuous flooding, and higher applications of inorganic nitrogen are important among them (Shukla and Anjaneyulu, 1981; Karuppusamy and Uthamasamy, 1984). Plant density usually affects the immigration and distribution of BPH after transplanting by creating a more favourable microclimate (Garcia et al. 1994).

Although the number of seedlings per hill per unit area is higher with conventional methods, the microclimate in SRI could be the same or even more favourable to BPH owing to an even larger number of tillers per unit area at the later stages, despite having transplanted a single seedling per hill. Increased levels of nitrogen application lead to BPH abundance. SRI not only increases N availability, but also sustains it so that plants remain green and more attractive to pests until harvest. Draining the field controls BPH populations (Das and Thomas, 1977) as BPH is never a problem in upland rice. Predators which can control these pest populations, especially C. lividipennis, were found to be significantly more numerous in SRI plots, actively preying on the eggs of hoppers. This indicates that BPH and GLH should not be as serious a problem in SRI (David et al. 2005).

9.1.4 Gall Midge

Dense planting, application of nitrogen fertilizers, presence of weeds, and continuously standing water, all favour heavy midge infestation, which declines during dry weather and due to the activity of parasitoids as with conventional methods. Earlier, alternate wetting and drying was reported to increase gall midge incidence (Karuppusamy and Uthamasamy, 1984).. However, sparse planting when coupled with intermittent irrigation may provide an environment less favourable for gall midges as observed in SRI. The extent of larval parasitism due to the parasitoid, Platygaster oryzae Cameron, may vary between conventional and SRI methods, owing to spacing and irrigation practices which influence not only crop growth and microclimate, but also natural enemies.

Midges cause more damage with increased N fertilization as well. Although SRI plants are likely to derive more N from the probable changes in soil conditions, midges did not cause more damage in SRI (Table 9.2), where suppression of weeds which act as alternative hosts could help to reduce gall midge attack compared to hand weeding with conventional methods (David et al. 2005).

9.1.5 Stem Borers and Leaffolder

Stem borers consist primarily of insects in the lepidopterous families, Noctuidae and Pyralidae. The adult moths lay eggs on rice leaves, and the larvae when they hatch bore into the stem. Feeding in the stem during the vegetative growth stage of the plant (seedling to stem elongation) causes death of the central shoot, leading to what are called "dead hearts." Damaged shoots do not produce a panicle, and thus, produce no grain. Feeding by stem borers during the reproductive stage (panicle initiation to milk grain) causes a severing of the developing panicle at its base. As a result, the panicle is unfilled and whitish in color, rather than being filled with grain and brownish in color. Such empty panicles are called "whiteheads" (http://ipmworld.umn.edu/chapters/heinrich.htm).

A large group of insects belonging to several insect orders feed on rice leaves. Most common are the larvae and adults of beetles (order Coleoptera), larvae of the order Lepidoptera, and grasshoppers (order Orthoptera). Defoliation reduces the photosynthetic capacity of the rice plant, and thereby decreases yields. However, when feeding damage occurs early in rice growth, plants have an ability to compensate for damage by producing new tillers. Thus, rice plants in their actively tillering stage of growth can tolerate a certain level of leaf damage without any yield loss.

Stem borers and leaffolders were the two kinds of pests that increased their population in SRI plots much more than in plots with conventional management (David et al. 2005). This is probably due to the effects of SRI management resulting in more productive phenotypes in terms of tiller number, leaf area index (LAI), and yield. When continuously flooded, 75% of rice plant roots remain in the top soil (6 cm) at 28 DAT (Kirk and Solivas, 1997), while with SRI, the roots go deeper (10-15 cm) with a 45% increase in dry weight (Tao et al. 2002).

Apart from improving soil aeration, rotary weeding prunes the roots to some extent, encouraging growth of more prolific root systems coupled with more attractive plants, which these two pests prefer. Large stems, heavy foliage and thick sheath favour the development of Chilo suppressalis (Walker) and S. incertulas (Chienyun, 1985) which usually increases with increase in plant density (Singh and Pandey, 1997). Irrigation methods and variations in water depths have been reported to have no significant influence on C. medinalis. However, draining the field suppresses yellow stem borer (Fang, 1977), a major pest of deep water rice.

Use of nitrogenous fertilizers pre-disposes rice plants to borer and folder infestation. Therefore, persistence of the 'edge effect' until grain maturity may be attributed to the abundance of both pests in SRI where aerobic and anaerobic soil conditions occur alternately, contributing to enriched plant nutrition, especially greater N availability than normal from the increased N mineralization (Birch, 1958). Thus, SRI plants ensure a more luxuriant growth, attracting more moths to shelter and oviposit (Chandramohan and Jayaraj, 1977). The flag leaves of SRI plants remain dark green even up to the time of harvest due to less senescence of leaves during the grain-filling period. In SRI, both stem borer and leaffolder moths were more abundant at the later stages, the peaks of which coincided with that of insect predators that are abundant in rice ecosystems and subsist on insect pests (David et al. 2005).

Experiments conducted at DRR, Hyderabad, in 2006, showed that yellow stem borer damage at maximum tillering and booting stages was lower in SRI as compared to conventional methods. But at reproductive stage, the damage (white earheads) was high in SRI (Padmavathi et al. 2007).

Some differences in the response of different varieties to pests when under SRI management have also been reported. Ravi et al. (2007) observed that BPT5204, which is susceptible to stem borer, showed lesser white ear damage under SRI (11.3%) when compared to conventional management (17.5%). The variety ADT48, known as a less-susceptible cultivar, experienced a higher level of leaffolder damage under SRI (15.0%) when compared to conventional method (1.0%).

The studies conducted by Sumathi et al. (2008) on the effect of manures on SRI crops showed that application of chemical fertilizers with and without organic manures increased the leaffolder damage. Leaffolder damage was minimum when FYM only was applied.

Field experiments conducted in Kerala have showed that the incidences of stem borer and leaffolder were significantly higher in SRI than normal method of cultivation (Karthikeyan et al. 2008).

9.2 Specific Effects of SRI Practices on Pest Incidence

Field trials conducted at the TNAU Agricultural College and Research Institute, Killikulam, during 2003-2004 to compare the abundance of insect pests and natural enemies between the conventional and SRI methods of cultivation showed that leaffolder, stem borers, and predators (Paederus fuscipes Curtis, Cyrtorhinus lividipennis Reuter) were found to be significantly more abundant, while Spodoptera mauritia Boisduval, Hydrellia philippina Ferino, Nymphula depunctalis Guenee, Orseolia oryzae Wood-Mason, Nilaparvata lugens Stal and Nephotettix spp. were significantly less abundant in SRI than with conventional methods (David et al. 2005).

Exposure to more sunlight and air due to wider spacing may help in reducing BPH incidence. As most of the weeds act as alternate hosts to major pests, removal of them at regular intervals by intercultivation with mechanical weeders reduces pest incidence and restricts further spread and development. At the tillering stage, vigorous growth with more tillers and foliage observed in the SRI crop may attract more defoliators such as cutworm, ear-cutting caterpillars, and leaffolder (Padmavathi et al. 2007).

Beneficial arthropod diversity (total abundance and species richness) was high in SRI plots as compared to conventional plot management (Padmavathi et al. 2007).

The water management practice with SRI is reported to have specific effects on pest incidence. Ravi et al. (2007) found that with SRI, leaffolder damage was higher and stem borer damage was less when compared with conventional method (Table 9.3). They also observed that alternate wetting and drying (AWD) facilitated higher leaffolder damage (21.2%) over flooding, but the effect on stem borer damage was the reverse.

Table 9.3 Effect of water management on pest incidence (%) in SRI, with two varieties

Treatment	Leaffolder damage		Stem borer damage	
	ADTRH1	ADT48	ADTRH1	ADT48
Conventional planting & flooding	7.42	11.31	15.11	12.97
SRI planting & conventional flooding	18.49	15.65	8.87	11.44
SRI planting & AWD	21.21	16.91	8.48	7.96

Studying the effects of individual components of SRI on pest incidence, Ravi et al. (2007) found that intermittent irrigation had a negative impact on whorl maggot; young seedlings reduced thrips damage both in nursery and main field; and both wider spacing and intermittent irrigation contributed to a reduction in BPH incidence. Wider spacing and intercultivation favoured leaffolder damage, which was associated with luxurious crop growth, higher chlorophyll content, and wider chlorophyll A and B ratio. The authors reported reduction of leaffolder damage in SRI when nitrogen application was guided by Leaf Colour Chart.

A field survey (121 farmers) conducted in Andhra Pradesh showed that 70% of the farmers did not feel a need to take up any control measures with SRI, whereas with conventional methods, they had used at least one spray of chemical insecticides. 35% of SRI farmers had used indigenously-prepared insecticides like Panchagavya, Amrita Jalam, and neem for protection against pests (Padmavathi et al. 2008).

Based on several field experiments with SRI, Ravi et al. (2007) concluded that insect pests, i.e., stem borer, gall midge, whorl maggot, and BPH were less active, but leaffolder caused significant damage. A multilocation trial in five locations for two years (2006 and 2007) showed that the incidences of stem borer, gall midge, and BPH were relatively less in SRI, while the incidence of leaffolder, GLH, and white-backed planthopper was higher when compared to conventional cultivation (Katti et al. 2008).

Experiments conducted during 2006–2007 and 2007–2008 at the Regional Agricultural Research Station, Pattambi, Kerala using two rice varieties, i.e., Jyothi and the hybrid CORH 2 under normal system and system of rice intensification, revealed that stem borer was significantly lower in SRI (4.82% in Jyothi and 2.35% in CORH 2) during the vegetative phase, compared to the standard method of cultivation (9.75% in Jyothi and 9.85% in CORH 2), while at the reproductive phase, there was no significant difference between the two systems of cultivation. The incidences of whorl maggot and caseworm were lower under SRI system, but the incidence of leaffolder was higher in the crop under SRI than the standard system. The occurrence of natural enemies like spiders and larval parasitoids was higher in SRI, while damselfly populations were lower in SRI system in comparison to the standard system of cultivation (Karthikeyan et al. 2010).

9.3 SRI and Rats

Rats are one of the most serious pests of rice, and they are extremely difficult to control. As in the control of insect pests, conservation of natural enemies is perhaps the most efficient approach. Unfortunately, the best natural enemy of rats is snakes, and many farmers are reluctant to encourage large snake populations. Another effective natural enemy is barn owls (http://www.aglearn.net/riceIPM Module4.html). SRI farmers in Tripura and other states often construct bird-stands in the middle of their fields to attract owls and raptors to perch there and thus reduce the intrusion of rats and some rice-eating birds.

Many SRI farmers in Tamil Nadu have reported that rat damage was almost nil in SRI crops, although neighbouring non-SRI crops were affected by rat damage. No research study has been taken up on this, however. The wider spacing between plants gives rats less cover in the early stages of plant growth.

9.4 Pest Management in Rice

Integrated pest management (IPM) through a smarter understanding of pest dynamics uses a variety of different strategies to minimize pest damage while eliminating or reducing pesticide use. IPM encourages farmers to limit pest damage through the use of pest-resistant varieties, by observing the activity of pests and their natural enemies, understanding the difference between when pest levels are a problem and when they are acceptable, and deciding rationally whether action is needed. Chemicals are used only as a last resort, and their application is aimed at maximizing natural biological control (http://irri.org/news-events/hot-topics/pesticides-and-rice-production).

Using chemical protection that eliminates or reduces pests' natural enemies, referred to as beneficials, is self-defeating. Even some neutral insects can be beneficial if they help to sustain the populations of the predators of pests. Control measures for some of the common rice pests are given in Table 9.4.

9.5 SRI and Non-Target Organisms

Misra et al. (2007) studied, for two years, the population density of non-target organisms in the soils in SRI and conventional rice cultivation at different dates after transplanting. Pooled data showed that SRI plots were harbouring more Enchytraeids population (3,609 m-2) than the conventionally transplanted plots (3,338 m-2); the collembolan populations were not different (3,892 and 3,889 m-2), and the soil mite populations were 2,663 and 2,601 m-2, respectively. The authors pointed out the potential of SRI for increasing the soil health and biodiversity.

9.6 SRI and Disease Incidences

Many species of bacteria, fungus, nematode, virus and mycoplasma-like organisms cause diseases in rice. Bacterial leaf blight, for example, is caused by Xanthomonas oryzae pv. oryzae. This disease is observed on both seedlings and older plants. On seedlings, infected leaves turn grayish green and roll up. As the disease progresses, leaves turn yellow and then become straw-colored and wilt, leading whole seedlings to dry up and die.

Blast is considered a major disease of rice because of its wide distribution and destructiveness under favorable conditions. All aboveground parts of the rice plant are attacked by the fungus. Susceptibility to blast is inversely related to soil moisture. Plants grown under lowland condition (i.e., flooded soil or with high soil moisture) become more resistant, while plants grown under upland conditions become more susceptible.

Table 9.4 Damage, economic thresholds, and suggested measures for management of common rice pests.

Pest	Characteristic damage	Economic thresholds	Control measures
Stem borer	Death of central shoot (dead heart,DH), white ear (WE), loss of tillers	10% DHs or 1 egg mass/m2 1 moth/m2, or 20-30 adult male moths/pheromone trap/week	Stubble destruction; planting of tolerant varieties like Vikas, Sasyasree, Ratna; chemical control when other measures are not sufficient
Gall midge	Central leaf sheath modified to a silver shoot (SS), loss of	5% SS (at active tillering stage)	Early planting; use of resistant varieties such as Phalguna, tillers Surekha, Suraksha; chemical control when other measures are not sufficient
Brown plant hopper &white-backed planthopper	Plants wilt and dry – Hopper burn	10 insects per hill at vegetative stage; 20 insects/hill at later stages	Resistant varieties; alleyways formation; draining the fields; judicious N use; chemical control when other measures are not sufficient
Green leaf hopper	Vector of tungro disease; plants wilt and dry in severe cases	2 insects/hill in tungro endemic areas; 20 – 30 insects/ hill in other areas	Resistant varieties; chemical control when other measures are not sufficient
Leaffolder	Leaf damage; poorly-filled grains	3 damaged leaves /hill (post-active tillering stage)	Judicious N use; destruction of alternate hosts; chemical control when other measures are not sufficient
Cutworm	Defoliation and damage to rachillae	1 leaf/hill stray incidence prior to harvesting	Flooding; chemical control when other measures are not sufficient
Gundhi bug	Partial chaffy grains	1 nymph/adult per hill	Removal of alternate host plants; chemical control when other measures not sufficient

Source: Padmavathi, 2011

Rice sheath blight occurs throughout rice-growing areas in temperate, subtropical, and tropical countries. It is found in diverse rice production systems, whether upland, rainfed, or irrigated (http://www.knowledgebank.irri.org/ipm/index.php/diseases-crop-health-2733).

In 2005-2006, an evaluation done in Vietnam by its National IPM programme across eight provinces, comparing SRI plots with neighbouring farmer-practice plots, found that the prevalence of four major rice diseases and pests (sheath blight, leaf blight, small leaf-folder, and brown plant hopper) was greatly reduced on SRI plants, 55% less in the spring season, and 70% less in the summer season (Dung, 2007).

Researchers at the China National Rice Research Institute have found sheath blight reduced by 70% in SRI fields in Tian-tai township of Zhejiang province (personal communications). In controlled trials, the index of sheath blight with SRI management was found to be 2.1% compared with 14.9% in control plots (Lin, 2010).

Overall, the studies on the effect of SRI on disease incidences are very limited so far. Field experiments conducted during 2004-2005 and 2005-2006 by Sinha and Kumar (2007) showed that sheath blight incidence was reduced significantly due to SRI when compared to standard method of cultivation (Table 9.5).

Table 9.5 Sheath blight incidence and grain yield under SRI and standard method of cultivation.

Method of cultivation	2004-2005		2005-2006	
	Sheath blight incidence (%)	Grain yield (t ha^{-1})	Sheath blight incidence (%)	Grain yield (t ha^{-1})
Standard	45.60	2.940	35.50	4.057
SRI	20.75	6.110	15.50	5.035

9.7 SRI and Nematodes

Any change in cultivation system has a concomitant effect on the rice ecosystem and associated biological communities. Plant parasitic (root-feeding) nematodes are an important component of the microfauna associated with the rhizosphere of rice plants.

Hirschmanniella oryzae and M. graminicola are common plant parasitic nematodes associated with irrigated rice systems, but Hirschmanniella spp., which are specialized to thrive under anaerobic ecosystems, are commonly predominant. Both nematodes occur in irrigated rice. The reported build-up of nematodes in rice fields when converted from flood irrigation to alternate wetting and drying (aerobic) conditions (Bouman, 2002) has raised concerns on such possibilities when SRI is followed (Prasad et al. 2002).

There was greater increase of M. graminicola in SRI plots than in conventional irrigated rice plots indicating that SRI is more favourable to this nematode. The alternate wetting and drying with weeding by a hand-operated rotary weeder that is followed under SRI results in alternating periods of aerobic and anaerobic soil conditions, and this might have permitted the multiplication of M. graminicola (Seenivasan et al. 2010).

Prasad et al. (2008) hypothesized that switching to SRI might result in a gradual decline in populations of rice root nematode species, which prefer irrigated systems, and an increase in populations of more pathogenic species such as root-knot and lesion nematodes, which prefer upland and aerobic environments.

Application of Super Pseudomonas as a seed treatment (@ 10 g/kg of seed) decreased the population of the rice root nematode, Hirschmanniellaoryzae and the root-knot nematode, Meloidogyne graminicola, by 67-73% (Proceedings of Rice Scientists Meet, TNAU, 2008).

Research in northern Thailand has showed that SRI practices contributed to higher populations of root-knot nematodes which offset the potential productivity gains from SRI management (Sooksa-nguan et al. 2009). Possibly altered schedules of wetting and drying could reduce or minimize nematode damage by creating anaerobic soil conditions that disrupt nematode growth cycles. But such experimentation and validation remains to be done in areas where root-knot nematodes are endemic. Where significantly higher yields are obtained with SRI management, as reported from a wide variety of places, this parasite is not evidently a constraint. Attention must be paid to it, however, wherever the water and oxygen status of soils is modified.

9.8 Summary

SRI has both advantages and disadvantages in terms of insect and other pest abundance. Culturally, it departs from traditional methods in the management of nursery, planting and spacing, weeding, irrigation, and inorganic N applications, leading to production of more tillers and foliage coupled with grain yield. Each component of SRI is related to the abundance of one or more pests as well. Thus, SRI encompasses several IPM cultural techniques which suppress most pests. Overall, there are more gains in the suppression of pests and diseases reported with SRI management than there are increased losses. But the latter must be attended to get the most net benefit from SRI methods.

Nitrogen management, a crucial factor affecting the incidence of stem borers and leaffolders, holds the key to managing both of these pests in SRI. Overuse of insecticides may cause them to die or lead to resurgence of leaffolder as both are highly responsive to nitrogenous fertilizers. Thus, insecticides and nitrogen fertilizers need to be applied more judiciously in SRI to manage these two pests. LCC may be popularized to avoid application of nitrogenous fertilizers in excess when the plants remain greener from SRI advantage.

Ravi et al. (2007) have suggested biointensive pest management in SRI, involving different components like the use of botanical pesticides, augmentative release of egg parasitoids (Trichoderma spp.) and pathogens (Bacillus thuringiensis), and the use of novel tools like pheromones and light traps.

The interaction of SRI practices with responses of the rice crop to various pests and diseases is yet to be understood thoroughly. However, publications like 'Integrated Disease Pest Management in SRI Paddy' (SRI Secretariat, 2011) have become useful for SRI practitioners.

10 EFFECTS OF SRI ON SOIL AND CROP PERFORMANCE

SRI is certainly a major breakthrough in rice cultivation. More than just improving practice, it has contributed to different thinking that can enable farmers to get more production from their existing, available resources. It challenges the conventional approach of pursuing high-input-oriented agriculture to get more production. SRI reverses the logic of current thinking about modernizing agriculture for the simple reason that more productivity can be achieved just by modifying common agronomic practices for transplanted rice.

Rice farmers do not need to learn something entirely new and unfamiliar, but instead they just alter practices that they are accustomed to doing.

The SRI principles, when adopted properly and with understanding, result in a crop that grows in a different manner, not experienced with any other method of rice cultivation. Using just 160,000 seeds (seedlings) in a hectare and getting 350,000,000 to 400,000,000 seeds back represents an output of 7 to 8 t ha^{-1} grain yield from 3.2 kg of seed weight (individual grain weight assumed to be 20 mg). This is a very welcome production result brought about by SRI methods (Figure 10.1). This return of 2,000-2,500 times is remarkable, and this ratio can be even greater when soil fertility is accelerated through promotion of biodiversity and abundance of life in the soil.

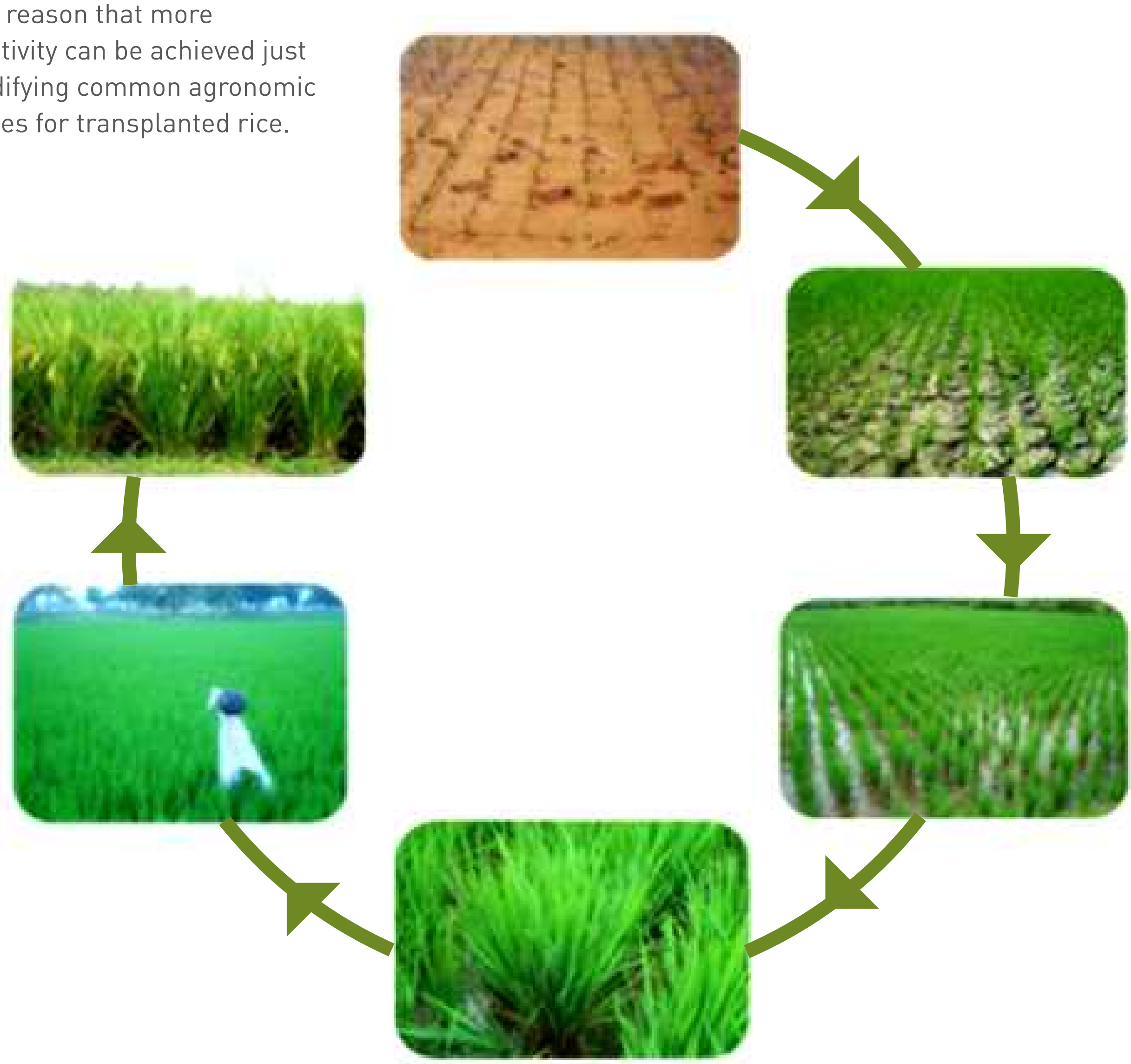


Figure 10.1 SRI crop growth cycle

This is the outcome of the effects brought about by the SRI principles individually and through synergy. Much experimental evidence and many farmer experiences confirm this SRI effect on yield. How and why this happens is understood to some extent, but it remains to be explained fully.

For the first several weeks after transplanting his or her field, a first-time SRI farmer will be disheartened as the field will look at first like it has not even been planted. Further, he will receive criticisms from family members and passers-by for several weeks. But within a month, in response to SRI practices the crop will begin surprising everyone with its profuse tillering. There will be growing confidence as the time of harvest approaches and a big surge of satisfaction when the crop is 'in the bag' (Figure 10.2).

Field immediately after planting with single seedlings

Same field at tillering stage

Same field at harvest stage

Figure 10.2 SRI rice field at planting, tillering and harvest stages.

10.1 Evaluation of SRI

Evaluation of SRI outside Madagascar began only in 1999, almost two decades after it was developed in that country by Fr.Laulanié. Some scientists in India, Indonesia and China began systematic experiments employing accepted scientific methods at the start of the past decade, and some farmers and NGOs in India particularly showed interest in SRI because of its orientation towards organic farming.

Research on SRI in India

Standard experiments on SRI were first initiated in Tamil Nadu Agricultural University (TNAU) from 2000 onwards, and SRI-related research is still going on in the University. The experiments conducted during 2000–2002 were aimed at understanding the influence of SRI principles on crop growth, crop physiology, rhizosphere soil dynamics, and soil microbiology.

Water saving was documented to the extent of 47% without detrimental effect on yield. The most important result observed was the significant effect of weeder use on grain yield. Two reasons for this were inferred: the green-manure effect of returning weeds into the soil to enhance soil organic matter, and the soil-aeration effect of breaking the surface horizon to increase oxygen availability for roots and the soil biota.

Since then, various experiments were initiated and are still being conducted. After 2003, a variety of studies by scientists across the country have been carried out. Three National Symposia on SRI, organized and held in 2006, 2007 and 2008 at Hyderabad, Agartala, and Coimbatore, provided opportunity to bring together information collected from such scientific studies from all across India. These studies compared the performance of SRI vs. conventional cultivation; the effects of changes made in seedling age, spacing etc.; the effects of SRI management on pest and diseases, water productivity, and nutrient uptake; the adoption dynamics of SRI, etc.

Research carried out so far has focused particularly on root growth, crop growth, tillering, lodging, crop duration, physiology and yield attributes, and also changes in soil biology, pest and disease incidences, and nutrient dynamics.

On-Farm Evaluations

All the agencies involved in promoting SRI started with on-farm evaluations and demonstrations, combining these with different kinds of training. The first evaluations commenced in 2003 in Tamil Nadu, Tripura, and Andhra Pradesh, and later by several civil society organizations (CSOs) in different parts of the country such as PRADAN, People's Science Institute, AME Foundation, and the Green Foundation. In Tripura, the Department of Agriculture started SRI demonstrations in 2002-2003, with the number of farmers using the new methods increasing from 44 in that first year,to 162,485 in 2007- 2008.

The joint WWF-ICRISAT project supported systematic evaluation of SRI methods by the state university, ANGRAU, and a local NGO, CROPS, in Warangal, through on-farm field trials in 11 districts of Andhra Pradesh over several years, starting with the rabi season of 2004-2005. Since then, on-farm evaluations have been carried out in many different regions of the country.

The changes brought about in the growing environment of the plants due to the use of young single seedlings, wider spacing, soil-aerating weeder operations, and reduced, controlled irrigation have been found to have a positive influence on the growth of plants as well as on the soil dynamics in a manner not found in non-SRI cultivation.

From whatever scientific and field observations are available, it can be stated that there are significant effects on the crop as well as on the soil system. These can be grouped into two categories:

- Creating a better growing environment for the plants
- Exploiting more fully the genetic potential of rice plants

10.2 Creating a Better Growing Environment for Rice Plants above and below the Ground

The number of seedlings planted per square meter being usually 16, when 25x25 cm spacing is adopted, the space for the photosynthesis in leaves and room for root growth below-ground is greater than in conventionally-planted crops. This makes for less competition for sunlight, water, and nutrients. Cessation of continuous flooding avoids anaerobic soil conditions that permit only anaerobic soil organisms to survive, and soil churning by intercultivation with a mechanical weeder changes the physical, chemical and biological conditions of the soil. Together, they induce an array of changes in the growth of the crop and in soil conditions.

10.2.1 Effects of SRI Practices on the above Ground Environment

The main effect on the aboveground environment is on the availability of more sunlight for the leaves and enhanced canopy photosynthesis because of the wider spacing and single seedling per hill.
It is known that the lower leaves supply most of the photosynthate to rice plant roots (Tanaka, 1958). So, any limitation on the ability of these leaves to carry out photosynthesis (due to crowding and shading) will have an adverse effect upon the roots' growth and capacity for metabolism. This aggravates the negative effects of hypoxic soil conditions upon roots' health and functioning (Uphoff, 2008).

Experiments conducted in Indonesia in 2002 showed that the radiation intercepted, increased with wider spacing; with conventional narrow spacing, the lower third of leaves did not receive enough sunlight to accomplish photosynthesis. So, instead of contributing to the plants' pool of photosynthate, these leaves relied upon that pool for their own metabolism, becoming in effect parasitic (Table 10.1).

Table 10.1 Radiation intercepted (lux), at heading stage, of Ciherang variety at different spacings, Sukamandi, dry season, 2002

Spacing (cm)	20x20cm	30x30cm	40x40cm	50x50cm
Plant population m-2	25.0	11.1	6.3	4.0
Radiation above canopy	235	235	243	254
Radiation below canopy	78	88	131	153
% radiation below canopy	33.2	37.4	53.9	60.2

Note: Radiation intercepted above and below the canopy is average of 8 points measured in each plot, observed at 9:24-10:40 am, 14 July 2002.

Source: Data collected by Dr. Anischan Gani, Agency for Agricultural Research and Development rice research station at Sukamandi (reported by Uphoff, 2008)

Results of the experiment conducted by Thakur et al. (2011) showed that during the initial growth stages until 40 days after germination (DAG), the canopy of the crop under standard management (SMP) with conventional flooding intercepted more solar radiation than did the SRI canopy with alternate wetting and drying. But, beyond 50 DAG, light interception with SRI was significantly more than with SMP. At the panicle initiation stage, light interception reached 89% in SRI, while it was only 78% in SMP canopies, giving a 15 % advantage. The study showed that SRI leaves had higher light utilization capacity and greater photosynthetic rate, especially during the reproductive and ripening stages of the crop.

The above-ground environment under SRI is expected to maintain a different micro-climate and to have its own favourable impact not only on the growth of the crop but also on pest and disease interactions; but this has to be studied more. The reduction or absence of rodent damage in SRI fields, reported by many farmers, is probably due to the changed above-ground environment.

10.2.2 Effects of SRI Practices on the Below-Ground Environment

The below-ground environment under SRI is also different from conventional cultivation in terms of more room for root growth, root activity, nutrient availability, soil microbial activity, soil aeration, and redox potential. These effects have been studied to some extent.

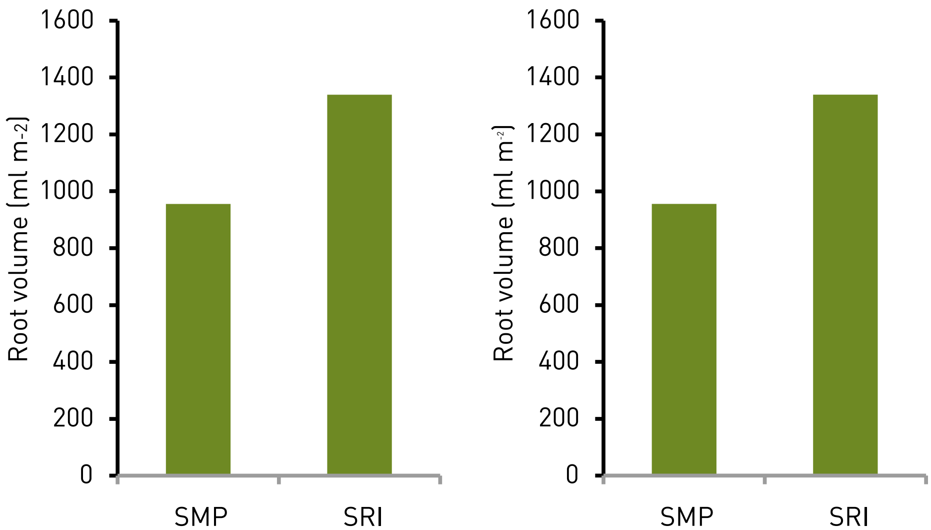
Root Growth and Activity

Although root growth is a plant behavior, it is considered under this heading as the changed soil environment plays a major role in it. A number of experiments and farmer experiences have shown how the root system of SRI crop is distinctly different from that of a conventional rice crop. Photos 10.1 and 10.2 show the impressive root system observed in farmers' fields.

Rice plants in the SRI plots had 10 times more root mass, about 5 times more root length density, and about 7 times more root volume in the top 30 cm of soil profile, compared with roots in the plots of flooded rice (Rupela et al. 2006). Barison and Uphoff (2011) found that, on average, uprooting single SRI plants required 55.2 kg of force per plant, while pulling up clumps of three conventionally-grown plants required 20.7 kg per hill.

SRI methods achieved better nodal root development than conventional methods at the initial growth stage when soil nutrients were not a limiting factor. Reduced intra-hill competition favoured the development of more lateral roots (Mishra and Salokhe, 2011). According to Lin et al. (2011), root growth was positively and significantly influenced by aerobic irrigation and by organic manure application. They also reported that higher the proportion of organic application for a given level of N provision, the stronger was the reduction of the soil.

Photos 10. 1. and 10.2. Extensive root system of single hills observed by farmers (Jharkhand and Tamil Nadu).



Figures 10.3 and 10.4
Root volume and root length density under standard management practice (SMP) and SRI. (Source: Thakur et al. 2011)

Observations of Thakur et al. (2011) showed that SRI crop had 40% more root volume per sq.m and 125% more root length density than the crop under standard management practice (Figures 10.3 and 10.4).

While degeneration of roots is common in flooded soil (Kar et al. 1974), with SRI water management there was negligible root degeneration. Brownish roots due to coating of ferrous compounds and degeneration are common from the panicle initiation stage onwards. Drained field conditions enhanced the root oxidizing power and reduced the fraction of dark coloured roots (Ramasamy et al. 1997). Under SRI, whitish roots with virtually no degeneration are observed by farmers, indicating clearly a different environment faced by the roots (Photos 10.3 and 10.4). Mishra and Salokhe (2011) have documented how flooding and crowding of plants leads to degeneration of roots.

It is considered that SRI root system is more active than in conventional rice crop. Thakur et al. (2011) found greater xylem exudation rates from SRI roots, indicating enhanced root activity. Mishra and Salokhe (2011) observed higher root-oxidizing activity at the later growth stage of the SRI crop.

The higher root biomass in SRI plants will establish a larger rhizosphere, and according to Armstrong (1970), plants with larger rhizosphere regions will be significantly better protected from absorbing large amounts of reduced products and the oxygenation of small lateral roots is higher than the primary roots.

Photo 10.3 Comparison of roots of conventional and SRI crop

Photo 10.4 Completely white roots in SRI at panicle initiation stage.

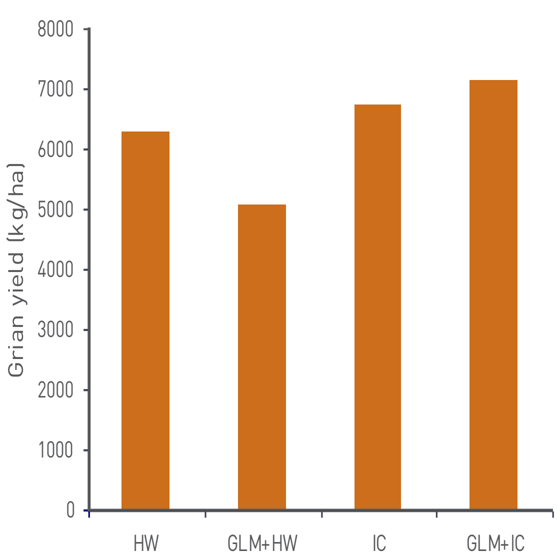


Figure 10.5 Effect of intercultivation on the grain yield of rice.
HW: hand weeding; GLM: green leaf manure;
ZIC: intercultivation with weeder 4 times.

Effects of Intercultivation

The intercultivation operation brings about considerable changes below the ground which have been found to be reflected in crop response.

The importance of intercultivation and its interaction with green leaf manure (GLM) and young seedlings was brought to light by the studies of Thiyagarajan et al. (2002). In their experiment, 14-day-old seedlings, single seedlings per hill, 20 x 20 cm spacing, alternate wetting and drying, and NPK application were common factors; the treatment differences were made in GLM application and in weeding. When no GLM was applied, intercultivation with weeder increased yield by 7.0% over hand weeding. Application of GLM when combined with hand weeding reduced the yield by 19.3%, but when hand weeding was replaced by mechanical intercultivation, there was a 13.7% increase in yield. This showed that the negative interaction of GLM with young seedlings was reversed and turned positive when intercultivation was done; the impact was to the extent of nearly 2 t ha^{-1} (Figure 10.5). The decrease in redox potential due to organic manure application and the increase of the same due to intercultivation (Jayakumar et al. 2005; Sudhalakshmi et al. 2007; and Lin et al. 2011) may be the causes for these effects.

Further, mixing aerobic and anaerobic soil horizons may contribute to greater biological nitrogen fixation (Magdoff and Bouldin 1970).

Data collected from 76 farmers using SRI methods in Madagascar in the 1997- 1998 season showed that each weeding beyond two added 1 to 2.5 t ha^{-1} to yield (Uphoff, 2002). In Nepal, data from 412 farmers showed that farmers who used the weeder three times got yields of 7.87 t ha^{-1}, 2 t ha^{-1} higher than the majority of farmers who weeded only twice (5.87 t ha^{-1}). Farmers who weeded only once lowered their yield (5.16 t ha^{-1}) by 600 kg ha^{-1} compared to those who did two weedings.

Vijayakumar et al. (2004) also found a significant yield increase of 9.7% (with 20 x 20 cm plant spacing) and 11.1% (with 25 x 25 cm plant spacing) which could be attributable to weeder use when compared to conventional weeding (herbicide + hand weeding) using 14-day-old seedlings and limited irrigation.

The experiments carried out for two seasons by Ramamurthy (2004) on intercultivation showed very interesting results (Table 10.2):

- Four times intercultivation (T2) resulted in significantly higher yield and least cost of production of grain (Rs 4.57 kg-1) than conventional methods having two hand weedings (T1) or herbicide plus one hand weeding (T3) in the first season. But in the second season, non-removal of left-out weeds by weeder significantly reduced the grain yield, and the cost of production was the highest (Rs.6.80 kg grain-1). This effect might be location- and season-specific with respect to weed species and growth.
- Comparison of other treatment results (T1-T4) also showed the necessity of removing left- out weeds after intercultivation.
- Using the weeder after the removal of all weeds by hand had significantly higher effect (T6-T7) than doing it vice versa, showing that incorporating the weeds reduced the grain yield in these trials.
- Maximum yield was obtained when the intercultivation was done after removal of weeds at 15 and 35 DAT in both the seasons. Although the cost of this method was highest (Rs.5,112 ha^{-1}), the B:C ratio was higher (2.11 and 2.34) than conventional weed control methods. This effect showed that removal of weeds without incorporation and subsequent soil stirring by the weeder has more beneficial effect. It is, however, still to be verified whether this is site-specific.

Table 10.2 Effect of weeder use on grain yield, cost of weeding, cost of grain production, and B:C ratio (Ramamurthy, 2004)

Treatment number	Treatment details	Treatment effect	Grain yield (Rs. ha^{-1})		Weeding cost (kg ha^{-1})		Cost of production per kg grain (Rs)		B:C ratio	
			EXPT-1	EXPT-2	EXPT-1	EXPT-2	EXPT-1	EXPT-2	EXPT-1	EXPT-2
T1	Hand weeding at 15 and 30 DAT	All weeds removed (2 times)	5,655	5,550	3,960	3,960	5.04	5.14	1.89	1.85
T2	Rotary weeder at 10, 20, 30 and 40 DAT	Intercultivation (4 times) – left -out weeds remain	5,873	3,949	2,304	2,304	4.57	6.80	2.11	1.42
T3	Weedicide at 3 DAT + hand weeding at 30 DAT	Weeds inhibited + all weeds removed at 30 DAT	5,470	5,223	2,417	2,417	4.93	5.17	1.95	1.86
T4	Weedicide at 3 DAT + rotary weeder at 30 DAT	Weeds inhibited + intercultivation at 30 DAT (1 time))- weeds escaping the weeder remain	5,016	5,036	833	833	5.06	5.04	1.90	1.91
T5	Weedicide at 3 DAT + hand weeding followed by rotary weeder at 30 DAT	Weeds inhibited + intercultivation after removal of weeds by hand at 30 DAT	5,643	5,555	2,993	2,993	4.88	4.96	1.97	1.95
T6	Hand weeding followed by rotary weeder at 15 and 30 DAT	Intercultivation after removal of weeds (2 times)	6,480	7,249	5,112	5,112	4.58	4.09	2.11	2.34
T7	Rotary weeder followed by hand weeding at 15 and 30 DAT	Intercultivation + left-out weeds removed by hand two times	-	6,349	-	1,728	-	4.14	-	2.32
T8	Rotary weeder at 10 and 20 DAT + hand weeding at 30 DAT	Intercultivation two times with left-out weeds remaining and third time all weeds removed by hand	-	4,835	-	3,312	-	5.76	-	1.67
T9	Rotary weeder at 10 and 20 DAT + rotary weeder followed by hand weeding at 30 DAT	Intercultivation three times. Left-out weeds remain after first two times and removed after third time	-	5,905	-	2,016	-	4.50	-	2.14
T10	Rotary weeder at 10 and 20 DAT + rotary weeder followed by hand weeding at 30 and 40 DAT	Intercultivation four times. Left-out weeds remain after first two times and removed after third and fourth time	-	5,900	-	2,880	-	4.65	-	2.07
T11	Weedicide at 3 DAT + rotary weeder followed by hand weeding at 30 DAT	Weeds inhibited + intercultivation and left-out weeds removed at 30 DAT	-	6,062	-	1,049	-	4.22	-	2.26
T12	No weed control	Weeds allowed to grow	-	1,953	-	0	-	12.58	-	0.77
	L.S.D (0.05)		272	331	-	-	-	-	-	-

SRI-practicing farmers feel that the pruning of the roots by the weeder has a similar influence like the pruning the shoots of guava, grapes, mango, etc. The regeneration of roots due to the pruning effect has been confirmed by Jayakumar et al. (2005). The intercultivation also results in some earthing-up effect, and Ramamoorthy (2004) found new roots formed above the original soil level because of this (Photos 10.5 and 10.6).

Photo 10.5 Earthing-up by intercultivation

Photo 10.6 New roots grown because of earthing-up by weeder

Enhancing Soil Biological Activity

Application of organic manures to the soil in SRI is favourable to microbes as these materials become a source of energy for them. Besides, alternate wetting and drying combined with intercultivation practice adds active soil aeration to the passive soil aeration that results from SRI water management practices which, as seen above, can enhance the growth of phosphobacteria and possibly of N-fixing bacteria by alternatively wetting and drying the soil (Uphoff et al. 2009).

Research on the effect of SRI on soil biological activity is very limited and needs more attention. However, some research information on soil microbial activity is available.

Studies done at three different locations, at Tamil Nadu Agricultural University (TNAU) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India, and at the national agricultural university in Indonesia, Institut Pertanian Bogor (IPB), looked at the effects of changes in water regime and associated SRI practices on microbial populations and activity in the rhizosphere soil of rice plants.

Data from the three studies showed SRI management associated with some significant differences in soil microbial populations; higher levels of enzyme activity in SRI plant rhizospheres, indicative of increased N and P availability; and more soil microbial C and N, which would enlarge the nutrient pool for both plants and microbes. These studies, although more exploratory than conclusive, showed enough similarity to suggest that SRI practices, which make paddy soils more aerobic and enhance soil organic matter, are supportive of enhanced populations of beneficial soil organisms. If this relationship is confirmed by further assessments, it could help researchers and practitioners to improve paddy production in resource-conserving, cost-effective ways (Anas et. al. 2011).

Gayathry (2002) investigated the impact of the SRI management practices of younger seedlings, soil-aerating weeding with a mechanical weeder, water management to avoid continuous soil saturation, and green manures to enhance soil organic matter. These practices, in combination, had positive effects on soil biota (Table 10.3).

Gayathry found that the numbers of all aerobic bacteria in the SRI rhizosphere were increased by more than 50% before and during panicle initiation, compared to those in the rhizosphere of conventionally grown rice of same variety. The populations of Azospirillum also increased similarly, while Azotobacter, another diazotroph (N-fixing bacterium) and phosphate-solubilizing bacteria increased by even more, by about 75%. During panicle initiation, the numbers of diazotrophs were more than twice as high under SRI management as with conventional practice.

Throughout the crop cycle, not only were more bacteria found in SRI rhizospheres overall, but there were even more of those species that enhance nutrient availability for plants. The levels of enzymes that reflect the processes of N and P mobilization and uptake in the soil were also measured. This showed enzyme levels significantly greater at almost all phases of crop growth when SRI practice altered the management of plants, soil, water and nutrients (Table 10.4).

Table 10.3 Microbial population in the rhizosphere soil in rice crop under two different crop management conditions, Coimbatore, wet season, 2001-2002.

Parameter	Treatment	Crop growth stage			
		Active tillering	Panicle initiation	Flowering	Maturity
Total bacteria	Conventional	9.35	14.91	9.73	7.64
	SRI	14.66	21.64	10.99	7.51
Azospirillum	Conventional	4.69	7.39	3.13	1.42
	SRI	7.17	9.08	4.23	1.52
Azotobacter	Conventional	8.88	25.57	10.45	5.56
	SRI	20.15	31.17	10.92	6.45
Total diazotrophs	Conventional	9.11	10.52	7.14	4.71
	SRI	14.62	22.91	7.68	5.43
Phosphobacteria	Conventional	9.15	17.65	7.76	2.28
	SRI	16.19	23.75	13.79	2.66

Table 10.4 Microbial activities in the rhizosphere soil in rice crop under two different crop management conditions, Coimbatore, dry season, 2002.

Parameter	Treatment	Crop growth stage				
		Active tillering	Panicle initiation	Flowering	Grain filling	Maturity
Dehydrogenase activity (μg TPF g^{-1} soil 24 hr^{-1})	Conventional	81	263.00	78.00	24	16.00
	SRI	369	467.00	139.00	95	42.00
Urease activity (μg NH_4-N g^{-1} soil 24 hr^{-1})	Conventional	189	1794.00	457.00	134	87.00
	SRI	230	2840.00	618.00	228	173.00
Acid phosphate activity (μg p-Nitrophenol g^{-1}soil hr^{-1})	Conventional	1800	2123.00	957.00	384	214.00
	SRI	1984	2762.00	2653.00	995	686.00
Alkaline phosphate activity (μg p-Nitrophenol g^{-1}soil hr^{-1})	Conventional	261	372.00	332.00	124	120.00
	SRI	234	397.00	324.00	189	146.00
Nitrogenase activity (nano moles C_2H_4 g^{-1} soil 24 hr^{-1})	Conventional	-	3.15	7.63	-	1.94
	SRI	-	3.70	11.13	-	1.87

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

Conventional: 24-day-old seedlings; irrigating to 5 cm depth one day after disappearance of ponded water; hand weeding twice; recommended fertilizers

SRI: 14-day-old seedling; 2 cm irrigation (after hairline crack up to panicle initiation and after that one day after disappearance of ponded water); rotary weeding 4 times at 10 day interval; recommended fertilizer plus green leaf manure

Studies conducted at the Directorate of Rice Research, Hyderabad, showed that dehydrogenase activity in the soil increased by 23% in the rhizospheric and bulk soil during vegetative stage in SRI plants as compared to those transplanted conventionally (Mahender Kumar et al. 2009).

Lin et al. (2011) observed that more input of organic material and aerobic irrigation (AI), both, respectively, and together, increased the numbers of actinomycetes significantly.

When organic fertilization was increased from 25 to 100% with AI, the increase in actinomycete numbers was 292%,while with inundated (anaerobic) soil, the increase was only78%. When organic fertilization was 25%, shifting from continuous flooding (CF) to AI increased actinomycete number by 26.7%, while with organic fertilization of 50 and 100%, the respective increases were 41.8 and 178.2%.

10.3 Exploiting More Fully the Genetic Potential of Rice Plants

The dramatic changes in observable phenotypes that SRI practices underscore the importance of looking beyond genetic traits and of dealing with GxE (genetic-environmental) interactions (Uphoff, unpublished)

Field experiments and on-farm observations have shown that rice plants grown under SRI management behave differently from what is usually observed in conventional and standard non-SRI practices. These changes are manifested in terms of root growth and function, profuse tillering, non-lodging, prolonged leaf greenness, higher number of panicles and number of grains per panicle, and lower spikelet sterility which are easily observable. Changes measurable in the laboratory and using instruments include physiological and phytochemical parameters.

10.3.1 Root Function

Thesis research by Nisha (2002) confirmed that plants grown with SRI methods had greater root length and root volume, as well as about 40% higher root cation exchange capacity (CEC) and about 27% more ATPase activity and cytokinin content of roots (Table 10.5). CEC reflects the capacity of roots to absorb cations and thus vital nutrients. ATPase is a key enzyme required for the absorption of nutrients, and cytokinin is a growth hormone

Table 10.5 Root characteristics and activity in the crop under different crop management conditions, Coimbatore, India, wet season, 2001-2002

Parameter	Treatment	Crop growth stages			
		Transplanting	Active tillering	Panicle initiation	Flowering
Total root length (m)	Conventional	1.02	6.08	17.42	55.71
	SRI	0.88	22.50	31.05	67.50
Root volume (cc $hill^{-1}$)	Conventional	1.48	10.70	25.5	42.5
	SRI	0.83	15.50	26.30	57.5
ATPase activity of fresh root (µg of inorganic P g^{-1} hr^{-1})	Conventional	NA	0.24	0.53	0.62
	SRI	NA	0.34	0.69	0.74
CEC of dried and milled roots (me 100 g^{-1} of dry root)	Conventional	NA	7.20	9.80	10.60
	SRI	NA	10.60	14.60	13.40
Cytokinin content of roots (pmol g^{-1})	Conventional	NA	46.20	73.60	50.50
	SRI	NA	58.90	86.00	72.50

Conventional practice: 24-day-old seedlings; irrigating to 5 cm depth one day after disappearance of ponded water; hand weeding twice; recommended fertilizers;

SRI practice: 14-day-old seedlings; 2 cm irrigation, after hairline cracks in the soil surface appeared, up to panicle initiation; after PI, irrigate one day after disappearance of ponded water; inter-cultivation with rotary weeder 4 times at 10-day intervals; recommended fertilizer plus green leaf manure. Source: Nisha (2002).

involved in cytogenesis, being synthesized in the root tips and translocated to other parts of the plant. SRI root systems were thus not only larger, but can function more effectively in support of rice plants' growth and grain production. These data were consistent with the reports that SRI methods affect the size and performance of roots, which would reciprocally have positive effects on the soil biota through root exudation (Anas et al. 2011).

Higher root oxidizing activity at the later growth stage of the SRI crop, along with better root distribution in the soil, might be related to the delayed senescence and prolonged photosynthetic activity of the lower leaves and consequently to higher yields that is observed in SRI-grown plants (Mishra and Salokhe, 2011).

10.3.2 Phenotypical Changes

Thakur et al. (2009) showed that alterations in management practices can induce multiple, significant, and positive changes in phenotype from a given rice genotype. The increase in yield with SRI when compared with those used with recommended management practices reached 42%, and it was associated with various phenotypical alterations such as longer panicles, more grains panicle−1, higher percent of grain-filling, more open plant architecture with more erect and larger leaves, more light interception, higher leaf chlorophyll content at ripening stage, delayed senescence and greater fluorescence efficiency, higher photosynthesis rate, and lower transpiration.

Profuse tillering, leaves' remaining green even after physiological maturity, and resistance to lodging are observed in the field (Photos 10.7 to 10.12).

Photo 10.7 Enhanced tillering in normally shy-tillering variety ASD16

Photo 10.8 Profuse tillering

Photo 10.9 SRI leaves remaining green at harvest stage

Photo 10.10 Non-lodging of SRI crop seen in the background, with normally-grown crop in the foreground

Photo 10.11 More than 100 panicles from a single seedling

Photo 10.12 More than 350 grains in one SRI panicle

10.3.3 SRI and Rice Genotypes

On-farm evaluations and farmers' experiences have showed that practically all genotypes, i.e, land races, high-yielding varieties, hybrids and scented varieties, have responded to SRI management positively. A high-yielding variety ASD16, considered as a shy-tillering variety by breeders in Tamil Nadu, has showed profuse tillering with SRI methods (Photo 10.11). Many of the varieties grown under SRI in farmers' fields have exceeded the expected yield declared by breeders.

Observations in Tripura showed that the grain yields of all genotypes including land races were increased under SRI (Table 10.6). In Timbuktu region of Mali, evaluation by farmers showed that all five varieties raised with SRI methods yielded more than plants of same variety using standard methods as a control. The yield increase under SRI ranged from 44 to 99% (Styger et al. 2011).Similar positive response of all five varieties studied in Afghanistan has been reported by Thomas and Ramzi (2011).

Multilocation trials conducted by DRR have showed significant differences between the varieties under SRI management. In general, it was observed that, compared with standard transplanting, hybrids performed better (with a 4 - 42% yield advantage) than did other improved varieties (with a 2-7% increase). The hybrids KRH2, HRI 126 and PHB-71 and DRRH2 performed better as compared to the varieties (Mahender Kumar et al. 2009).

The very low seed requirement for growing rice with SRI methods is beneficial in conserving and multiplying traditional varieties with special qualities. It also makes the adoption of hybrids more feasible for small and poor farmers who otherwise find the cost of purchasing hybrid seed prohibitive.

Table 10.6 Grain yield of varieties, hybrids and land races in Tripura (t ha^{-1})

	Conventional		SRI	
	Minimum	Maximum	Minimum	Maximum
High yielding varieties	2.5	5.2	4.6	8.5
Hybrids	6.0	7.0	7.2	8.7
Land races	2.0	3.0	3.8	4.3
Scented land races	1.5	2.0	3.1	3.4
Average	3.0	4.3	4.7	6.2

10.3.4 Grain Quality

The effects of SRI on the quality of grains have also been reported. The quality of the seed produced in SRI is far superior to the seed produced conventionally (Subba Rao et al. 2007). The quality traits of basmati rice was also found to be enhanced in SRI (Tewari and Barai, 2007; TildaRicelands Pvt. Ltd., 2008). A higher milling percentage has also been reported.

10.4 Synergistic Effects

One of the significant knowledge advances generated from field experiments is appreciation for the synergistic effects of SRI practices. Such an outcome has not been reported in any other existing package of practices. These appear to result from the way that beneficial biological processes are promoted through simple but unconventional management practices which require only labour and skill. This strategy of agricultural advancement is different from one that relies on genetic modifications and on inputs of fertilizers and other chemicals (Uphoff, 2008).

Factorial trials combining various SRI practices have demonstrated a synergy among these practices that helps to explain the positive-sum increases (Rajaonarison 2000; Andriankaja 2001). Only four factors, i.e., seedling age, number of seedlings per hill, compost application, and water management were considered in an ambitious pair of factorial trials under contrasting agroecological conditions. Intercultivation was not included, and the spacings of trials (25 vs. 30 cm) were within the recommended distance range for SRI, so the full set of SRI practices was not evaluated in these trials. To do so would have required four times more trials, and N's of 288 and 240 were already very demanding of the researchers.

From Figures 10.6 to 10.9, one can see how the addition of SRI practices raises yield steadily from conventional practice. This involved flooded (saturated) soil, older seedings (20 days is actually quite younger than the norm for farmer practice, which is 30 to 50 days), three plants per hill, and application of NPK fertilizer (the recommended dose of 16-11-22 mixture), although not all practices made equal contributions.

On better (clay) soil, the SRI practices evaluated (not testing wider spacing and not including soil-aerating weeding) raised yield by more than three times, while on poorer (loam) soil, they effected a tripling of yield. It is evident that among the practices evaluated within this set of trials, the age of seedling had the most powerful effect, with water management (aerobic soil conditions) as the next most influential factor. The fertilization effect might have been more powerful for NPK if an improved variety had been used in the trials, instead of a local variety, which responded well to compost (Uphoff, 2008).

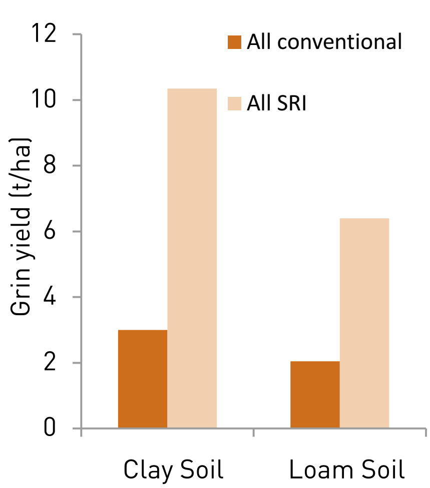


Figure 10.6 Grain yield under conventional and SRI practices (Source: Andriankaja, 2001)

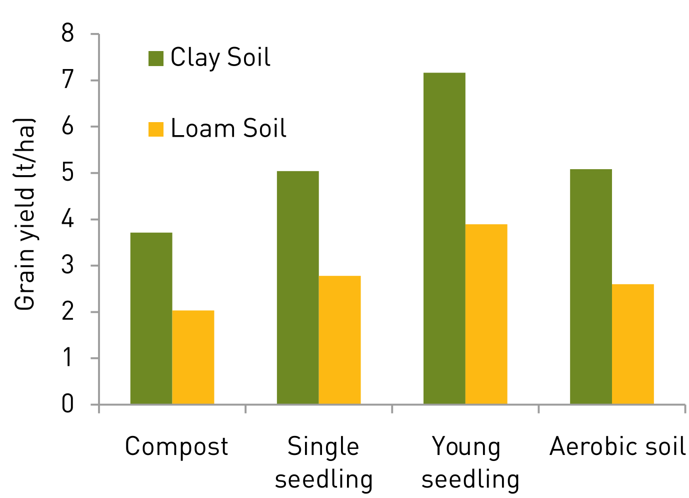


Figure 10.7 Grain yield with one SRI practice included (and the other three practices being conventional) (Source: Andriankaja, 2001)

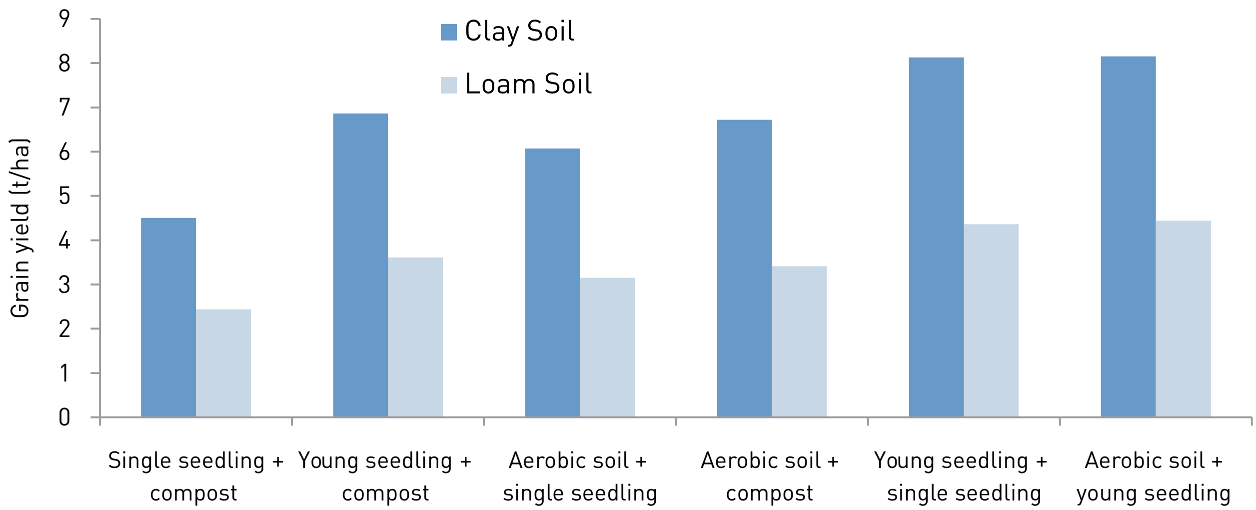


Figure 10.8 Grain yield with two SRI practices included (the other two practices being conventional) (Source: Andriankaja, 2001)

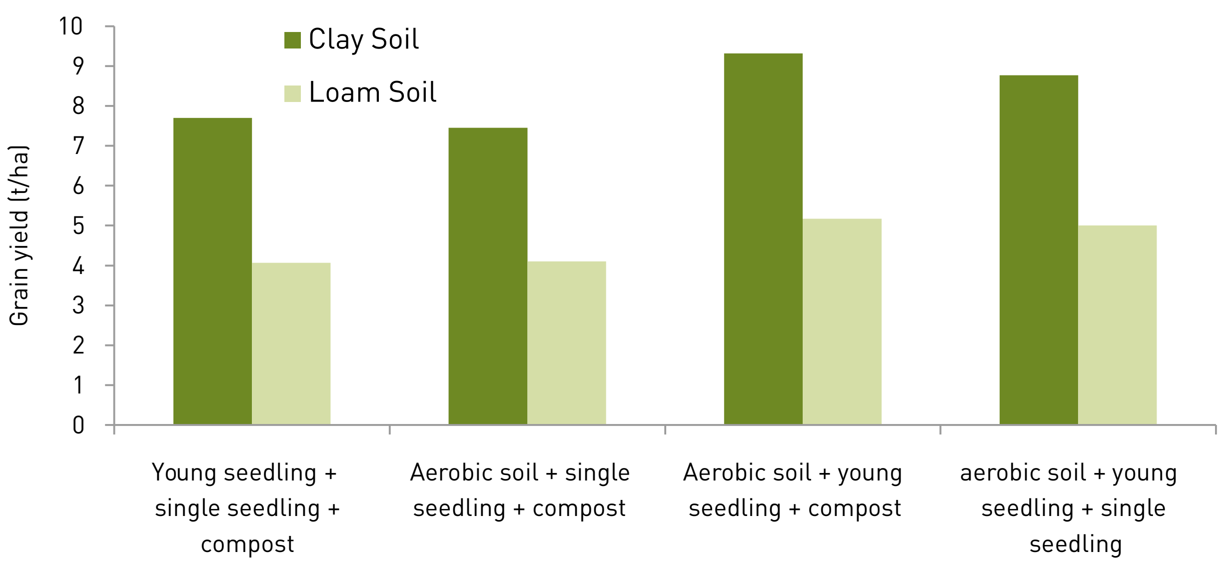


Figure 10.9 Grain yield with three SRI practices included (the remaining practice being conventional) (Source: Andriankaja, 2001)

Rajendran et al. (2005) studied the respective contributions of the practices, when all other SRI practices were kept equal and the non-adoption of respective individual SRI principles was studied. The increase in yield due to all SRI practices over conventional practice in these trials was 48.8%. In comparison with full use of SRI practices, the greatest yield reduction occurred when intercultivation was not done (19.0%) (Table 10.7). Similarly when compared to conventional practice results, missing intercultivation brought about the largest (20.1%) decrease in yield. These results showed intercultivation as more important than the other principles (younger seedlings, single seedling per hill, and intermittent irrigation) under the trial conditions.

Table 10.7 Respective contributions of individual SRI practices on grain yield

Seedling age (days)	No. of seedlings per hill	Weeding practice	Irrigation practice	Grain yield		
				(kg ha^{-1})	Increase over conventional (%)	Increase over full SRI use (%)
15	1	Intercultivation	Intermittent	7,061	(+) 48.8	-
25	1	Intercultivation	Intermittent	5,864	(+ 23.6	(-) 17.0
15	3 – 4	Intercultivation	Intermittent	6,138	(+) 29.4	(-) 13.1
15	1	Hand weeding	Intermittent	5,698	(+) 20.1	(-) 19.0
15	1	Intercultivation	Flooding	6,425	(+) 35.4	(-) 9.0
25	3 – 4	Hand weeding	Flooding	4,745	-	(-) 34.2

Source :Rajendran et al. 2005

10.5 Summary

The agronomic practices followed in SRI has been found to create a different environment for the rice plants resulting in more favourable growth and better physiological functioning leading to higher yields. The influence of SRI practices on the soil biological and nutrient dynamics appears to enhance the response of SRI plants. However, more research is required to fully understand soil-plant-water-nutrient-biotic interactions within the SRI system. Because SRI results depend more on the interaction among a number of factors, some of them being biological and inherently quite variable, such results commonly range fairly widely, more than if just a single external input is being put into this complex soil-plant-water-nutrient-biotic environment.

The principles of SRI, if understood properly and if applied through appropriate practices, have significant effects on the plants and soil. These have been experienced by now several million SRI farmers around the world and in numerous experimental evaluations. But a lot more is still to be understood. It has to be remembered that almost all of the previous scientific knowledge generated about rice plants' performance and response has been derived from plants grown with non-SRI agronomic practices – older seedlings, crowding and flooding in both nurseries and main fields, root-traumatizing transplanting, anaerobic soil condition, and inorganic nutrient applications, with little enhancement of soil organic matter and no active soil aeration. Comparisons with information and knowledge generated under such conditions are not necessarily applicable to SRI crops because they represent phenotypes that are different in structure and functioning from rice plants grown under conventional management.

11 BENEFITS OF SRI

The benefits of adopting SRI in rice production are multifold. The overall benefits accruing to the individual farmer are increased production and net income, and for some farmers it enhances their household food security. The water-saving part of the benefit has huge implications for the society and country as a whole in addressing the hydrological poverty and heavy energy utilization for pumping irrigation water. There are various benefits experienced by farmers in terms of enhanced efficiency of their inputs for rice production (seeds, water, labour, nutrients) and also some social benefits.

11.1 GRAIN

The yield increase by adopting SRI has been observed in on-station experiments, on-farm evaluations, and by farmers themselves. Because the yield gains are driven by biological processes rather than mechanistic response to external inputs, the gains are quite variable and range widely, 25%, 50%, 100%. But the results are also occasionally negative, and sometimes (when the soil biological dynamics are most favourable) they can be quite spectacular. Some persons regard this variability as invalidating all SRI reports, expecting that there should be just one SRI result that is correct. But in fact there continues to be a wide range of results that are all correct, for their respective combinations of conditions.

Grain yield in rice is determined by the number of panicles per unit area, the number of grains per panicle, and grain weight. The higher yield in SRI is associated with higher number of panicles and number of grains per panicle. Thakur et al. (2011) reported 23.7% more panicles per sq.m, 40.5% more grains per panicle, and 2.9% higher grain weight in the SRI crop compared to the crop of same variety grown with best recommended practices from the Central Rice Research Institute of India. Variations in the effect of SRI practices on yield attributes are also reported. Zhao et al. (2011) reported that while the number of panicles per unit area and the grain weight were more in SRI, the number of grains per panicle was lower than in the conventional flood-irrigated crop. Most studies, on the other hand, report higher number of grains per panicle. How different varieties respond to SRI practices varies, as do the responses of rice crops to SRI methods under different soil, climatic and other conditions.

Yield information from different countries has shown considerable country-to-country and intra-country variations, for both SRI and conventional management. Overall, the average yield advantage with SRI practices appears to be over 60 % (Kassam et al. 2011). Another assessment averaging results from 11 studies across 8 countries reported a 47% average increase in yield (Africare/Oxfam America/WWF-ICRISAT Project, 2010).

11.1.1 Experimental Evidence

Available data from SRI experiments across India show an increase in grain yield up to 68%. A few experimental results obtained across the country are summarised in Table 11.1.

Table 11.1 Grain yields in SRI recorded in experiments across India

S.No	Location	Grain yield (t ha^{-1})			Source
		Conventional	SRI	% increase / decrease	
1	Tamil Nadu Rice Research Institute, TNAU, Aduthurai	4.70	7.10	+ 48.9	Rajendran et al. 2005
2	14 Research stations, ANGRAU, Andhra Pradesh	4.90	5.70	+ 16.6	Mallikarjuna Reddy et al. 2007
3	Indira Gandhi Agricultural University, Raipur, Chhattisgarh	5.90 (2006) 4.30 (2007)	6.60 5.10	+ 12.0 + 17.8	Chitale et al. 2007
4	Agricultural Research Institute, Patna, Bihar	3.90	6.10	+ 55.1	Ajaykumar et al. 2007
5	Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puduchery	2.20	3.70	+ 68.3	Sridevi and Chellamuthu, 2007
6	ICAR Research Complex, Umiam, Meghalaya	4.00 (2005) 4.70 (2006)	4.40 5.20	+ 9.3 + 10.2	Munda et al. 2007
7	Central Rice Research Institute, Cuttack, Odisha	4.90 (2005) 5.60 (2006)	5.90 7.00	+ 20.4 + 25.0	Rao et al. 2007
8	Regional Agricultural Research Station, Shillongani, Assam	3.10	4.50	+ 45.2	Bora and Dutta, 2007
9	Agricultural Research Station, UAS, Kathalagere, Karnataka	8.80 (2005) 9.10 (2006)	10.20 10.50	+ 15.9 + 15.4	Jayadeva et al. 2008
10	Main Rice Research Station, AAU, Nawagam, Gujarat	4.00 (2006) 4.70 (2007)	6.30 7.50	+ 35.9 37.1	Chauhan et al. 2008
11	Birsa Agricultural University, Ranchi, Jharkhand	4.30	5.00	+ 16.3	Singh et al. 2009
12	Deras Farm, Mendhasal, Khurda District, Odisha	4.40	6.50	+ 47.7	Thakur et al. 2011
13	DRR/ICRISAT Farm, Hyderabad	7.65	8.17	+ 6.8	Gujja and Thiyagarajan, 2011

Though evidences of increased yields due to SRI are more, there is a case of no such increase reported by Anita and Chellappan (2011) under humid tropical conditions of Kerala.

At the Indian Agricultural Research Institute (IARI), SRI was first evaluated in 2002 and compared with transplanted puddled rice (TPR); wet seeded puddled rice (WSR); SRI; dry seeded rice (DSR); dry seeded rice on flat beds (FB); and dry seeded on raised beds (RB). The grain yield was highest in SRI (5,452 kg ha^{-1}), but statistically similar to TPR (5,440 kg ha^{-1}). However, water productivity was significantly higher (Choudhury et al. 2005).

11.1.2 On-Farm Trials

Results of evaluations in farmers' fields showed yield advantages of 1.5 t ha^{-1} in Tamil Nadu, and 1.67 t ha^{-1} in Andhra Pradesh. On-farm evaluations in Tripura with different land races, high-yielding varieties and hybrids showed that irrespective of the varieties, yield increases under SRI were up to 100%. The evaluations carried out by PSI (Peoples' Science Institute, Dehradun) in Himachal Pradesh and Uttarakhand (2007) showed an average increase in yield of 89% over conventional cultivation. SRI results have often showed greater yields on farmers' fields than on experiment stations, for reasons not yet researchers or clarified. This is the reverse of usual situation where farmers have a hard time replicating researchers' results. With SRI it is often vice versa.

Grain yields obtained by farmers of different states in SRI and non-SRI cultivation are presented in Table 11.2. The yield increase is seen to have varied from 23.0 to 96.4%, with a simple average of 45%. The data from Andhra Pradesh show fluctuations in yield advantage.

Table 11.2 Average grain yields in SRI and conventional cultivation observed in farmers' fields in several states.

S.No	State	Year	Season	Grain yield (t ha^{-1})			Percent increase
				Conventional	SRI	Increase	
1	Tamil Nadu	2003-2004	Rabi	5.7	7.2	1.5	26.3
		2007-2008	Rabi	4.4	5.7	1.3	29.5
2	Andhra Pradesh	2003	Kharif	4.9	8.4	2.5	51.0
		2003-2004	Rabi	5.5	7.9	2.4	43.6
		2007	Kharif	5.0	6.2	1.2	24.0
		2007-2008	Rabi	5.2	6.6	1.4	26.9
3	Tripura	2006	Kharif	4.5	7.0	2.5	55.6
4	Himachal Pradesh	2007	Kharif	2.8	5.5	2.7	96.4
5	Uttarakhand	2007	Kharif	2.9	5.3	2.4	82.7
6	Bihar	2004-2006	Kharif	3.8	4.7	0.9	23.0
7	Kerala	2007-2008	Late second season	3.0	3.4	0.4	12.0
8	Gujarat	2007	Kharif	2.9	5.4	2.4	82.8
9	Punjab	2007	Kharif	7.7	9.8	2.1	27.3

Source: Presentations in National Seminar on SRI, 2007 and 2008

Photo 11.1 Happy SRI farmer with a 10 t/ha yield crop

Photo 11.2 A proud SRI farmer showing SRI panicles from her field

There are large inter-country variations in SRI results (Table 11.3), reflecting differences in soil, climatic, and other conditions (Kassam et al. 2011). These data show a range of 11 to 204%, with an average of 69%; excluding the two extreme values, the average is 58%.

Table 11.3. Grain yields recorded in on-station and on-farm trials in other countries

S.No	Country	Year	Grain yield (t ha^{-1})		
			Conventional	SRI	Increase
	On-station trials				
1	Hangzhou, China	2006-2007	7.3	8.1	11.0
2	Eastern region, Gambia	2000-2002	2.5	7.6	204.0
3	Southern region, Iraq	2009	3.8	5.3	39.5
4	Eastern region, Madagascar	2000-2001	4.9	6.3	28.6
	On-farm trials				
5	Baghlan Province, Afghanistan	2008-2009	5.6	9.3	66.1
6	Eastern Province, Indonesia	2002-2006	4.3	7.6	76.7
7	Central and northern regions, Madagascar	2000-2001	3.4	6.4	88.2
8	Timbuktu, Mali	2008	5.5	9.1	65.5
9	Central Provinces, Panama	2009-2010	3.4	4.8	41.2

Source: Kassam et al. (2011)

11.1.3 Farmer Experiences

The grain yields obtained by farmers in larger areas, unlike demonstrations, reflect the response in farm fields. The variations in these yields may also reflect the extent of adopting the SRI principles. A lot of information is available on the experience of the farmers who have been associated with some civil society organizations. A few examples are given here.

PRADAN started promoting SRI in 2003 with 4 families, which grew up to 6,200 families in 2006. In 2008, 43.7% of the cooperating farmers in Purulia district, West Bengal, harvested 6-8 t ha^{-1} yield, and 24% harvested yields of 8-10 t ha^{-1}. In rainfed areas of Purulia district, the average productivity with SRI was 7.7 t ha^{-1}, in spite of high incidence of disease and pest attacks coupled with dry spells immediately after transplanting and during grain-filling stage of the crop. 90% of the farmers had yields above 5 t ha^{-1}, which is around 2.5 times the district average (http://ciifad.cornell.edu/sri/countries/india/inpradan406.pdf).

Evaluations carried out by PSI (Peoples' Science Institute, Dehradun) in Himachal Pradesh and Uttarakhand in 2006 showed that in HP, the average productivity of paddy went up from 3. 2 t ha^{-1} to 5.0 t ha^{-1}(about 56%), and in UKD, the average yield jumped about 77% from 3.1 t ha^{-1} to 5.5 t ha^{-1}. The results from 2007 showed that the non-SRI yields stood close to 2.8 t ha^{-1}, and the SRI yields were around 5.4 t ha^{-1}, giving an average increase of 89%.

The average grain yields obtained by farmers in conventional and SRI cultivation in various river basins assisted by the World Bank-IAMWARM Project in Tamil Nadu are presented in Table 11.4. Average yield with conventional methods ranged from 3.5 t ha^{-1} to 5.3 t ha^{-1}, while the SRI yields ranged from 4.5 t ha^{-1} to 10.0 t ha^{-1}. The increases in yield ranged from 16.2 to 46.5%, with an average of 28.3% (Thiyagarajan et al. 2009). Field reviews have concluded that not all of the recommended SRI practices have been used by farmers, or used as recommended, so these results are from what should be considered as 'partial SRI.' This problem of assessing what represents full or correct SRI is a widespread one for this innovation, since SRI use, with its set of half a dozen practices, is a matter of degree more than of kind.

Table 11.4 Yields obtained by farmers in different river sub-basins under World Bank-IAMWARM Project, Tamil Nadu, 2007- 2008.

River sub-basin	Grain yield (kg ha^{-1})		Range of grain yields with SRI		Increase in SRI over conventional
	Conventional	SRI	Minimum	Maximum	(%)
Aliyar	3,484	4,488	2,958	6,475	28.8
Arjunanadhi	5,488	6,375	4,000	7,880	16.2
Kottakaraiyar	4,044	5,023	2,625	7,500	24.2
Manimuthar	4,185	5,596	4,000	7,500	33.7
Pambar	4,050	4,924	3,040	6,740	21.6
South Vellar	4,100	6,005	3,040	7,500	46.5
Upper Vellar	5,250	7,140	4,313	9,987	36.0

Source: Thiyagarajan et al. 2009.

A paddy yield of 22.4 tons/hectare reported from the SRI plot of a farmer in Darveshpura village (Nalanda district, Bihar state), Shri Sumant Kumar, has attracted considerable attention as it surpasses the previously accepted world record yield of 19 tons/ha reported from China(The Pioneer, Nov. 27, 2011: http://www.dailypioneer.com/nation/23641-bihar-farmer-beats-world-in-paddy-cultivation. html). Since four other farmers in the village, also first-time SRI practitioners, achieved paddy yield levels of 18 or 19 tons/ha, Sumant Kumar's achievement was not an isolated occurrence.

11.2 Household Food Security

The increased productivity by adopting SRI has been a boon to families which grow rice for their own consumption, especially in rainfed areas. The annual per capita rice consumption in eastern India is higher than rest of the country: 133 kg versus 37 kg in the western region, 39 kg in the northern region, and 113 kg in the southern region (Singh and Singh 2000). A study report on the enhanced household food security in Jharkhand (NABARD 2011) demonstrates the potential of SRI in this regard (Table 11.5)

Table 11.5 Household food security and SRI

Landholding (acres)	No. of days of food security		
	With traditional methods	With SRI methods	Additional days of food security
0 - 1	153	217	64 (41.8 %)
1 – 2	268	416	148 (55.2 %)
> 2	326	738	412 (126.4 %)

Source: NABARD (2011)

11.3 Straw Yield

Information on straw yield is not reported much, and the numbers have not always been consistent with respect to the effects of SRI. A number of SRI farmers have reported increased straw yield along with increased grain yield. On-farm evaluation in Tirunelveli District, Tamil Nadu, showed a 29% increase in straw yield along with a 27.7% increase in grain yield (Thiyagarajan et al. 2005).

The straw volume with the SRI method is usually much higher, providing more fodder to the cattle of the mountainous rice areas of Himachal Pradesh and Uttarakhand, for example, which will in turn help to increase the farm yard manure (Sen et al. 2007).

A field experiment conducted in Hyderabad in 2009-2010 showed that the straw yield with SRI was 8.17 t ha^{-1} while in control plots (farmer's practice) it was 6.27 t ha^{-1}, an increase of 33.5%. The experiment also showed that under organic SRI (SRI-ORG), the straw yield was 1.7 t more than conventional SRI (Figure 11.1) even though there was not much difference between the two sets of practices in grain yield.

A contradictory result was reported by Thakur et al. (2011), wherein there was a 20.6% reduction in straw yield of SRI when compared with standard management practice, although the SRI grain yield was 47.7% higher, showing considerably higher harvest index. Ravindra and Bhagya Laxmi (2011) also reported a 19% reduction in straw yield of the SRI crop from a survey with SRI farmers in Andhra Pradesh.

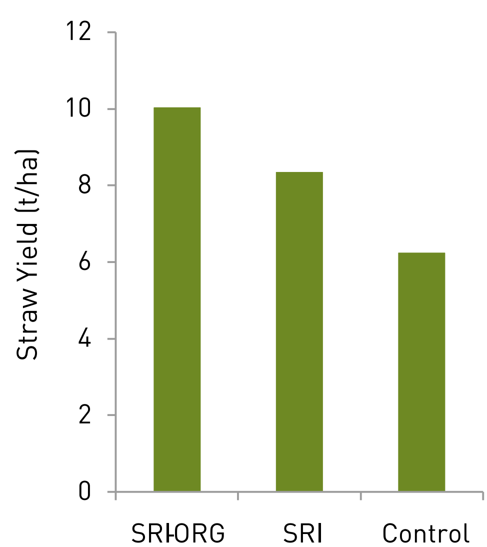


Figure 11.1. Straw yield in SRI, organic SRI and control, Hyderabad, 2009-2010

11.4 Land Saving

Photo 11.3 Inter-space in banana field was utilized for SRI nursery

Photo 11.4 Unused conventional nursery (in background) of a farmer who raised it for conventional planting but then did SRI planting

Since grain productivity is higher under SRI, farmers cultivating rice for home consumption only can reduce their area under rice and can diversify their farming system with other remunerative crops. Further, the land area required for an SRI nursery is just one-tenth of the area required for conventional cultivation, so managing a separate field for the nursery, as is generally practiced, is not necessary. In fact, some farmers have raised their SRI nursery in their home backyards or on house terraces or even on roofs. One farmer in Tamil Nadu raised his nursery in a banana field (Photo 11.3). A farmer who raised a conventional nursery but then planted with SRI methods could realize the savings in SRI nursery (Photo 11.4)

11.5 Seed Saving

The nursery required for one ha under SRI management could be raised using just 5-7.5 kg seed as against 20-30 kg ha^{-1} under conventional method. For conventional planting, farmers generally use high seed rates, up to 75 kg ha^{-1}.

In the case of hybrids, 66% of seed cost could be saved by adopting SRI method. The significant seed saving will promote higher seed multiplication rate, greater purity of seed (single seedling planting), and faster availability/spread of released varieties (Mahender Kumar et al. 2010). Styger et al. (2011) reported 80-90% saving of seeds in Timbuktu, Mali.

The seed-saving part of SRI is very much appreciated by practicing farmers, especially the poor, as their seed cost will not be prohibitive to commence rice cultivation. In fact, SRI farmers are advised to collect good panicles from their standing crop before harvest (as only 5-7.5 kg is required for 1 ha) and store the seeds for next season (good quality seeds can be recycled for three seasons). The seed saving of 45–60 kg ha^{-1} will improve household food security of resource-poor farmers.

With the introduction of SRI in Tripura, the total seed requirement has decreased as can be seen in Table 11.6. On a regional and country scale, the quantity of seed that can be saved by SRI adoption will have added advantages in reduced storage facilities and transport of seeds. Another benefit of the very low seed rate with SRI is the easiness and cost reduction in seed treatment.

Table 11.6 Year-wise savings of seeds in Tripura

Year	Area under SRI(ha)	Requirement of seeds under recommended practice (tonnes) @50 kg ha^{-1}	Requirement of seeds under SRI (tonnes) @ 5 kg ha^{-1}	Net savings (tonnes)
2006-2007	14,678	733.9	73.4	660.5
2007-2008	32,497	1,624.8	162.5	1,462.3

Source : SRI Fact Sheet – Tripura. WWF-ICRISAT Project, 2008.

11.6 Water Saving

Not much systematic research has yet been done on water management options and optimization within the framework of SRI management (Kassam et al. 2011). However some standard experiments have shown significant water saving in SRI cultivation, averaging 33.5% (Table 11.7).

Table 11.7 Water use in conventional and SRI cultivation and water saving in SRI

S.No.	Water used		Water saved (%)	Reference
	Conventional	SRI		
1	16,634 (m3 ha^{-1})	8,419 (m3 ha^{-1})	49.4	Thiyagarajan et al. (2005)
2	13,055 (m3 ha^{-1})	8,906 (m3 ha^{-1})	32.0	Mahenderkumar et al. (2010)
3	1,223 x 104 (l/ha)	952 x 104 (l/ha)	22.2	Thakur et al. (2011)
4	1,774 mm	1,298 mm	26.8	Zhao et al. (2011)
5	34,500 (m3 ha^{-1})	21,600 (m3 ha^{-1})	37.4	Hameed et al. (2011)

11.7 Labour Saving

One of the criticisms on SRI was that it is 'labour-intensive'. The extra time needed to master the new techniques, and to negotiate new divisions of rice-production labour, are essentially transitory adjustments (Ravindra and Bhagya Laxmi 2011). Experiments conducted in Coimbatore showed a 41% increase in labour productivity in the wet season of 2001-2002 and a 13% increase in the dry season of 2002 (Thiyagarajan et al. 2002). Experiments conducted in Kerala have shown that cono-weeding reduced the labour required for weeding by 35 man-days ha^{-1} and labour cost by Rs 3,125 ha^{-1} (Anita and Chellappan 2011).

Several observations with farmers have shown that SRI requires less labour than conventional cultivation. The on-farm trials in Tamiraparani river basin showed an overall reduction of 8% in labour inputs, with a significant shift of labour inputs for weeding from women to men (Thiyagarajan et al. 2005). Women's inputs overall declined by 25%, largely due to a shift in the gendered division of labour. Men's inputs increased by 60% when they took over mechanical weeding as this was considered more appropriate for males.

This transfer of responsibility was made more acceptable within households by a more than doubled net income per hectare. Labour requirement was mainly reduced by less time for seedling pulling and transplanting. Many SRI farmers report almost negligible expenditure on seedling pulling as one or two labourers only are required, compared to 6-10 labourers for conventional seedling pulling and transport.

Labour saving in weeding is also realized by many farmers because the mechanical weeder reduces the time needed for this operation. It has been observed that farmers having only about 1 acre of land do not need to depend upon external labour for any of their field operations and can manage with their own family labour, employing a machine for harvesting.

11.8 Cost Saving

On-farm trials in the Tamiraparani river basin in 2003 showed that there was a 11% reduction in overall costs of cultivation (Thiyagarajan, 2005). Based on 12,133 on-farm comparison trials that covered a total area of 9,429 ha in Eastern Indonesia, Sato et al. (2011) reported that an average yield increase under SRI management of 3.3 t ha^{-1} was achieved with about 40% reduction in water use, 50% reduction in chemical fertilizers, and 20% lower costs of production.

A survey in Mahabubnagar District of Andhra Pradesh with 55 SRI and 55 non-SRI farmers (Ravindra and Bhagya Laxmi 2011) showed a yield advantage of 18% achieved by SRI methods with a decrease in total expenditure of Rs.9187 ha^{-1}. This represented a 50% reduction in input costs, with 43% lower labour costs.

11.9 Net Income

There are several examples showing significantly increased net income by adopting SRI which have been documented in the Proceedings of National Seminar on SRI, conducted during 2007 at Tripura and in 2008 at Coimbatore. Publications of the WWF-ICRISAT project on farmer experiences on SRI also have many such cases reported. Studies in Gambia showed that the net returns with current production techniques was $37.30 ha^{-1} while with SRI methods, the net returns were $852.70 ha^{-1} (Ceesay, 2011). A few examples from different parts of India are given in Table 11.8.

Table 11.8. Net income obtained in conventional and SRI cultivation

Location	Net returns (Rupees ha^{-1})		Increase in net income (%)	Reference
Tirunelveli District, Tamil Nadu	11,149	23,868	114	Thiyagarajan et al. 2005
Madanapalli, Andhra Pradesh	11,830	31, 264	165	Radha et al. 2007
Tripura	15,007	39,769	165	SRI Fact Sheet, Tripura, WWF-ICRISAT Project, 2008
Mahbubnagar, Andhra Pradesh	22,257	41,389	86	Ravindra and Bhagya Laxmi, 2011

11.10 Nutrient use Efficiency

Experimental evidence has showed higher nutrient efficiency in SRI crops compared to conventional crops. Jothimani (2004) studied the effect of controlled-release nitrogen fertilizer on an SRI crop, and found that partial factor productivity (kg grain produced per kg N applied), agronomic efficiency (kg grain increase per kg N applied), physiological efficiency (kg grain produced by kg N taken up by crop), and recovery of applied N were all higher for the SRI crop than for the conventionally-planted crop (Figure 11.2).

Nutrient use efficiency was marginally higher in SRI (by 8, 8 and 12% for N, P and K, respectively, during kharif and 5% for N during rabi) compared to standard transplanting (Mahender Kumar et al. 2010). Higher N use efficiency for SRI practices, as well as higher water use efficiency, was reported by Zhao et al. (2009).

Barison and Uphoff (2011) found that concentrations of N and K in the grain were higher in SRI plants than conventional rice, while concentration of P was lower. In the rice straw, concentration of all the nutrients was lower in SRI plants. As SRI yields were higher than for conventional crop, the total uptake of the nutrients was thus higher in SRI plants. P was more efficiently used in grain production than N and K in SRI cultivation (Table 11.9). Nutrient concentrations in sink storage were not very different between conventional and SRI methods, but grain yields were significantly higher. This could be attributed to conventionally-cultivated plants having lower root capacity to take up nutrients in the later stages of plant growth and/or to lower remobilization of previously stored shoot nutrients.

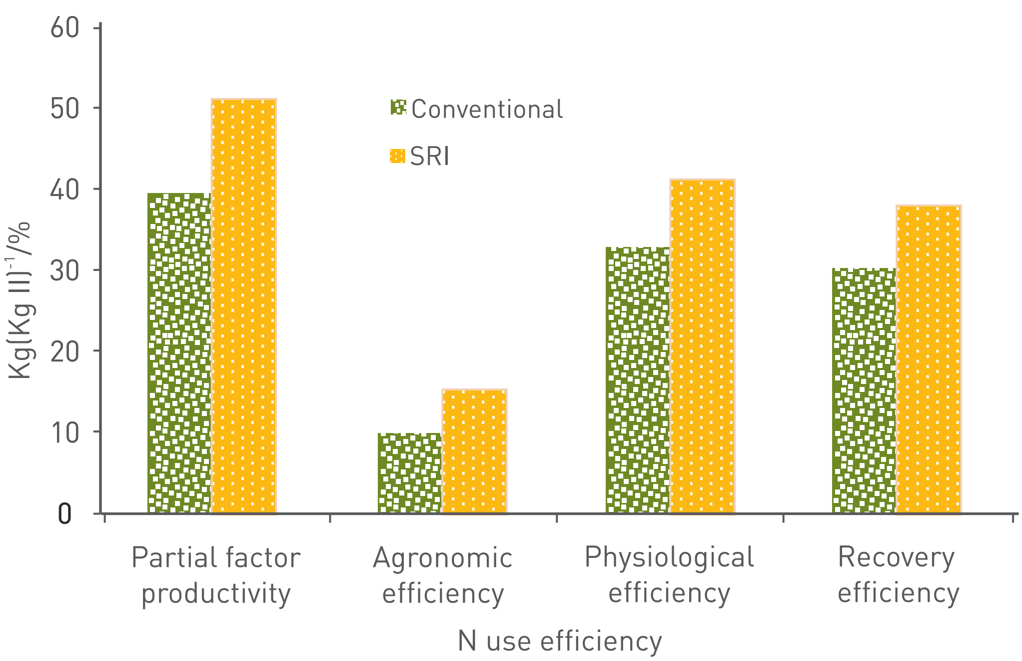


Figure 11.2 Nitrogen use efficiency of cultivar ADT43 with conventional and SRI cultivation (Source: Jothimani, 2004)

Table 11.9 Nutrient concentration, nutrient uptake and internal use efficiency of nutrients in conventional and SRI plants.

Parameter	Nitrogen		Phosphorus		Potassium	
	Conv.	SRI	Conv.	SRI	Conv.	SRI
Concentration in the grain (g kg-1)	9.90	10.18	2.69	2.35	3.54	3.96
Concentration in the straw (g kg-1)	5.39	4.98	1.16	0.93	15.29	14.98
Total uptake (g kg-1) Internal efficiency	49.99	95.07	12.69	21.03	56.77	108.64
(kg grain kg nutrient-1)	74.89	69.20	291.1	347.2	70.41	69.70

Source: Barison and Uphoff (2011)

11.11 Climate Change Adaptation

The benefits of SRI are manifold, and various observations of crop performances have shown the potential of SRI in addressing the challenges of climate change also. Experiences of escaping drought by SRI crops have been observed in both irrigated and rainfed areas (http://www.sri-india.net/documents/More_Water_For_The_Planet.pdf ; Patwardan and Patel 2007).

During 2009 kharif, out of 526 meteorological districts in India for which data are available, 215 districts (41%) received excess/normal rainfall and the remaining 311 districts (59%) received deficient/scanty rainfall. The agricultural operation of paddy was severely affected due to scanty rainfall in the early part of the monsoon. Paddy cultivation area thus came down to 327.40 lakh hectares, compared to a normal area of 391.17 lakh hectares. A survey on drought-coping ability of SRI vs. CMP (common management practices) rice cultivation was carried out in Jharkhand, Maharashtra, West Bengal, Odisha, Chattisgarh, Manipur and Uttarakhand by contacting 241 farmers who were using both methods. The results showed that the average grain yield under SRI was 54% higher than CMP, showing the ability of SRI crops to cope up with drought (http://sdtt-sri.org/publications-and-other-reports)

The smaller nursery required and the shorter nursery period for SRI facilitates the raising of staggered nurseries to adjust to delayed onset of the monsoon in rainfed areas. An emphasis on providing surface drainage in SRI will help to drain excess rainfall. Contributions of SRI to climate change adaptability are summarised in Table 11.10.

Table 11.10 SRI benefits supporting farm household resilience and climate change adaptability.

Reported and Validated Benefits	Contribution to Resilience and Climate Change Adaptability
Higher yields per unit of land, labor and capital invested	Grain yields are increased on an average by 20-50%. This not only generates more food, but releases some land and labor for other productive activities, buffering household resources. Higher productivity per unit of land reduces pressure to expand cultivated area at the expense of other ecosystems.
Lightened workload for women	Women farmers widely report that SRI methods save them time and reduce the drudgery of rice cultivation, due to less time for nursery management and transplanting, ease of working with smaller seedlings and less time laboring in standing water. It frees their time for activities of their choice (such as vegetable growing for profit or improved family diet) and enabling other family members to seek non-farm employment, thereby diversifying household income.
Reduced requirements for irrigation water	With SRI, irrigation water use is generally reduced by 25-50%, as water is managed to maintain mostly-aerobic soil conditions. Farmers can continue to cultivate rice where water is becoming scarcer or rains unpredictable, and can mitigate losses from late monsoons or less rainfall. Less water used at the head of canals means more water is available for farmers at the end. Water can be freed up for other crops and people, and for the maintenance of natural ecosystems.
Reduced seed rate	Since farmers need 80-90% fewer seeds for transplanting, they need much less space to sow the seed nurseries. Flooded nurseries are planted with a seed rate of 120-150 g/m2 whereas SRI nurseries are planted with a seed rate of only 20 g/m2, leaving farmers more rice to use for food rather than planting. Smaller nurseries are easier to manage and require a lot less land, freeing up land for other crops.
Reduced reliance on chemical fertilizers, herbicides, and pesticides	The high and rising cost of fertilizer and other inputs is one of the main attractions for farmers to use SRI as it allows them reduce chemical applications without loss of yield. Fewer chemicals around farmsteads has health benefits for people and their livestock. Reduced chemical loads, and higher soil and water quality has beneficial effects throughout the environment.
Resistance to lodging and storm damage (possibly also cold spells)	Climate change is contributing to more frequent and more severe storms, which cause rice plants to fall over or lodge. This can be devastating to farmers. A fallen crop is vulnerable to rotting and also more difficult to harvest. SRI practices produce stronger straw (tillers) and larger, deeper root systems that make rice plants less susceptible to being blown down or pushed over.
Increased resistance to pest damage	Climate change is expected to increase the prevalence and distribution of pest species as temperatures and rainfall patterns change. With SRI management, farmers observe less loss to pests and diseases even though they use fewer agrochemicals.
Increased drought tolerance	SRI rice plants exhibit stronger root systems that grow deeper into the soil profile. At greater depth they can access deeper reserves of soil moisture (and nutrients). This is a particularly important given the increasing risk of rainfall variation during the growing season.
Shorter growing season	SRI crops can often be harvested 1-2 weeks, even sometimes 3 weeks earlier than the same variety conventionally grown. This has economic and environmental advantages. Farmers can use the same field for a short-season crop like a vegetable, or can plant a following crop such as wheat sooner to get higher yield. A shorter growing period reduces water needs and the crop's exposure to pests and storms that arrive late in the season.

Reported and Validated Benefits	Contribution to Resilience and Climate Change Adaptability
Reduced seed rates and planting times give more flexibility	If a farmer's crop succumbs to adverse weather patterns, farmers can more easily find the seeds and time to replant the nursery and replant since SRI requires only one-tenth of the seeds and seedlings can be planted within 8-15 days of sowing, rather than 25-35. People reliant on travelling after planting to find paid work can get on the road much sooner and if they have to return to replant a failed crop they only have to come home for a short time.
Increased production and marketing potential from traditional varieties keeps them viable	With SRI methods, farmers are able to achieve higher yields from their traditional varieties, most of which are better adapted genetically to a range of climate stresses. These local varieties often command a better price in the market. Rice biodiversity has plummeted since the 1960s; however, studies show many traditional varieties offer higher iron and protein content. Rehabilitation and conservation of landraces and local cultivars can give more genetic diversity for dealing with adverse growing conditions.
Improved farmer knowledge, experimentation and innovation	Good SRI extension promotes farmer initiative and evaluation It encourages farmers to take more responsibility for adaptation and innovation, contributing to human resource development in rural areas and the prospect of farmers being able to identify and exploit other innovations as they emerge.
Diversified cropping systems	With higher yields per unit of land, some farmers convert part of their land to growing more nutritional and more profitable crops, fruits, vegetables, legumes and small livestock that diversify their diets and raise incomes. Reductions in chemical use makes farming systems more compatible with fish, ducks and other non-crop components. More diversification of cropping systems helps to restore biodiversity and sequester carbon in the soil.

Source : http://www.sri-india.net/documents/More_Water_For_The_Planet.pdf

11.12 Summary

SRI is more than an agronomic package of practices to boost the rice productivity. Rather, it is a set of ideas or principles for improving the growing environment of rice plants below and above ground, to be adapted to local conditions and constraints. The advantages accruing to SRI cultivation are manifold, benefiting not only the rice farmers but also with positive influence on the livelihoods of farm families; agro-ecological sustainability; agro-industrial development and agri-business; and overall impacts on the state / national economy.

Benefits Realized by Farmers

- Nursery area (for planting 1 ha) can be reduced from 800 m2 to 100 m2.
- Seed requirement is reduced from 30-60 kg ha^{-1} to 5.0-7.5 kg ha^{-1}.
- Nursery maintenance is reduced from 25-30 days to 10-14 days.
- Nursery costs are reduced by about 68%.
- Seedling pulling costs are reduced from Rs.800 to Rs.150.
- Labour requirements for planting can be reduced from 60 to 35 days.
- Labour requirements for weeding are reduced by as much as50%.
- Savings can be made in water, electricity for pumping, and labour for irrigation.
- Lodging of crops due to storms or wind is reduced due to stronger plant roots and tillers.
- Crops on balance have less susceptibility to damage from pests and diseases.
- Rat damage is almost nil in some cases.

- Earlier maturity (up to 10 days) is seen in many cases.
- Grain yield is increased on average by 1.5 t, although with considerable variation.
- Straw yield is increased on average by 2.6 t.
- Higher net income for farmers is achieved, up to 165%.
- Known shy-tillering varieties are found to produce a higher number of tillers.
- Good panicles from the SRI crop can be handpicked for meeting seed requirements of the next crop with higher-quality stock.
- Higher milling outturn (by 10-20%), with more kg of polished rice per bushel or bag of paddy rice. This is attributable to less chaff (fewer unfilled grains) and less broken grains (less shattering during milling). This is a 'bonus' on top of the higher production of paddy rice.

Ecological And Agro-ecological Benefits

- No use of herbicides.
- Reduced or possibly no use of chemical fertilizers.
- Enhanced soil biological activity in the soil and greater soil health.
- Adaptability to hazards of climate change (more drought tolerance, resistance to storms, reduced pest damage, tolerance of colder temperatures once established).
- Possibly some greenhouse gas mitigation as methane emissions from rice paddy fields (no longer flooded and anaerobic) can be reduced without offsetting increases in N2O, according to several studies in Indonesia, Nepal and India.
- Reduced carbon footprint from total production process; possibly greater carbon sequestration in the soil due to a build-up of soil organic carbon through organic fertilization, larger root systems with SRI plants, and increased root exudation.
- Conserving rice biodiversity (good response from indigenous varieties from SRI management) plus buffering of biodiversity in general (less requirements for irrigation water, reducing competition with natural ecosystems; more production from already-cultivated area so there is less pressure for expansion of agriculture into uncultivated areas).

Benefits For Agro-industry

- Opportunities for development and supply of tools and implements for SRI.
- Better quality grain with higher milling out-turn.

Benefits To States / Nation

- Substantial reduction in the need for storage and supply of seeds.
- Increasing national and household food security.
- More scope for reducing poverty because new methods with minimal capital requirements are accessible to the poor, without taking loans, suitable for use on even small parcels of land, giving higher production from already available resources through using them more productively.
- Low-cost strategy to government for meeting food needs and reducing poverty.
- Reduced requirements for irrigation water for rice cultivation, and reduced need for power subsidies for pumping groundwater.

Field experiences have demonstrated the benefits of adopting SRI that will address the concerns of rice farmers as well as policy makers. Realizing this and taking positive steps to promote SRI in all rice growing areas is the best agenda for national food security.

12 SRI EXTENSION, ADOPTION AND CONSTRAINTS

The efforts taken to promote SRI in India are unique as they have been essentially voluntary and not promoted by any official process. The role of civil society organizations in this aspect has been an unprecedented one in agricultural extension. However, the extent of spread and adoption of SRI has also been influenced by certain limitations. In several states, like Bihar, Tamil Nadu and Tripura, it has been see that spread can become rapid when there is active support from government agencies, especially if acting in concert with farmer-oriented NGOs.

12.1 Spread of SRI in the Country

SRI was introduced into the country in 2000, and extension efforts commenced in 2003 in Tamil Nadu, Tripura, and Andhra Pradesh. The spread of SRI in other states was rather slow, but picked up from 2006 on with the active involvement of a variety of interested stakeholders. All the agencies involved in SRI extension started with demonstrations in farmers' fields. Most government-supported programmes have had an element of subsidy built in, mainly providing SRI tools and in some cases other inputs. Most CSOs have concentrated on capacity-building with technical backstopping by engaging and training local resource persons.

The dissemination and adoption of SRI in India has been on different scales in different parts of the country. In some places, SRI has been embraced by organic farmers also as a special group. A national movement to promote SRI began from 2006 by organizing a series of national symposia, establishing google groups and websites, publishing newsletters, and developing policy frameworks by the initiative and support of several agencies.

Research in SRI to complement the extension effort was limited to TNAU and ANGRAU in the beginning, but slowly, ICAR institutes (DRR, CRRI, and regional centres) and other state agricultural universities have started working on SRI. There is still more to be done on research as many questions on the effects of SRI principles on soil and plant system remain unanswered. Also there is no study on the long-term effects on soil fertility of practicing SRI. However, Bidhan Chandra Krishi Vishwavidyalay (BCKV) has started such research with active support from SDTT. Some ATMA programs and KVKs have taken initiative with SRI at local levels, and the Directorate of Rice Development in Patna became involved with SRI evaluation and spread earlier than some other agencies. The National Food Security Mission began supporting SRI extension in targeted food-insecure districts in 2006.

SRI is a striking case of 'land to lab', reversing the usual 'lab to land' presupposition. New crop production techniques have usually come from research establishments after standard experimentation and evaluation. SRI has not come through that channel, however, but is being followed by increasing numbers of farmers: first dozens, then hundreds and thousands, and now hundreds of thousands. Still, SRI requires research support not only to explain how it makes the difference from conventional and existing recommended practices, but also to understand the effect of the modified agronomic practices on the soil-plant-water system. Although considerable research efforts are underway, there is no systematic and organized research to address the broader issues concerning SRI. More importantly, there are no national policies and institutional mechanisms for investment in SRI research.

Efforts have also been taken to develop a national policy on SRI adoption and scaling-upas part of achieving national food security while reducing water constraints and conflicts. An initiative has now been taken up to establish a National SRI Consortium to streamline and guide the promotion and scaling-up of SRI. A state-level Consortium is also active in Andhra Pradesh, and there are bodies, each different, operating now in states like Bihar, Odisha, and Himachal Pradesh.

12.2 Institutional Architecture In SRI Extension

At present, SRI has been promoted through multiple streams of funding as well as implementation agencies (Table 12.1).

Table 12.1 Sources of funding and implementing agencies for SRI extension

Sl. No.	Source of funding	Implementing agencies
1.	Donors (e.g., SDTT, WWF, Deshpande Foundation)	NGOs (playing role as innovation incubators)
2.	National Bank for Agriculture and Rural Development (NABARD)	NGOs (upscaling of innovations in contiguous areas)
3.	Autonomous societies (e.g., SERP, Bihar Rural Livelihood Promotion Society, etc.)	NGOs, CBOs (scaling at district level)
4.	GOI Ministry of Agriculture, (under NFSM, RKVY, special projects, etc.)	State Depts.of Agriculture, Project staff
5.	State Governments (using combination of NFSM, RKVY, MNREGA, and World Bank resources)	Own grass root Departmental staff + NGOs
6.	State Agricultural Universities / ICAR / Externally-funded projects	Scientists and field staff of SAUs / KVKs

The NGOs / CSOs have adopted a unique model of creating local resource persons in the villages (either local farmers or local literate persons) who give technical support and advice throughout the implementing period. These people are trained by master trainers of the organizations. Some input incentives are also often provided. Some NGOs have approached the task of training through Farmer Field Schools. The close rapport between NGOs and farmers has been very helpful in gaining acceptance of SRI. Government/externally-funded project support usually includes material incentives for SRI tools (weeders and markers), and also for inputs like seeds and fertilizers are given. All of the implementing agencies arrange for trainings, demonstrations and exposure visits.

12.3 Platforms for Mainstreaming SRI

It is unusual to create platforms to promote a single method of cultivating a crop. This is another way in which SRI is unique. SRI extension is being promoted in manners unpracticed before. The SRI extension seen in India is itself a revolution in agricultural extension, perhaps contributing to new and better modes of operation.

12.3.1 Seminars

The prospects of SRI were first discussed in India during an

International Symposium on 'Transitions in Agriculture for Enhancing Water Productivity' held at the Agricultural College and Research Institute of TNAU, Killikulam, Tamil Nadu, in September 2003. Dr. Norman Uphoff (Cornell University), Dr. Bas Bouman (IRRI), and Dr. Christopher Scott (IMWI) were among the participants.

Realizing the potential of SRI for water saving and responding to the need for creating more awareness, a series of National Seminars on SRI in India was organized by the WWF-ICRISAT project in collaboration with several other stakeholders, first in Hyderabad in 2006, hosted by ANGRAU; then in Agartala in 2007, hosted by the Govt. of Tripura; and finally in Coimbatore in 2008, hosted by TNAU. WWF took the initiative to develop a national platform to facilitate: 1) collaborative synergies among key stakeholders, namely, national and state research institutes, agricultural universities, civil society organizations, government officials, and donors; 2) research and extension activities; 3) synthesis and sharing of information; and 4) dialogue among stakeholders from the farm level to national level.

These symposia have served many purposes: facilitating cross-learning, supporting the development of networks of interested individuals and groups, strengthening the efforts of farmer-innovators, and refining the research agenda for persons engaged with elucidating the issues concerning SRI. Proceedings of the seminars have been made available. Seminars have also been organized by CSOs at national and state level with support from donor agencies like SDTT and NABARD in Assam, Manipur, West Bengal, Bihar, Odisha, Jharkhand, Chhattisgarh, Maharashtra and Uttarakhand. The WWF-ICRISAT project also organized workshops to converge ideas on up-scaling SRI in the country by inviting policy makers from the Planning Commission, the Ministry of Agriculture, and State Governments to interact with civil society representatives and farmers.

12.3.2 Organic Farming Movements

The emphasis on increasing use of organic manures, recommended use of hand mechanical weeders as an alternative to weedicides, and making use of agrochemicals for plant protection less necessary and less economic has attracted the organic farmers all over the country towards SRI.Establishments like the Organic Farmers' Association in Tamil Nadu, SAMBHAV in Odisha, CIKS in Chennai, and the Richharia Foundation in Chhattisgarh are actively promoting organic SRI.

12.3.3 Publications

An array of manuals, books, video films, reports, newsletters, proceedings, fact sheets, and case history compendiums have been made available by several agencies to disseminate the knowledge on SRI. These could be accessed through the websites listed in Table 12.2.

12.3.4 Electronic Media

Online discussion groups and websites on SRI have been created to promote information and discussion among farmers, civil society organizations, researchers, and others interested in SRI (Table 12.2). An SRI International Network and Resources Center (SRI-Rice) is operating from Cornell University in USA, providing valuable information service on SRI (http://sri.ciifad.cornell.edu).

Table 12.2 Electronic support for SRI extension.

Name	Nature of activity	Maintenance	IP address
SRI-India network	Website providing information on SRI	WWF-ICRISAT project, Hyderabad	http://www.sri-india.net/
sriindiagoogle group	Online discussion and sharing information	SDTT SRI Secretariat, Bhubaneshwar	http://groups.google.com/group/sriindia/
SRI-Orissa	Online discussion and sharing information	Odisha SRI Learning Alliance, Bhubaneswar	http://groups.google.com/group/srioriss a/
SRI CSO website	Providing information on SRI	WASSAN, Secunderabad	http://wassan.org/sri/
SRI website	Providing information on SRI	SDTT, SRI, Secretariat, Bhubaneswar	http://sdtt sri.org/-
SRI international website	Advance and share knowledge on SRI	SRI International Network and Resources Center (SRI-Rice), Cornell University	http://sri.ciifad.cornell.edu
SRI training website	Multimedia toolkit	World Bank Institute	http://info.worldbank.org/etools/docs/lib rary/245848/index.html
JaiSRI network	Online discussion and sharing information	SRI Consortium	jaisri@srigooglegroups.com

12.4 Policy Support from Governments

The Governments of Tamil Nadu and Tripura took an early lead in promoting SRI on a large scale. The initiatives from other State Governments were lukewarm for quite some time. But now, the state Governments of Andhra Pradesh, Bihar, Odisha, Jharkhand and Chhattisgarh have taken policy decisions to scale up SRI in their respective states. The Ministry of Agriculture, Govt. of India, has supported the promotion of SRI to a limited extent through the National Food Security Mission (NFSM).

12.4.1 Government of India

Policy support for SRI from the Govt. of India has not been very ambitious so far. The NFSM targeted an increase in rice production of about 10 million tonnes by 2012 with an allocation of Rs. 5,000 crores. NFSM specifically has targeted 133 districts out of the total 534 rice-producing districts in the country. SRI is one among the strategies in the project, and only a few states have actively taken up SRI under this scheme. The Directorate of Rice Development (DRD), Patna has been active in implementing this activity. During 2007-2010, 4,915 demonstrations with an allocation of 86 lakh rupees were carried out.

Efforts are now on to project SRI as one of the solutions towards food security during the Twelfth Five Year Plan.

12.4.2 Tamil Nadu

Realizing the need for raising total rice production and productivity, the TN Department of Agriculture has taken up an ambitious plan to promote SRI in the state. Although SRI was officially recommended for adoption in the state by TNAU already in the year 2003, the extension of the technique was initially slow, owing to apprehensions surrounding the principles of SRI. However, a stream of convincing success stories from farmers has enabled the scaling up of SRI adoption in the state.

The Department of Agriculture has included SRI in all existing and new programmes, like the Integrated Cereal Development Programme (ICDP) and National Food Security Mission (NFSM) that focus on increasing food production. The NFSM project is being implemented in Nagapattinam, Tiruvarur, Pudukottai and Namakkal districts. The farmers there are given certified seeds, weeders and markers. During 2007-2008, SRI was demonstrated in 11,320 ha under the ICDP by extending a subsidy of Rs. 2,000 per ha and imparting training to 56,600 farmers. This contributed to the spread of SRI on 4.2 lakh hectares during that year, and productivity of 10 t ha^{-1} was achieved by some farmers who used the methods properly. During the kuruvai season 2008, 420 crop-cutting experiments with SRI were conducted across the state. Yields recorded in 92 measurements, from 25 sq.m each, showed an average yield of 7.4 t ha^{-1} which is nearly 40 % more than the state average.

Triggered by the success, the Department has embarked on scaling up SRI and has set a target of 11 lakh hectares (about 55% of total rice area in a year) in 2011-2012. The Department is also planning to use laser levelers to help farmers achieve good leveling for their SRI planting.

The state government has recently announced a Rupees five lakh cash award to farmers registering maximum production, under SRI. Farmers who had cultivated paddy over a minimum of 50 cents of land where eligible for this award and the conditions include a minimum produce of 2500 kg per acre.

12.4.3 Tripura

Tripura launched a "Perspective Plan for Self Sufficiency in Food Grains by 2010" in 2001, about the same time that the first tests of SRI suitability under Tripura conditions were done. In 2002, the first SRI trials/demonstrations began with 44 farmers; the next year, this number was doubled. With evident success, the number of farmers using SRI methods grew to 440 and 880 in the next two years. The continuing good results persuaded the state's political leadership to support SRI extension to enable reaching the goal of self-sufficiency. In 2005, one-third of the state's agricultural budget was reallocated to SRI extension, and under the leadership of Dr. Baharul Majumdar, the number of SRI users topped 70,000 in 2006 - 2007 and reached about 250,000 farmers within two more years.

During a midterm review, it was observed that the growth rate of food production was not at a desired level to minimize the gap of food requirements for the state. Hence, the government decided to cover at least 1 lakh ha paddy area through SRI which will increase rice production by a minimum of 1 lakh tonnes by 2011-2012 as SRI methods were adding at least 1 t ha^{-1} to farmers' present production levels.

SRI is being promoted under the

Tripura State Plan and the Government of India's (GOI) Macro Management Scheme. Research has been conducted solely under the State Plan, and popularization/ adoption in fields was done through convergence of the State Plan and the Macro Management Scheme of GoI. Panchayati Raj institutions have been collaborating in SRI demonstrations across the state, more actively than in other states of India.

Training programmes have been conducted locally for all categories of field functionaries. District-level trainers' teams were developed through rigorous on-farm practical and theoretical training who have imparted training to grass root-level field staff.

12.4.4 Andhra Pradesh

The state Department of Agriculture organized its first SRI demonstrations since 2003-2004, and a thrust had been given to SRI promotion since rabi season 2005-2006, organizing at least one demonstration in every Gram Panchayat in the state. This was at the impetus of the state agricultural university (ANGRAU). Under the National Food Security Mission (NFSM), 1,680 SRI demonstrations were targeted for 2008-2009 (1,272 demonstrations for the kharif season, and 408 demonstrations for the rabi season) with a financial outlay of Rs.5.0 million @ Rs.3,000/- per demonstration and with financial assistance of Rs. 3000/- for purchase of conoweeders. Also, 4,446 one-acre demonstrations were organized during 2008-2009 under the Work Plan (Rice) with a total outlay of Rs.26.7 million in the 11 non-NFSM districts of East Godavari, West Godavari, Prakasam, Kurnool, Ananthapur, Kadapa, Chittoor, Warangal, Rangareddy, Nizamabad, and Karimnagar.

A Consortium on SRI has been formed in the state in 2010, and implementation of SRI in the state is in full swing now to bring 8.5 lakh ha under SRI. The state Government has also decided to set up 110 SRI Centres to reduce labour costs by providing machinery, soil pulverisers, transplanters, weeders, harvesters, and other implements on hire to farmers. The government will give 50 per cent and 25 per cent subsidy for setting up SRI Centres.

12.4.5 Bihar

The State Government has taken up a fast-track mode of promoting SRI and expects to cover 3.5 lakh ha of rice area under SRI management (about 10% of the rice area of the state) during 2011-2012 through its Rural Livelihood Programme. Probably only about half this much area was actually brought under SRI management, but a combination of SRI methods and good rainfall has contributed to a 2011 kharif harvest about double the usual level, and four times the drought-affected 2010 kharif production. The government has been encouraged by results and farmer acceptance (paddy yield averaged 8.2 t ha^{-1} in Gaya district, where SRI work was initiated by PRADAN in 2006), so that a target of 1.4 million lakh hectares, 40% of the state's paddy area, has been set for kharif 2012.

12.4.6 Jharkhand

The state Agriculture Department has introduced an award scheme for farmers to encourage them to take up SRI. Under the scheme named Birsa Krishi Padam, a cash reward of Rs. 2 lakh will be given to a farmer at the state level who demonstrates maximum yield and carries out rice cultivation using SRI techniques on a plot measuring 4 hectares or more. At the state level, three farmers will be selected for second prize carrying a purse of Rs. 1 lakh each, and 10 farmers for third place for a cash reward of Rs 50,000 each. The scheme will be followed up at block level.

At the district level, the best performing farmer will be rewarded with Birsa Krishak Deep Sarvashrestha carrying a cash reward of Rs 15,000. For this category, the farmer must take up rice cultivation using SRI techniques on a plot measuring not less than 2 hectares. Four more farmers, two each for second and third prize, will be selected for a cash reward of Rs. 12,000 and 10,000 each, respectively. At the block level, best performing farmer will be felicitated as BirsaKrishak Sri Sarvashreshta along with a cash reward of Rs. 5,000. The second and third place holders will be given prizes worth Rs. 3,000 and Rs. 2,000 each, respectively.

12.4.7 Other States

In Punjab, promotion of SRI started in Gurdaspur district through the Department of Agriculture's ATMA program. The State Governments in Odisha, Uttarakhand, Himachal Pradesh, and Chhattisgarh have taken positive steps to promote SRI in their respective states. The following Table 12.3 presents the current targets to promote SRI in some of these states.

Table 12.3. Area to be managed under SRI methods targeted in different states

State	Total rice area (lakh ha)	SRI area targeted (lakh ha)	% rice area under SRI
Tamil Nadu	20.5	11.0	53.7
Tripura	2.5	1.0	40.0
Chhattisgarh	37.5	8.5	22.7
Andhra Pradesh	39.8	7.5	18.8
Jharkhand	13.6	1.6	11.8
Bihar	32.5	3.5	10.8
Uttar Pradesh	55.8	1.5	2.7

12.5 Financial Support from Non-governmental Organizations

Financial support to promote SRI in different parts of the country is being provided by various agencies like World Bank, the WWF-ICRISAT project, the National Bank for Agriculture and Rural Development (NABARD), the Sir Dorabji Tata Trust (SDTT), and the Deshpande Foundation.

12.5.1 World Bank

In Tamil Nadu, an amount of Rs. 40.5 crores has been allocated in the World Bank-funded IAMWARM project for supporting SRI during the period 2007- 2008 to 2012- 2013. The programme is being implemented both by the state's Dept. of Agriculture and the Tamil Nadu Agricultural University. World Bank support for promoting SRI in other states is also taking place, such as through the Bihar Rural Livelihood Promotion Society, with an IDA (soft) loan to the state government.

12.5.2 WWF-ICRISAT Project

WWF-supported programmes have included research to generate scientific understanding of SRI principles, initiatives to support SRI introduction in different agro-climatic conditions, field trials and demonstrations, farmer interaction workshops and field days, field-based resource centres, media events, capacity-building of change agents in the government and NGOs, and policy advocacy at state and national levels.

The project has funded CSO and university initiatives in Karnataka, Andhra Pradesh, Jharkhand, Himachal Pradesh, Jammu & Kashmir, and Odisha to promote SRI and has also provided financial assistance for SRI-related publications. From 2004 to 2010 this was done in conjunction with the joint 'Water, Food and Environment' Dialogue Project with the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad.

12.5.3 Sir Dorabji Tata Trust (SDTT)

SDTT began working on SRI from 2006, and SRI programme was adopted by SDTT under its Natural Resources and Rural Livelihoods initiative. "Food Security for Small and Marginal Farmers" was identified as a key focus area for its 2007-2012 country programme, and Rs. 10.94 crores were allocated for a dedicated program on SRI. Currently, SDTT is collaborating with 161 NGO partners in 104 districts of 10 states (Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Manipur, Odisha, Uttar Pradesh, and Uttarakhand), assisting 65,000 farmers in poverty-defined areas. SDTT has also set up a SRI secretariat at Bhubaneshwar. The Trust also supported organization of the Second and Third National Symposiums on SRI in India in 2007 and 2008. During 2009-2012, it has allocated an additional amount of Rs 24.00 crores to assist SRI activities across India, particularly in poverty-stricken areas.

12.4.4 National Bank For Agriculture and Rural Development (NABARD)

NABARD has taken a multi-pronged approach in popularizing SRI technology. A combination of awareness creation, capacity-building methods, and results demonstrations to farmers has been adopted. Community-based organizations such as Farmers' Clubs, NGOs, Primary Agriculture Cooperative Societies (PACS)/ Samabai Krishi Unnayan Samity (SKUS), and banks have been involved in the process.

The approach starts with identification of an area where paddy cultivation is more concentrated and where farmers are eager to adopt new technologies. NABARD has sanctioned grants for the promotion of SRI in many states (Andhra Pradesh, Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Manipur, Odisha, Uttar Pradesh, and Uttarakhand) through CSOs and is also facilitating seminars and training programmes at state and national level.

12.4.5 Ministry of Agriculture, Govt. of India

Funds allocated by the Ministry under NFSM, ICDP, RKVY and ATMA are being utilized for promoting SRI in some of the states. The Directorate of Rice Development (DRD) in Patna has also been supportive of SRI evaluation and dissemination.

12.6 Role of Civil Society Organizations

The role played by CSOs in promoting SRI across the country is an unprecedented one, especially in enhancing the livelihood of poor rice farmers in remote and tribal areas. These organizations not only provide capacity-building services, but also give technical support and back-up by stationing village-level extension functionaries. A large number of CSOs are actively involved in promoting SRI in different states (Table 12.4). One of the major extension support activities by the CSOs is creating local cadres to guide farmers in adopting SRI. We cannot list all of the NGOs that have taken up SRI in their programs, so this discussion is intended to be illustrative of the reach and activities of CSOs promoting SRI in India. Dozens of other NGOs could be mentioned.

12.6.1 Professional Assistance for Development Action (PRADAN)

PRADAN started promoting SRI in 2003 in Purulia district of West Bengal with 4 families. This number grew to 39,614 farmers in eight states by 2010. In 2008, 44% of the farmers being assisted by PRADAN staff in Purulia harvested 6-8 t ha^{-1} yield and 24% harvested 8-10 t ha^{-1} yield. PRADAN is now supporting SRI activities going on in Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha and West Bengal. PRADAN's contribution in promoting SRI in rainfed areas of eastern India is significant.

A documentary film on SRI, Ek Ropa Dhan, produced by PRADAN in Hindi language, won the Rajat Kamal Award at the 58th National Film Awards (2010) under the 'best promotional film' category given by Union Information and Broadcasting Ministry with the citation: "A succinct and well-researched film that looks closely at an innovation in the farming of rice. The film engages successfully with the issue and makes a strong case for the promotion of the practice called Ek Ropa Dhan'. PRADAN has also supported the work of the National SRI Consortium in New Delhi.

12.6.2 Watershed Support Services and Activities Network (WASSAN)

Watershed Support Services and Activities Network (WASSAN) has undertaken responsibility particularly for experimenting with SRI in rainfed conditions in Andhra Pradesh. WASSAN, in close collaboration with WWF, has been in the forefront in advocating and propagating of SRI and has been conducting training programmes for trainers and farmers in Andhra Pradesh, Himachal Pradesh, Uttarakhand, and in other countries. More important, it has become a resource centre on SRI by providing information in the public domain also to states outside Andhra Pradesh. WASSAN is also playing a key role in the AP-SRI Consortium activities.

12.6.3 Peoples' Science Institute (PSI)

The mountain states of Uttarakhand (UK) and Himachal Pradesh (HP) are characterized by inaccessibility, fragility, marginality, and diversity. In 2006, SRI was introduced by PSI in 40 paddy farms in 25 villages of UK (Dehradun, Rudraprayag and Tehri-Garhwal districts) and HP (Kangra district), seeking to study its potential. The results showed an average increase of about 66 per cent in paddy yields from the SRI plots compared to the conventional plots. PSI began organizing capacity-building workshops and district-level experience-sharing workshops.

Table 12.4 List of CSOs involved in promoting SRI in different states

No	State	Key civil society organizations in SRI
1	Andhra Pradesh	WASSAN, CROPS, Nava Jyothi, CWS, Timbaktu Collective, Jalaspandana, AME Foundation
2	Assam	Rashtriya Gramin Vikas Nidhi, NEST, Gramin Sahara, Gramya Vikas Mancho, PRADAN, North East Centre for Rural Livelihood Research
3	Bihar	PRADAN, Indian Gramin Services, ASA.
4	Chhattisgarh	Richaria Campaign, Choupal, PRADAN, CARMDAKSH,
5	Gujarat	BAIF Development Research Foundation, Aga Khan Rural Support Programme (AKRSP)
6	Himachal	Peoples' Science Institute (PSI) through its partners
7	Jharkhand	PRADAN, Society for Promotion of Wastelands Development (SPWD), Collectives for Integrated Livelihood Initiatives(CInI), NEEDS, Jan Seva Parishad, ,
8	Karnataka	AMEF, Green Foundation, Srijan, Deshpande Foundation
9	Kerala	Rural Agency for Social and Technological Advancement (RASTA)

Table 12.4 List of CSOs involved in promoting SRI in different states

No	State	Key civil society organizations in SRI
10	Madhya Pradesh	ASA, Bypass, PRADAN
11	Maharashtra	BAIF Development Research Foundation, Rural Communes, Amhi Amcha Arogyasathi.
12	Manipur	Rongmei Naga Baptist Association (RNBA), Rural Aids Support, PRDA
13	Odisha	Centre for World Solidarity (CWS), Sahabhagi Vikas Abhiyan, PRADAN, , Sambhav, Rishikulya Raitha Sabha, Karrtabya, PRAGATI
14	Tamil Nadu	MSSRF, AME Foundation , Centre For Ecology and Research,Vaanghai, Ekoventure, Kudumbam, CCD, Sri Sadada Ashram, CIKS, Farmers' networks of Murugamangalam, Tamilaga Velaan Neervala Niruvanam
15	Uttar Pradesh	Development Centre for Alternative Policies (DCAP)
16	Uttarakhand	PSI and its partners, Garhwal Vikas Kendra, Mount Valley Development Association (MVDA)
17	West Bengal	PRADAN, Ambuja Cement Foundation, PRASARI, Baradrone Social Welfare Institution, International Development Enterprises India (IDEI)

The results in 2006 showed that in HP, the average productivity of paddy went up from 3. 2 t ha^{-1} to 5.0 t ha^{-1} (56% increase). In UK, the average yield jumped about 77% from 3.1 t ha^{-1} to 5.5 t ha^{-1}. The results from 2007 showed that while the non-SRI yields stood close to 2.8-2.9 t ha^{-1}, the SRI yields were around 5.3-5.5 t ha^{-1}, an average increase of 89%. Over 15,000 farmers were practicing SRI in 2008 from the modest beginning of 40 made in 2006 – an achievement that indicates as much about the strength of PSI as about its network partners.

12.6.4 Agriculture-Man-Ecology Foundation (AMEF)

AME Foundation has been promoting System of Rice Intensification (SRI) in its operational areas in Andhra Pradesh, Tamil Nadu and Karnataka. In 2004-2005, AMEF started promoting SRI only with those farmers who expressed interest and were willing to try out new practices, particularly in Andhra Pradesh. AMEF seriously started promoting SRI in paddy during the year 2008-2009, with the support of Deshpande Foundation and WWF-ICRISAT project. While in its Andhra Pradesh and Tamil Nadu working areas, paddy is sown under irrigated conditions, AMEF had a unique challenge of promoting SRI under rainfed conditions in Dharwad area where paddy is cultivated in medium black soils. AMEF has already promoted SRI practices among more than 7,000 farmers across three states. AMEF is also helping farmers to apply SRI principles in ragi and redgram crops.

12.7 Research Institution Support

The involvement of established agricultural research institutes of the country on SRI has been very limited even now. Active roles have been played by TNAU, ANGRAU, and DRR.

12.7.1 Tamil Nadu Agricultural University (TNAU)

TNAU was the first institution in India to take up research on SRI and has been actively involved in up-scaling it in the State through the World Bank-funded TN-IAMWARM project. The activities are presented separately as a success story below.

12.7.2 Acharya N.G. Ranga Agricultural University (ANGRAU)

SRI evaluation was introduced in Andhra Pradesh in kharif 2003 in all 22 districts of the state by the ANGRAU Director of Extension, Dr. A. Satyanarayana. Since 2003, ANGRAU has taken several initiatives to promote SRI in Andhra Pradesh:

·National-level training programme on SRI for Nodal Officers of Department of Agriculture from various states of the country in 2004.

- 250 front-line demonstrations of SRI.
- Farmer workshops on SRI.
- Collaborative programmes with WWF-ICRISAT, in promoting SRI and organizing farmers meet.
- A dialogue on SRI with the Hon'ble Chief Minister, politicians, scientists, farmers and media jointly organized with WWF-ICRISAT in November, 2005, and explanation of SRI to visiting US President George W. Bush in March 2006.
- With the support of WWF-ICRISAT, ANGRAU has produced 5,000 SRI manuals, 10,000 booklets (5000 each in English and Telugu), 2,000 copies of farmers' experiences, and 100 CDs on SRI cultivation.
- ANGRAU has also collaborated with print media and television channels in popularizing SRI.
- ANGRAU organized the first National Symposium on SRI jointly with Directorate of Rice Research (DRR-ICAR) and WWF.
- Conducted state-level three-day workshop on 'SRI Implements' involving 50 farmers and entrepreneurs.

12.7.3 Xavier Institute of Management, Bhubaneswar (XIMB)

XIMB has been playing a key role in the SRI up-scaling process through Professor C. Shambu Prasad by actively participating in online discussions, establishment of SRI Learning Alliance in Odisha, publications, and supporting the National Consortium on SRI. The partners of the Learning Alliance are the Directorate of Agriculture and Food Production, Government of Odisha, Oxfam Eastern Region, World Wide Fund for Nature (WWF), Dialogue Project on Water, Food and Environment, the Odisha Resource Centre of the Centre for World Solidarity (CWS), Sambhav, and the Xavier Institute of Management, Bhubaneswar (XIMB).

The 'learning alliance' approach emphasises the processes of innovation, and involves collective learning by research organisations, donor agencies, policy makers, civil society organisations, and even private businesses. The alliances enable participants to learn across organisational and geographical boundaries and provide vehicles for collaboration and sharing of knowledge about approaches, methods and policies that work, and those that do not. By improving the flows of information and knowledge, these multi-stakeholder platforms help to speed up the process of identifying and developing innovations, and ensuring their adoption by farmers.

12.7.4 Directorate of Rice Research (DRR)

This ICAR institute has taken up research at station level and multi-location level to evaluate SRI and provided support for organizing seminars on SRI with support from the WWF-ICRISAT program. DRR's initiative to organize trainings on SRI helped promotion of SRI in other states.

12.8 Scaling up of SRI in Tamil Nadu Through TN-Iamwarm Project - A Success Story

The Tamil Nadu Irrigated Agriculture Modernization and Water Bodies Restoration and Management, known briefly as TN-IAMWARM, a unique World Bank-funded project, was introduced during 2007-2008. It has provided an ambient platform for the large-scale demonstration of SRI with technical and financial assistance and awareness creation in Tamil Nadu. SRI has been implemented in 50 river sub-basins through this project, and an area of 7,892 ha under SRI was covered from 2007 to 2010 (Pandian, 2010). The implementation of SRI in the project involved several strategies and steps that ensured spread of SRI in the state.

12.8.1 Capacity Building

- Training of farmers on the know-how for applying SRI principles.
- Training of farm labourers in SRI operations to create skills.
- Training of rural artisans on the production and servicing of weeders and markers to ensure their timely supply and availability.
- Farmers were taken to successful SRI farmers' field as exposure visits as the fundamental tool to get first-hand information on SRI, even before the commencement of the season where they were given with training also. Interaction with lead farmers helped the others to know the practical problems and ways to solve them.

12.8.2 Augmenting Political and Administrative Support

- Field visits were organized for the Hon'ble Agricultural Minister, Members of Legislative Assembly, Secretaries to the Govt., other Govt. officials to see the success of SRI in the field.
- Workshops were held at Coimbatore and Madurai to sensitize District Collectors and officials for effective implementation of SRI.
- Field days were organized with VIPs' participation at the demonstration sites to get the exclusive attention of administrators and policy makers as such events attracted press coverage.

12.8.3 Knowledge Disposal and Sharing

- Trained Research Fellows were stationed in villages to interact with farmers and provide backstopping.
- On All-India Radio (AIR), Trichy, a programme for farmers was broadcast in Tamil language for 13 weeks in 2009 called 'Orunellu Orunathu' (Single seed, Single seedling).
- Wall paintings and hoardings were installed in strategic locations.
- Mobile campaigning (TN-IAMWARM on Wheels) had greater impact, and a propaganda van with personnel from all the line departments was designed, so farmer's queries could be answered on the spot.
- Gramasabha meetings were conducted at village panchayats as a platform to propagate SRI technologies and as a medium to consult with the farmers to upgrade the technology.
- At various important stages of crop growth and cultural operations, i.e., square transplanting using markers, mechanical weeding, and harvesting, field days were organized by gathering neighbouring farmers.
- A comprehensive book on SRI in self-learning mode and a handbook manual were published to help the farmers. A video film on SRI
- was prepared and distributed. Short versions were shown in cinema theatres. The films were displayed during night meetings in the villages.

12.8.4 Publicity

- In order to attract passing-by farmers, unique flags were installed in SRI fields.
- To boost the self-confidence of farmers, greetings were sent to farmers with the message of SRI on the occasion of Pongal (Tamilar Thirunal).
- In leading dailies, FM stations, and over All- India Radio (AIR), advertisements were given regarding SRI.

12.8.5 Community Involvement

- Local people's representatives like WUA presidents and panchayat presidents were roped in for the demonstration and publicity processes.
- The 'community nursery' concept was introduced to share land and water resources.
- Facilitation of the formation of the 'Thumbal Semmai Nel Sagupadi Farmers Association' which was registered as a recognized society. A large number of rice-growing farmers from various districts of Tamil Nadu visited Thumbal to understand and experience SRI at field level.
- Facilitated the Ponnaiyar sub-basin farmers of Pillekothur village, Krishnagiri, to register another association as 'Water-Saving Farmers' Association' and linking them with NABARD.

12.8.6 Monitoring

- Monitoring Committees were established to oversee the implementation of SRI, and their reports were discussed during workshops with personnel who were involved in promoting SRI.

12.9 SRI Adoption in India

Adoption of SRI by a farmer for the first time requires a lot of motivation, and continued adoption depends upon several factors (Table 12.5).

Table 12.5 Factors affecting adoption of SRI by farmers

Main factors	Subsidiary factors	Impact
Farm-level conditions	Motivation Self-interest Attitude Land ownership Land size Soil fertility Labour availability Labourers' mindset Capital Water availability Organic manure availability Tools availability Tangible benefits	Adoption Variations Disadoption Sustained adoption
Technical interventions	Research support Training Exposure Technical backstopping Regular follow-up	
Policy support	Determination Specific programmes Subsidies / incentives Irrigation water supply regulation Monitoring mechanisms	

Cases of disadoption have been reported. How to help farmers to overcome the difficulties faced by them in this regard is a real challenge in SRI extension.

Variations in Adopting SRI Principles

It has been well recognized that the full potential of SRI is realized only when all the six principles are followed properly. However, due to various reasons, there are considerable variations in the practices when adopting the principles (Table 12.6). These variations are to be accepted because they still have SRI effects even if not to the full extent possible. SRI practices are best followed more faithfully with limited flexibilities and in a timely way to get the full benefits compared with conventional practices which have a lot of flexibilities (Table 12.7). Thus, SRI farmers, for greatest success, need to be more disciplined than farmers cultivating in conventional manner and to be able to visit their fields more often than they are used to doing.

Although adopting all of the six principles of SRI brings maximum benefits, contingent situations at the farmer and field level due to limited availability of water, labour constraints, no access to implements, etc. or little water control can come in the way of fully adopting the principles.

Farmers should be encouraged to adopt SRI to the extent that they can, even if they are not able to adopt all of the principles as recommended. Even a single principle of SRI introduced in the farmers' practice can have positive influence on the crop performance and benefit the farmer. Thus, some amount of flexibility in the SRI practices should be accepted (Table 12.7). However, farmers should realize that they should try to adopt all the SRI principles if they want to derive the full benefit of SRI.

Table 12.6 Variations in adopting the principles of SRI

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

Table 12.7 Flexibility in adopting SRI practices

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

The following map (Figure 12.1) shows the districts in the country where SRI has been introduced and adopted by about 250,000 farmers to date. Some estimated put the number at 600,000-800,000.

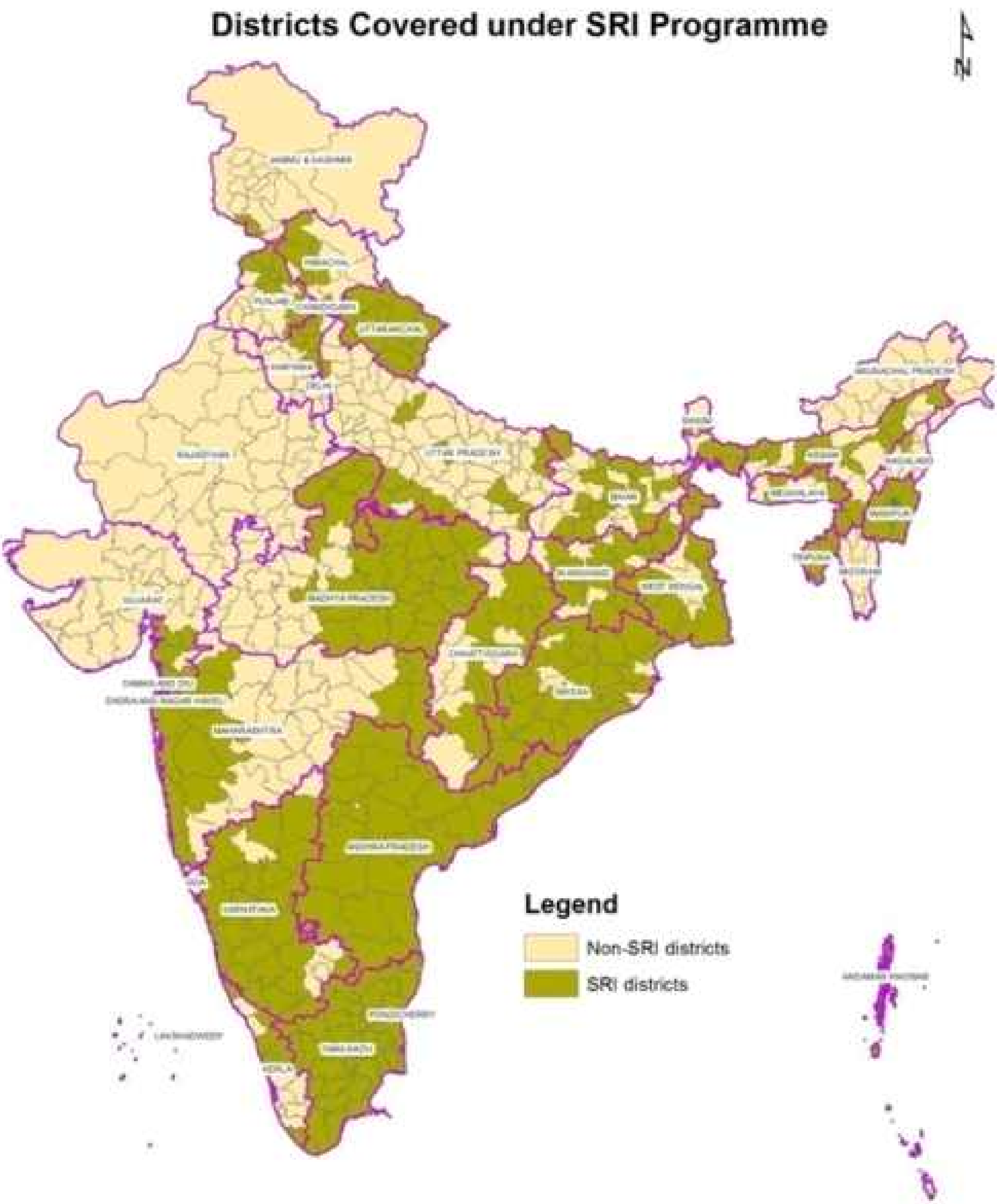


Figure 12.1 Map of India showing the districts where SRI is known and being practiced (the map is not to scale and is not indicative of the area under SRI)

12.10 Constraints in Adopting SRI

Throughout history, humankind has been resistant to change and to the acceptance of new ideas. SRI is no exception. Farmers' acceptance is subject to the profitability of SRI cultivation which could be understood very well. SRI has taken roots most successfully in several parts of the country. Adoption has been slow in many areas, and the reasons for this could be traced out. These are listed below.

12.10.1 Farmer Level

To the farmer who has been cultivating rice for decades, if it is advocated that only 5-7.5 kg seed be used per hectare; that seedlings be only 10-14 days old; that seedlings be planted only one per hill; that hills be spaced in a square pattern 25 cm apart instead of in rows; that a mechanical weeder be used in preference to hand weeding or herbicides; and that the field not be kept continuously flooded, the immediate reaction will be disbelief!

Thus, it is imperative to convince the farmer of the merits of these different changes in age-old practices first by showing and explaining. So, demonstrations and trainings are a must. The farmer should be gotten to try SRI in a small part of his rice area, adopting SRI principles properly. Although the impression that the field makes on everyone immediately after planting, looking muddy and bare, will be shocking, the subsequent booming growth of tillers after 3-4 weeks will raise the confidence limits, especially after considering how much this can raise farmers' net income, getting more yield with less expenditure. From the next SRI crop on, he will start adjusting the practices to suit his (or her) convenience and become a successful SRI farmer.

Yet, not all farmers get easily convinced to try SRI, and those who practice it can also face problems. So, there will be full adoption, partial adoption, no-adoption, and even disadoption.

- SRI demands more personal attention and constant involvement. Farmers who could not afford to take rice-growing seriously and invest themselves in their crop shun SRI.
- Apprehensions about the new way of raising seedlings, handling young seedlings, and square planting need to be overcome by seeing the results.
- Resistance of contract labourers for planting in the SRI mode can be a problem, as they either perceive this as more laborious or do not like the idea of their making more income for their employers without themselves getting a larger share of the benefit.
- Labour scarcity for transplanting at critical time.
- Perceived drudgery of using the mechanical weeder, although some consider it a boon.
- Potential pest attacks due to lush growth of the crop.

12.10.2 Extension Agency Level

- Little allocation of time for direct contact with farmers which is important to get an innovation understood and started.
- Need for frequent visits to monitor the implementation.
- Lack of technical knowledge to give effective technical support.

12.10.3 Government Level

- Inadequate understanding of this opportunity to ensure national and household food security through SRI.
- Lack of sense of urgency in adopting water-saving methods for the agricultural sector.
- Poor operation and maintenance of irrigation facilities that would enable farmers to get higher yields with less application of water. Farmers can make SRI succeed with less water, but this supply needs to be reliable and controllable.
- Prevailing mentality that agricultural improvement is a matter of providing more, new and better inputs, rather than patiently and knowledgeably improving farmers' understanding of better agronomic practice.

12.11 Constraints in Adopting the Principles

The principles of SRI, viz., younger seedlings, wider spacing, square planting, weeder use, minimized water use, and more application of organic manures, are all important, but farmers can face some problems in adopting the respective principles.

Using Younger Seedlings

- Farmers who depend on tanks for main field irrigation being monsoon-dependent could not start their SRI nursery if water is not available for planting young seedlings.
- Lack of faith and poor understanding of how to prepare raised beds for a nursery.
- Sometimes the seedling growth in the raised-bed nursery is poor due to less fertile soil being used in the bed.
- Seedlings can get scorched after a week if undecomposed manure is used in the nursery bed.
- Improper use of fertilizer to boost the growth of the seedlings can also lead to mortality.

Transplanting for SRI

- The immediate concern of a farmer when told to have only 16 plants per sq.m will be whether there will be sufficient tillers. This apprehension will be warded off when he sees the field after 3 - 4 weeks.
- Where there is labour scarcity, the mindset of the labourers seems to be the main problem in carrying out square planting.
- When using a rope for spacing, frequent bending over for every shift of the rope is said to be a negative issue with labourers in some areas. When a roller-marker or rake is used, this problem will go away because with one bend they can plant several hills at a time.
- Markers are not known to some farmers, and they are often not easily available.
- Field conditions should be such that grid lines made by the marker do not fade away due to standing water. If the muddy field cannot hold the lines marked, it is too wet. So the marker is a good indicator of optimum timing for transplanting operations.
- When planting is done on a contract basis (per acre), labourers prefer to finish the planting quickly, and they can feel that separating out single seedlings to transplant takes time.
- Handling the young seedlings is awkward for some as they are reluctant to push the delicate little plants into the soil. They need to learn how hardy rice plants (grasses) can be if they have a suitable soil environment to grow in.
- Mortality of single seedlings occurs in low-lying patches of improperly-leveled fields.
- Farmers feel that if heavy rains submerge the young seedlings for more than a week, they will die. Indeed, this is true. Where there is seedling mortality, a new batch of seedling can be raised within 10 days, giving more flexibility than when 25-30 day seedlings are used.
- Planting seedlings with their roots not thrust straight down into the soil (making the root profile like a J with the root tip pointed upwards) is not carried out in general. Learning to slip a seedling in horizontally, with a root profile like an L and with a root tip ready to resume downward growth, with little transplanting shock, takes a little time to learn.
- Planting the seedling along the soil attached to the roots is felt difficult at first. Getting easy-to-manage nursery soil that permits separation of plants while retaining soil around the roots can take some experimentation.

Water Control For SRI

- Inadequate structures to control water supply, especially for draining excess water.
- Discontinuous or unreliable availability of irrigation water also encourages farmers to flood their fields when it is available.
- In areas of cascade (field-to-field) irrigation, water control is difficult as individual paddies do not have their own supply from a canal system.

- Young seedlings face establishment problems due to flooding if caught in monsoon rains.
- Seepage water near an irrigation source can prevent farmers from having unflooded water situation in their paddies.

Intercultivation with Weeder

- If one labourer has to do the entire operation (with 25 x 25 cm spacing creating four rows per meter width) to weed/aerate 1 hectare, he has to walk 40 km to cover one direction, and 80 km to do weeding in both directions.
- Heavy weeders (like conoweeder) can cause shoulder pain, especially when just beginning with a new, unfamiliar implement.
- Weeders are often not easily available to the farmers.
- Some of the existing weeders do not work well in certain soil conditions and get stuck or clogged with weeds. Weeder design should be appropriate to field conditions.
- Difficulties in drafting labour for weeder operations.
- In some deltaic areas, the common weed Cyperus rotundus poses a particular problem as it is not readily controlled by weeders, and manual weeding has to be resorted to.

In a study conducted by Rao et al. (2007), the items perceived as driving forces for adopting SRI were: higher grain yield (83%), low seed rate (81%) water saving (81%), more number of productive tillers (80%), reduced pest and diseases (79%), suitability for seed multiplication (78%), higher grain weight (47%), and good quality grain (29%). The items that were perceived as restraining forces in adopting SRI were: drudgery in weeding (90%), difficulty in transplanting young seedlings (81%), difficulty in alternate wetting and drying of the field (58%), non-availability of organic manures (51%), requirement of skilled labour (46%), and no suitable agricultural implements (45%).

Scaling up SRI in the Timbuktu region of Mali showed that the implementation processes and approaches depended on: (i) technical adaptation of SRI practices to the Timbuktu environment, (ii) farmers' and technicians' know-how of the SRI technical requirements, (iii) collaboration with the government extension and research agencies, and (iv) the funding level. SRI practices induced a dramatic shift in the perception and understanding of how to achieve sustainable and productive rice cropping systems, stimulating farmers and technicians to initiate a series of innovations inspired by the SRI system (Styger et al. 2011).

12.12 Constraints in Scaling up

The scaling up of SRI in the country has been largely the result of efforts of certain individuals and agencies who could visualize the potential of SRI for addressing the contemporary issues in rice cultivation.

In spite of the efforts of some state Agricultural Departments and several CSOs, and the assured advantages of SRI cultivation, rapid spread has yet to take place due to the following constraints:

Inadequate Knowledge Exposure

Although it would appear simple to explain SRI principles, getting farmers to adopt them requires a well-conceived and reliably-operating delivery mechanism comprising of several approaches as explained in the TN-IAMWARM project success story.

Most people, including scientists, understand the effects of SRI only when they see the crop growth in the field. Only those farmers who are convinced of the advantages will practice it. Thus, exposing farmers to SRI crops in the field is essential.

A mechanism for raising a battery of master trainers and providing technical support at the village level are crucial. These resource persons should have a thorough understanding of SRI principles and practices and also be able to facilitate required support. Lack of such a system is one of the major constraints in scaling up.

Educating farmers to know that rice crops do not require flood water is important to minimize water use for rice cultivation. SRI requires different skills in nursery raising, transplanting, weeding, and water management. Thus, training and exposing farmers and labourers to SRI ideas and demonstrations is essential.

Inadequate Availability of SRI Tools

The weeder has become an essential tool in SRI cultivation as it reduces labour requirements for weeding besides having measurable and observable positive effects on the crop due to the intercultivation. To enable square planting, markers are also very handy. Thus, the availability of these two tools has become pivotal for SRI spread. A number of types of weeders are forthcoming through innovative ideas.

Availability of weeders is a particular problem faced by many farmers, and lack of access prevents them from executing the operations at the appropriate time. Sometimes, the available weeders are not suitable for the farmers' field conditions, so getting better designs and the available supply of suitably designed and well-built weeders is a priority.

Policy Support

Lack of adequate policy and financial support from Governments is one of the major constraints for scaling up SRI adoption as the efforts of CSOs alone cannot achieve large-scale adoption. Proactive state Governments like Tamil Nadu, Andhra Pradesh, Tripura, Bihar, and Jharkhand have allocated funds for proper scaling up of SRI. However, a serious national initiative is still pending.

12.13 Summary

The System of Rice Intensification (SRI) is now known in many rice-growing countries and in most of the rice-growing states in India. This new method of cultivation is not easy to follow by a farmer just from hearing about it. Systematic exposure is essential to fully understand the principles involved and the procedures to be followed. The six principles of SRI are to be followed fully to derive all the potential benefits of SRI cultivation.

Conventional rice cultivation under irrigated conditions includes growing a nursery, transplanting the seedlings, weeding, irrigation, and using organic and inorganic sources of nutrients to amend the soil. SRI also has these practices, but how these are done with respect to the basic principles is where the big difference lies. Thus, unless farmers are educated thoroughly about SRI, they are bound to face problems in adopting it, in spite of the proven fact that SRI brings in numerous advantages to ensure the profitability of rice cultivation.

In all the SRI extension programmes, whether of government or NGOs, it is necessary that the extension personnel have a good knowledge of the principles and practices of SRI. The farmers have to understand the theoretical basis of the principles and also have hands-on training and exposure to carry out the different practices, viz., raising a special nursery, using a marker, planting single seedlings, using the weeder for intercultivation, and controlled irrigation. Failure to understand these will lead to lack of interest and fear of unsuccessful adoption.

13 RICE MARKETING

Being the main staple for people in the rice-growing regions, rice is primarily produced for domestic consumption. International rice trade is estimated between 25 and 27 million tonnes per year, which corresponds to only 5-6 percent of world production. This makes the international rice market one of the smallest in the world, compared to other grain markets such as wheat (113 million tonnes) and corn (80 million tonnes).

Besides the traditional main exporters, a relatively important but still limited part of the rice that is traded worldwide comes from certain developed countries in Mediterranean Europe and from the United States.

There are two major reasons behind this: new food habits in the more developed countries themselves are affecting demand for rice, and new market niches are opening up in developing countries (http://www.unctad.org/infocomm/anglais/rice/ecopolicies.htm).

Thailand, Vietnam, India and Pakistan are the main exporters internationally (Table 13.1). The major rice markets are shifting now from Mediterranean Europe and the US, to West Asia. In Africa and Latin America, consumption is expanding more rapidly than domestic production, so these countries are also becoming more important export destinations.

Global rice exports increased considerably after 1993, and reached a peak of 31.8 million tonnes in 2006. Export of milled rice from India was a mere 0.5 million tonnes in 1989, but it reached 6.7 million tonnes during 2001 (Fig 13.1). During the last decade, rice exports from India have been fluctuating between 1.4 million tonnes and 6.65 million tonnes. In 2008, only 2.5 million tonnes were exported (http://beta.irri.org/ USDA data). Government policies like banning the export of non-basmati rice, and local production and demand dynamics affect the level of rice exports.

Table 13.1 Main Rice-Exporting and Rice-Importing Countries

Rice-Exporting Countries	Rice-Importing Countries
USA	Nigeria
India	Bangladesh
China	South Africa
Thailand	Japan
Pakistan	Brazil
Vietnam	Malaysia

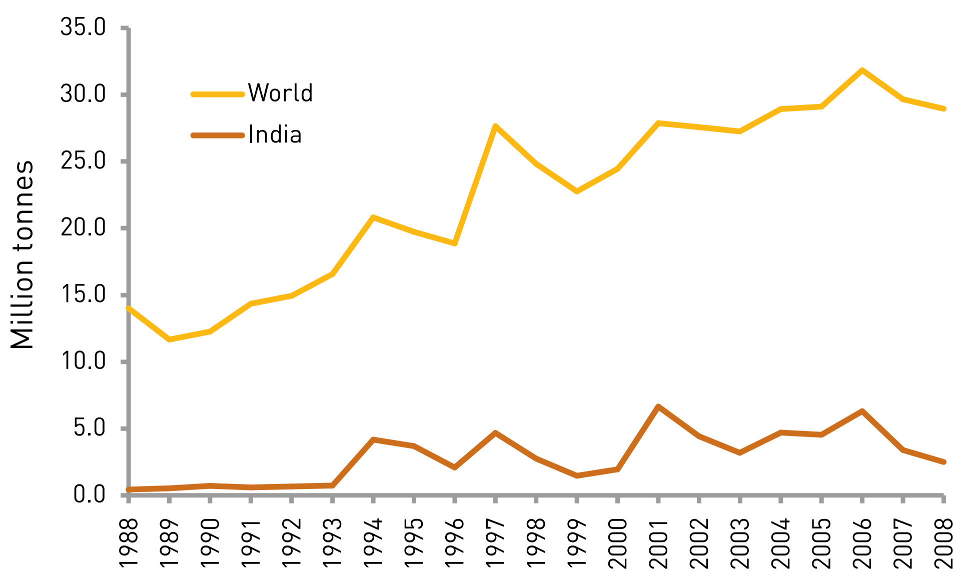


Figure 13.1 Global and Indian milled rice exports from 1988 to 2008. Source: http://beta.irri.org/USDA

Globally, the quantity of milled rice exported during 2008 was 24.1 million tonnes, out of the 459 million tonnes produced during that year, just 5.2%. The export of milled rice from India during 2008 was just 2.47 million tonnes (Table 13.2), while the production was 89 million tonnes; so exports were 2.8% of production. During that year, total agricultural exports from India were US$ 17,307 million, and cereal exports of US$ 3,493 million constituted about 20% of the total.

Various rice commodities like rice bran oil, broken rice, fermented beverages, and rice flour are also traded internationally, but there has been no significant contribution from India.

Table 13.2. Rice commodity exports in the world and India during 2008.

Rice commodity	World		India	
	Quantity (tonnes)	Value (1000 $)	Quantity (tonnes)	Value (1000 $)
Rice -milled	24,131,474	16,637,798	2,474,250	2,577,400
Broken rice	2,281,999	1,057,800	2,306	425
Rice - paddy	1,992,392	872,525	11,473	4,447
Rice - husked	1,425,501	923,815	260	57
Rice flour	44,308	36,150	0	0
Rice bran oil	25,868	34,273	0	0
Rice fermented beverages	12,583	75,511	NA	NA

Source : FAOSTAT, May 2011

The global rice export market is highly concentrated with contributions from Thailand (30%), Vietnam (18%), United States (12%), Pakistan (10%), China (8%), India (4%), and others (18%). The quality of the rice also plays a role in the market shares. The share of global rice trade by the type of rice is japonica (10%), glutinous (5%), indica (75%), and aromatic (10%).

Government policies also add to world price variability. Governments in developing Asian countries seek to ensure adequate rice supplies at low prices for consumers, and higher-income Asian countries (Japan, Taiwan, and South Korea) protect their producers from lower-priced imports. The small amount of rice traded, relative to the amount produced, provides potential for highly variable world prices, resulting primarily from shifts in exportable supplies in the major exporting countries and/or domestic production shortfalls in the large consuming countries (Paggi and Yamazaki 2001).

Thailand, India and U.S.A. are the only countries making parboiled rice and exporting it. Thailand, Vietnam and India are also exporting 100% broken rice. Basmati rice is fetching a good export price in the international markets for its three district quality features, i.e.,pleasant aroma, superfine grains, and extreme grain elongation. About two-thirds of the basmati rice produced in India is exported.

13.1 Traditional Rice Varieties and Reported Health Benefits

The rich biodiversity in India is reflected in its rice genetic resources. According to Dr. Richharia, 400,000 varieties of rice existed in India during the Vedic period, and he estimated that 200,000 varieties of rice still existed in India. The beginning of a rice breeding programme in India in 1911 exploited pure line selection initially. It was followed with an inter-breeding programme between japonicas and indicas. Introduction of dwarf high-yielding varieties led to a hybridization programme between semi-dwarf Taiwanese types or derivatives and certain indica varieties. A research programme was initiated during 1970 to develop hybrid rice varieties in the country, and some of these have been developed and are being promoted.

The introduction and spread of high-yielding varieties saw the erosion of traditional varieties from large areas of India; but some are still being cultivated because they enjoy consumer preference and often have specialized uses such as at weddings or other occasions. With awareness on organic farming and health consciousness, there is a growing interest in traditional varieties, especially of those varieties having special qualities for consumption and special ceremonial or medicinal uses.

Traditional rice varieties combine several good eating qualities, and there are some special quality rices that can fetch a premium price in the domestic as well as international markets. An array of such rice varieties are available in different parts of the country which can be grown in various seasons and in different agro-climatic conditions. Traditional varieties with special aroma, medicinal values, nutritional values, and suitability for special preparations, etc. are still available and grown in limited areas. Some of these varieties also have religious and cultural significance.

Some of the traditional varieties have been preferred for value-addition processing, e.g., rice flakes, popped rice, rice noodles, rice-based snacks, etc. Glutinous rice is used in making puttu in South India. In Himachal Pradesh, Jatu red rice is prized for its aroma and taste. Matali and Lal dhan of Himachal Pradesh are used for curing high blood pressure and fever. Kafalya from the hills of Himachal Pradesh and Uttar Pradesh is used for treating leucorrhea and abortion complications. Kari kagga and Atikaya of Karnataka are used for coolness and as tonic, while Neelam samba is used for lactating mothers in Tamil Nadu (Angusamy et al. 2001).

In China, red rice is used for preparing vinegar, tart, cosmetics, red kojic, and red rice yeast. The latter, used for medicinal purposes, is prepared by fermenting the yeast Monascus purpurea over red rice. It is said to promote better blood circulation and is used in treating upset stomach, indigestion, bruised muscles, and hangovers. It is also a cholesterol-lowering product that is commercially marketed the world over. Red rice in Japan is used for preparation of red sake, colored noodles, and cakes for ceremonial occasions. In Sri Lanka, red rices are a favorite as food, and some are used as medicines.

Black rice is full of antioxidant-rich bran, which is found in the outer layer that gets removed during the milling process to make white rice. Black-rice bran contains the antioxidants known as anthocyanins, purple and reddish pigments, also found in blueberries, grapes, and acai. These have been linked to a decreased risk of heart disease and cancer, improvements in memory, and other health benefits. One spoonful of black-rice bran - or 10 spoonfuls of cooked black rice –will contain the same amount of anthocyanin as a spoonful of fresh blueberries, according to a new study presented at the American Chemical Society in Boston (http://edition.cnn.com/2010/HEALTH/08/26/black.rice.new.brown/)

.\In India, red rices have occupied a special positionfor many ages. The founding fathers of ancient Ayurveda – Susruta (c. 400 BC), Charaka (c. 700 BC), and Vagbhata (c. 700 AD) – refer to the medicinal value of shali, vrihi, and shastika rices, and they list the rices according to their relative medicinal value, with the most useful type at the top of the list.

Ancient Ayurvedic treatises laud the Raktashali red rice as a nutritivefood and medicine. The medicinal value of other rices such as Sashtika, Sali, and parched rice have been documented in the Charaka Samhita (c. 700 BC) and the Susruta Samhita (c. 400 BC). They were used for treatment of various ailments such as diarrhea, vomiting, fever, hemorrhage, chest pain, wounds, and burns. Even today, certain rice varieties with medicinal value are used in Karnataka, Madhya Pradesh, Kerala, Tamil Nadu, Uttar Pradesh, the Western Ghats, and Himachal Pradesh to treat skin diseases, blood pressure, fever, paralysis, rheumatism, and leucorrhea, as well as a health tonic and for lactation.

The famous Nivara rice of Kerala is widely employed in Ayurvedic practice as a body-enriching item, to exclude toxins and delay premature ageing. Colored rices (black and red) are rich in minerals (iron and zinc) and polyphenols and have antioxidant properties. Traditional varieties such as basmati have a low glycemic index and are useful in weight-reducing diets. Rice-based oral rehydration solutions (ORS) are reported to be better than glucose-based ORS, and have been included in World Health Organization recommendations (Uma et al. 2008).

If such traditional rice varieties with special qualities are marketed internally and internationally, there will be a huge demand. What is required is proper awareness, production strategies, and appropriate market mechanisms. Already some market has been created for such varieties, especially for those varieties having medicinal values. Most organic rice farmers grow some of these traditional varieties. Many NGOs are also involved in conserving and promoting traditional varieties. The Centre for Indigenous Knowledge Systems (CIKS) in Tamil Nadu, SAMBHAV in Odisha, and the Richharia Foundation in Chhattisgarh are a few examples of such NGOs among others.

A marketing company in the USA, Lotus Foods of San Francisco, California, is importing 'specialty' (indigenous, organically-grown, fair-traded) rices from several countries, e.g., Kalajeera which is grown in eastern state of India, and is selling these in supermarkets all across the U.S. (3,500 outlets, nationally). Consumers in the U.S. are willing to pay about $4 for 15-ounce packets of these high quality rices. Kalajeera rice offers renowned quality (aroma, taste, elegance). There are surely a good number of indigenous Indian varieties that are quite superior (Uphoff, personal communication).

There are probably hundreds of rice varieties having special qualities that are not known widely. Thanks to the efforts of many NGOs and individuals, these are coming into the open. From an effort to compile a list of such varieties in India, details of 25 varieties are given in Table 13.3.

Table 13.3 List of some traditional specialty varieties in India

S.No.	Name of the variety	Specialty	Areas of cultivation
1	Alur Sanna	Tasty, suitable for porridge, good cooking quality	Hosagadde, Nada Kalasi, Talaguppa – Shimoga district, Karnataka
2	Chennellu	Non-scented. Red grain type used for treatment of diarrhea and vomiting. Red type given to patients recovering from jaundice	Kerala
3	Chittaga	Sweet rice, used for preparation of cattle medicine	Konjawalli, Mandavalli - Karnataka
4	Doobraj	Scented and tasty	Chuhi, Bara, Dalkojageer – Madya Pradesh
5	Hakkala Kari Saalai	Medicinal value for fever	Moogalihaal, Karnataka
6	Hansraj	Excellent aroma, very good eating and cooking qualities	Plains districts of Utterakhand
7	Holabatta	Tasty rice, suitable for beaten rice and curd rice	Saru, Chikkamagalur District, Karnataka
8	Indrashan	Good eating and cooking qualities	Plains of Utterakhand
9	Jeeraha Samba	Scented, preferred for biriyani	Tamil Nadu
10	Jenugoodu	Sweet rice, used for preparation of medicine for cattle	Yalakundi, Suraguppe, Hirenellur, Kagodu – Karnataka
11	Kallimadayan	Specifically used for Manapparai murukku'(snacks), suitable for meals	Tamil Nadu
12	Kappakkaar	Suitable for iddly, dosa, rice flakes. Used for meals in special functions	Tamil Nadu
13	Karunkuruvai	Suitable for iddly, dosa. Cooked rice used for medicine against the diseaseelephantiasis. Can be used as medicine for orthopaedic ailments and for filariasis.	Tamil Nadu
14	Kavunginpoothala	Non-scented. Given to diabetic patients. High amylase content	Palakkad district, Kerala

S.No.	Name of the variety	Specialty	Areas of cultivation
15	Kullakkaar	Best for iddly, dosa. Suitable for porridge. Increases nerves strength and controls diabetes and blood pressure	Tamil Nadu
16	Kuzhiyadichan	Suitable for iddly, dosa. Administered for lactating mothers	Tamil Nadu
17	Lochai Lohandi	Tasteful, digestive, low water requirement	Bokra-Bokri, Tanghar, Madhya Pradesh
18	Navali Saali	Nutritious and high mineral content	Daddikamalapur, Karnataka
19	Neelansamba	Rice suitable for lactating mothers	Tamil Nadu
20	Pichavaari	Best for puttu; cooked rice administered for treating cattle	Tamil Nadu
21	Ratna Chudi	Sweet rice, good for popping	Hosakoppa, Mallandur - Karnataka
22	Sembaalai	Suitable for meals, best for popped rice	Tamil Nadu
23	Shrikamal	Scented and tasty	Alahara, Umarghadadh, Pondikurd- Madhya Pradesh
24	Thinni	Suitable for biriyani, very good for meals	Tamil Nadu
25	Thooyamalli	Suitable for biriyani, meals. Healthy, tasty rice, increases nerves strength, and the cooked rice is very white	Tamil Nadu

Sources :	Himachal Pradesh :	SATHI, Thamba, Khundian, KangraDist,
	Karnataka:	JSS Rural Development Foundation, Mysore ShivarajHungund, Dharwad ManavVikasSansthan, Kalol, Bilaspur Dist.
	MadhyaPradesh :	MPRLP, Shahdol, Alhera. PFT Member Cluster, Tikhwa, BeohariDist
	Uttarakhand :	College of Agriculture, GBPUAT, Pantnagar 263145
	Tamil Nadu:	Centre for Indian Knowledge Systems, Chennai 600085
	Kerala :	http://kerala.gov.in/keralacalloct_07/pg16-17-18.pdf

13.2 SRI and Traditional Varieties

With increasing awareness on the value of quality rices, markets in future might be looking for more diverse food as consumers become more discerning and can afford to upgrade the quality of their diet. Many organic rice farmers are adopting SRI in India. Since the seed requirement is very much less with SRI, special varieties could be easily conserved and popularized. Special rice varieties grown under SRI are also being marketed locally. An international market has also been created for SRI rice. Madagascar Pink Rice imported from Madagascar, Organic Mekong Flower Rice imported from Cambodia, and Volcano Rice imported from West Java, Indonesia are being marketed online at about US$ 3.64 per pound (http://www.lotusfoods.com/SRI-Rice/c/LotusFoods@SRI).

If the farmers cultivating the traditional varieties adopt SRI for increased production of these varieties, it will benefit them immensely. Besides, if national and international markets for the specialty varieties are developed, they will fetch farmers more profit. SRI can in this way help in protecting the gene pool of rice, which is dangerously narrow now.

13.3 Factors Influencing Rice Markets

- Enterprise capacities : Management capacity, organization of export trade, linkages and market presence
- Transport and storage: Transport conditions and cost are particularly sensitive factors for developing-country exports, especially for the numerous land-locked and island countries. Organizing logistics is a core competency needed for most exporters in developing countries.
- Government policies: Exchange rates, fiscal policies, export incentives, and export promotion. (Source : http://finance.indiamart.com/markets/commodity/rice.html)

13.4 Summary

The rich biodiversity available in India is little known to consumers in other countries, and even unknown to many in contemporary India itself. SRI provides great opportunity to multiply these rices with a small quantity of seeds. Already we know that a number of the traditional ('unimproved') varieties can give yields over 10 t ha^{-1} with SRI management, and they command a higher market price than do the 'improved' varieties because of consumer preferences. So growing them with SRI methods can satisfy both producers and consumers. This application of SRI principles can give leverage to the marketing of specialty varieties of India not only within the country, but also globally.

14 CONCLUSIONS

Meeting the growing demand for more food grains requires more innovative approaches. Producing more with reduced drawdown of natural resources- land, water, and fossil fuels - requires radically different approaches. SRI is one such approach, which is producing more while reducing the inputs- seed, water, fertilizers, and pesticides. Since is it not a seed-based approach, farmers have options of growing whatever variety they and consumers like most. It is also reduces the financial burden of farmers as it reduces their costs of cultivation. So there is an opportunity here for farmers and Governments to capitalize on the potentials of SRI and similar methods to meet the growing concerns of food security in many developing counties.

SRI is in some ways a very conventional approach- optimizing plants' productivity by providing them with optimal field conditions - but it came into existence in a somewhat unconventional way, more through the efforts of farmers and civil society than from formal scientific investigation. That is becoming a challenge for the established agencies to visualize and endorse its potential. Field-based methods such as SRI were the foundations for improving the yields for centuries before the seed-based approaches came into existence. The seed-based approaches have only been in existence for the last six decades or so. So, SRI is about going back to basics – providing optimal conditions of soil, water and nutrients for the rice crop.

SRI as a term and as a package of practices came to light from Madagascar. However, some of these practices were known in India already at least a century ago. The use of single seedlings, wide spacing, and less water - the core principles and practices of SRI - were experimented with by Indian farmers in the early years of the 20th century. However, the term SRI and its nicely articulated principles and practices have caught the imagination of the millions of farmers and the socially conscious groups around the world. Although SRI was initially promoted by civil society groups, now it is an official programme actively promoted by Governments in many countries. The Ministry of Agriculture and Rural Development in Vietnam has issued a formal decision October 15, 2007, acknowledging SRI as "a technical advance," and directing government agencies to "guide and disseminate " this innovation.

SRI came to international attention only after two decades of its initial development in Madagascar, but today farmers in more than 40 countries and in all of the rice-growing areas of India are known to be making use of these methods. Being an innovation that does not depend on new or external inputs, but rather on changes in management of available resources, it is quite unprecedented. The pathway for SRI's spread has been likewise truly unconventional as there was no standard research accumulation in its development and little official extension support and government or donor funding for its dissemination. It has proceeded as mostly a civil society innovation, for which a great variety of organization, professions and individuals have joined.

Now there is a great opportunity for established research agencies to further refine and improvise SRI to suit local conditions and to extend the learning from SRI experience and study to making agriculture less dependent on external inputs. Further debate about the merits of SRI may not be a productive way of improving the food security given that several million farmers have already adapted this method and are expecting this to be further refined and improved to be even more effective.

There are still some policy makers, scientists and institutions who are raising doubts about the merit, validity and sustainability of SRI.

Certainly the debate on SRI should continue, as one way of further refining the method. But often such debates are based on certain prejudice and not on scientific evidence. Most of these doubts and demand for proof that SRI is working have come from some of the institutions which are expected to conduct independent research. Some of the repeated criticisms about SRI are mentioned below with suggestions for resolving them.

14.1 SRI Vs. Non-SRI

Understanding the results of SRI might require new tools and new models. Analyzing and evaluating SRI in terms of previously-known scientific findings and currently-accepted knowledge is not necessarily helpful. The facts and parameters accumulated by conducting experiments with rice grown withnon-SRI practices may not apply to SRI-grown plants. The physiological and morphological characteristics of rice plants raised under SRI management are significantly different in many respects from non-SRI rice plants, as observed by farmers and by researchers (Thakur et al. 2010). Thus, our knowledge of plant x soil x practice interactions needs to be validated rather than simply assumed, when comparing SRI performance with non-SRI rice relationships and results.

For example, it is sometimes objected that because SRI management makes rice plants grow vigorously with higher yields, there must be nutrient mining in the soil. This concern may be correct, but it is based on the non-SRI perspective that when a certain amount of nutrients are taken up by the plant to produce a unit quantity of yield, this higher yield means greater nutrient removal from the soil. This view does not consider the return of nutrients to the soil from organic matter applications, nor does it take account of the nutrient mobilization and recycling that can be accomplished by the soil biota under conducive conditions. Nor does it consider that SRI plant phenotypes are more efficient in utilizing sunlight and converting nutrients into biomass production (Zhao et al. 2009; Barison and Uphoff, 2011).

The sustainability of SRI yields should be tracked and evaluated over a decade or more before drawing firm conclusions. Also, because SRI is not necessarily an 'organic' methodology, any specific soil nutrient deficiencies could be remedied with nutrient amendments. In fact, a key macronutrient, phosphorus, exists in most soils in much abundance, but in plant-unavailable forms. Evaluations done in India and Indonesia that compared the soil organisms in the rhizosphere of SRI rice plants with those in the root zones of plants grown by usual methods have found that phosphorus-solubilizing microbes are more abundant in the former, as are diazotrophs, i.e., nitrogen-fixing organisms (Anas et al. 2011).

A lot more studies need yet to be conducted on such matters, but published information currently available indicates increased light use efficiency and higher nutrient use efficiency as well as more water use efficiency by SRI rice-plant phenotypes. Studies have shown greater nutrient productivity (biomass per unit of nutrient taken up) to be higher in SRI plants. So assumptions and conclusions based on previous research with non-SRI phenotypes do not necessarily apply.

The delayed leaf senescence along with a higher leaf area index (LAI), plus higher root activity during reproductive and grain-filling periods, offer favourable growth conditions not experienced by a non-SRI crop. Post-flowering plant physiology is likely to alter the source-sink relationships also. The knowledge on carbohydrate synthesis and partitioning during grain-filling acquired from non-SRI rice plants may not help us to understand the efficiency of SRI plants.

Similarly, there used to be arguments about the merit of plant density and its role in yield.

One of the core principles and practices of SRI is wide spacing of hills with single seedlings. Previously this has been challenged saying that such practice will not yield more since with lower plant populations per unit of area compared to non-SRI the number of tillers on an area basis will be significantly lower (Sinclair, 2004; Sinclair and Cassman, 2004).

But this has been proved wrong. Wide spacing, starting with young seedlings, transplanted carefully, quickly and shallow, actually results in more productive tillers per unit of area. Also, the length of panicles and number of grains per panicle, as well as grain weight, can be positively influenced by these practices. This was not known before. So, an assertion on which SRI was criticized is now known to be no longer valid. Such new knowledge has not emerged through research, but through the field practices demonstrated by farmers.

Rather excessive water use in rice cultivation has become a standard practice. But, it is still not widely recognized that the inundation of rice fields does not contribute to yield increase or growth of the rice plant. Actually, deep water is used mostly to control the weeds. If there is an effective and more economic way to control weeds, excess water used for rice cultivation can be saved. SRI for the first time has proved to farmers and scientists that rice does not require so much water, and indeed that less water actually helps in enhancing the yields.

Obviously more research is required to optimize the water requirement for rice cultivation. Since more and more new rice cultivation is expanding in uplands, often pumping water from great depths, a better understanding of how to use water more efficiently not only saves water but also saves energy. SRI is certainly a great opportunity to farmers who are pumping water and cultivating rice in uplands.

14.2 Adoption / Partial Adoption / Non-Adoption / Disadoption

SRI is knowledge-intensive. Most of the institutions are well-equipped to deal with input-intensive methods such as seed and fertilizers for improving the yields. SRI may appear simple, and its elements are each quite straightforward. But it is knowledge-intensive and requires more support and training for farmers initially. Like any other new methods, particularly field-based, farmers who try the methods for one year and may not continue for the next due to various reasons. Yes, there is disadoption of SRI by some farmers. It is important to assess disadoption separately from the merits of SRI. There are various pragmatic issues to be resolved, or solved, with SRI like with any innovation. Once farmers understand the innovation, and the reasons behind it, there can be various ways to take advantage of its opportunities to raise productivity if indeed there is such a payoff to be achieved.

Since the agronomic practices of SRI are different from conventionally followed ones, convincing farmers to take up the new practices is the difficult part of SRI extension. Just bringing farmers to see the differences in the growth of an SRI crop may convince them to try out the new methods, and thus, the extension strategy and support is very important for SRI adoption. Having data on the reductions in cash cost and/or labor inputs, and on impacts on farmers' net income, can also reinforce the visual message of seeing an SRI crop.

Various techniques adopted by extension agencies and civil society organizations have been helpful. Inspite of learning about the promising benefits, and seeing successful farmers, some farmers still do not decide to try out SRI. Also, there is disadoption with some farmers. While detailed analysis is to be taken up to understand the reasons and dynamics of non-adoption and disadoption, poor understanding of SRI principles, non-availability of SRI tools, labour-related constraints, insufficient water control in some places, and the requirement of more attention and monitoring of SRI crops appear to be the most important constraints on adoption. Thus, continued technical support for several crop seasons and ongoing encouragement are necessary for most farmers to transform their cropping operations.

Some farmers adopt only some of the SRI principles, and some skeptics object that if not all of the basic SRI principles are adopted by farmers, how can their crop be called SRI? This reflects the fact that a certain set of principles for cultivating rice has been given a name 'SRI', and we do not have such history for any other crop. The whole purpose of recommending SRI methods to farmers is to help them achieve more output with less input costs, and also to enhance the food security of a nation, not just to give publicity to a name. If farmers are able to boost their yield and income by adopting only some of the SRI principles, this is worthwhile. What is required is to get farmers to realize that adopting all of the principles will give them more benefits. This will be the challenge in SRI extension. SRI is not competing with any purchased technology; it has no patents or royalties; there are no intellectual property rights. SRI knowledge is available to anyone, free. The only persons who can get richer from SRI are the farmers. What is required is to help farmers realize the fact that by adopting all of the principles and using them appropriately, they will get more benefits. This will be the challenge in SRI extension, moving from an input-focused process to a knowledge-based one.

It is important to mention here that all of the packages of practices recommended by any agency, be it IRRI, ICAR or other institutions mandated to do that, are never fully adopted by the farmers. So, dis-adoption or partial adoption of package of practices is not unique to SRI. From sowing to harvest, what the farmer does is governed by innumerable local factors that force him or her to decide the practice in the field – nursery type, variety sown, seed treatment, seedling age, main field preparation, manure application, number of seedlings per hill, planting density, planting method, water management, weed management, plant protection, and fertilizer application, etc. If all the practices followed by 100 farmers in a typical rice belt are listed out, probably none of them will match the recommendations of any BMP proposed by researchers. This is the reality. So, there will be no justice in the complaint that if SRI farmers are not following all of the recommended SRI practices, what they are doing is 'not SRI.'

Adopting SRI on a community basis is one best way of scaling up SRI. Self Help Groups (SHG) can be effectively developed and utilized in this direction. Community SRI has several advantages:

- Community nurseries will help make maintenance and monitoring easier. It will also solve the problem water scarcity and unreliability before the monsoon by starting early cultivation. Staggered sowing of several nurseries can be done so as to have at least some nurseries with right-aged young seedlings when the rains do start.
- Trained manpower for the following could be established: for nursery raising, seedling pulling, leveling the main field, marker use, square planting, shallow irrigation, and weeder operation
- The implements / tools required for SRI (markers, weeders, laser leveler, and harvester) could be commonly maintained and shared.

14.3 SRI Research

Research on SRI in India has been carried out on the basis individual interests, with no major funding support so far for advancing scientific knowledge for SRI systematically. However, slowly many established institutions are beginning to conduct research on SRI. But clearly this is not enough. More systematic research on SRI, including critical evaluation of its merits, should be conducted in bigger way.

Changes in microbiological activity and pest / disease interactions due to SRI management have been studied to a limited extent, but they already show the potential for beneficial effects. The altered leaf morphology, surface characteristics, and phytochemical changes in rice plants under SRI management might play a role in the interactions with pests and diseases. Modified rhizosphere chemistry and enhanced xylem flow probably alter and influence the soil microbiological activity. Why there is little or no rat damage in SRI crops as reported by many farmers has not been understood scientifically up to now.

Drought-tolerance, lodging-resistance, and typhoon-resistance of SRI crops have been frequently experienced by farmers, and the mechanisms for this are yet to be studied. The extensive root system and stronger stems (with apparently higher silica content) appear to support these characteristics, but more thorough research remains to be done.

There are many opportunities to study the effect of SRI practices on soil system dynamics, plant behaviour, micro-climates, climate change adaptability, carbon sequestration in the soil, socio-economic impacts especially concerning gender, long-term effects of SRI management, etc.

14.4 Future of SRI in the Country

SRI has been found to have a number of advantages beyond the most obvious one of increasing rice productivity. The main one is bringing down the irrigation water requirement by nearly 30-40%. This alone should be attractive to water managers and to decision-makers who are responsible for ensuring adequate water supplies for agricultural, industrial and domestic uses.

The potential of SRI to meet the present-day challenges in rice production is remarkable:

1. SRI addresses the issues and concerns for labour scarcity, water scarcity, sustainable productivity, input-use efficiency, and encourages public-private partnerships.
2. SRI increases the productivity of land, water, nutrients, and labour; it also enhances land and water quality by building up soil fertility and reducing agrochemical build-up in soil, groundwater and surface bodies.
3. SRI exploits the genetic potentials of rice genotypes by creating better above-ground and below-ground environments for plant growth.
4. SRI principles have been extended to rainfed rice production so that upland areas, where poverty is often greatest, can be benefited.
5. SRI ensures household food security of resource-poor farmers because it can raise their food production without requiring the purchase of inputs that would require borrowing and debt.
6. For climate-change conditions, SRI is best suited because of its lower water requirements and the resilience that it confers on rice plants to deal with drought, cold spells, and storm effects, as well as with pest and disease damage.
7. SRI is attractive to tribal, marginal and organic farmers. Its extension and extrapolation to a variety of other crops beyond rice can lead to widespread improvement in the food security and incomes of rural households.

The following are some of the challenges that have to be suitably dealt with in scaling up SRI in the country.

- Training and extension: Providing suitable extension services on SRI including demonstrations, trainings, exposure visits, etc. is crucial. Systematic and continued support to farmers in acquiring skills is crucial in SRI adoption, and it should continue for a few years until it becomes a common practice.

- Irrigation: Improving irrigation service delivery in major irrigation schemes. Many farmers even if they want to reduce their water or apply in a more scientific way are not able to do this since the large irrigation systems are not designed for SRI management, applying smaller but reliable amounts of water. So there is need to re-orient our irrigation management towards less water-intensive and more scientific application of water to rice cultivation.

- Also incentives for saving water through SRI method will encourage the farmers to adopt SRI. Present policies and incentives do not encourage the careful application of less water to achieve higher production and more income. Once the benefits from SRI management are known by farmers, they should be self-sustaining because of farmers' economic advantages.

- Tools: Providing the most suitable weeders in adequate numbers to particular locations, and also markers and other implements. Development of motorized weeders to reduce the time and effort needed for weeding would provide a large impetus for SRI spread.

- Understanding and addressing the issues related to disadoption: Eliminating the constraints related to disadoption by analysis of local factors is important toward achieving the sustainability of SRI adoption

- National targets for SRI: Policies and institutional mechanisms for designing and delivering a common strategy for reaching a national target of 20% of rice-growing area under SRI, by end 2016 (XII Plan period). A clear policy framework for achieving an increase in rice production by 10-20 % through SRI spread has to be formulated and promulgated at national level. The state government in Bihar, having aimed for 3.5 lakh ha of SRI production in the 2011 kharif season (10% of the state's rice-growing area), has decided to set a state target of 1.4 million ha for 2012 kharif, 40% of its rice area.

It is hoped that SRI will find substantial and appropriate support in the 12th Five Year Plan for India which is now under formulation.

REFERENCES

(References not quoted in the chapters are included from http://sri.ciifad.cornell.edu/publications)

Abeysiriwardena, D. S. de Z., W. M. W. Weerakoon and W. M. A. D. B. Wickramasinghe. 2009. System of rice intensification (SRI) as a method of stand establishment in rice. American-Eurasian Journal of Agricultural and Environmental Science. 5:189-195.

Africare, Oxfam America, WWF-ICRISAT Project. 2010. More Rice for People, More Water for the Planet. WWF-ICRISAT Project, Hyderabad, India.

Ahmed, Q.N. 2006. Influence of different cultivation methods on growth and yield of hybrid and inbred rice. Master's thesis, Sher-e-Bangla Agricultural University, Dhaka. 165 p.

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

Anas, I, O. P. Rupela, T. M. Thiyagarajan and N. Uphoff. 2011. A review of studies on SRI effects on beneficial organisms in rice soil rhizospheres. Paddy and Water Environment 9:53-64. doi:10.1007/s10333-011-0260-8

Andriankaja, A.H. 2001. Mise en evidence des opportunités de développement de la riziculture par adoption du SRI, et evaluation de la fixation biologique du l'azote. Mémoire de fin d'etudes. École Supérieure des Sciences Agronomiques, University of Antananarivo.

Andry Andriankaja. 2003. Evidence on the opportunities for development of rice production with the adoption of the System of Rice Intensification, and evaluation of biological nitrogen fixation (in French). Memoire de Fin d'Etudes (thesis) University of Antananarivo, Madagascar. [English language summary]

Anita, S., and Mani Chellappan. 2011. Comparison of the system of rice intensification (SRI), recommended practices, and farmers' methods of rice (Oryza sativa L.) production in the humid tropics of Kerala, India. Journal of Tropical Agriculture 49 (1-2) : 64-71, 2011

Anonymous. 1911. Single planting of paddy. Practical Life 3: 249-252

Anonymous. 1913. Single planting of paddy. Practical Life. 5 (6) : 306 – 308.

Arena, J.A. 2005. Confronting Agrarian Crisis: Historical Food Insecurity, the Indian State, and the Green Revolution. Archive, A Journal of Undergraduate History. Volume 8

Armstrong, W., 1970. Rhizosphere oxidation in rice and other species: A mathematical model

Arumugasamy, S., N. Jayashankar, K. Subramanian, S.Sridhar, S., and K.Vijayalakshmi. 2001. Indigenous Rice Varieties. Centre for Indian Knowledge Systems (CIKS), Chennai, Tamil Nadu, India.

Aum Sarma. 2006. Status and future needs of farm mechanisation in System of Rice Intensification (SRI)' Paper presented in the National Symposium on ''System of Rice Intensification - Present Status and Future Prospects, held at Hyderabad on November 17-18, 2006.

Babou, C., G. Poyyamoli and B. Guna. 2009. Impact of LEISA based system of rice intensification (SRI) practices on rice grain yield and soil properties in rice-rice-rice cropping system in Puducherry region. International Journal of Agricultural Sciences. 5:43-45.

Barah, B.C. 2005. Dynamic of rice economy in India : emerging scenario an dpolicy options. Occasional Paper 47. NABARD, Mumbai. 82p.

Barah, B.C. 2009. Economic and ecological benefits of System of Rice Intensification (SRI) in Tamil Nadu. Agricultural Economics Research Review 22 (July-Dec. 2009):209-214.

Barison. J. 1998. Ecole superieure des sciences agronomiques departement agriculture perspective des developpement de la region de Ranomafana: Les mecanismes physiologiques du riz sur sols de bas-fonds, cas du Systeme de Riziculture Intensive. Memoire de Fin d'Etudes (thesis). Universite D'Antananarivo, Madagascar. (French) (103p., 403KB pdf)

Barison, J. 2003. "Nutrient-use efficiency and nutrient uptake in conventional and intensive (SRI) rice cultivation systems in Madagascar". M.Sc. thesis. Department of Crop and Soil Sciences, Cornell University, 2003. 94 p.

Barison, J, and N. Uphoff. 2011. Rice yield and its relation to root growth and nutrient-use efficiency under SRI and conventional cultivation: an evaluation in Madagascar. Paddy and Water Environment 9:65-78. doi:10.1007/s10333-010-0229-z

Barrett, C.B., C.M. Moser, O.V. McHugh, and J. Barison. 2004. Better Technology, Better Plots, or Better Farmers? Identifying Changes in Productivity and Risk among Malagasy Rice Farmers. American Journal of Agricultural Economics 86(4): 869-888 doi:10.1017/S0014479709990548.

Basavaraja, H., S. B. Mahajanashetti and P. Sivanagaraju. 2008. Technological change in paddy production: a comparative analysis of traditional and SRI methods of cultivation. Indian J.Agric.Econ. 63(4):629-640.

Berkhout, E., and D. Glover. 2011. The Evolution of the System of Rice Intensification as a Socio-Technical Phenomenon: A Report to the Bill & Melinda Gates Foundation. Aailable from the Social Science Research Network (SSRN): http://ssrn.com/abstract=1922760

Biksham Gujja, N. Loganandhan, V. Vinod Goud. 2008. System of Rice Intensification: Experiences of Farmers in India. WWF-ICRISAT Project, http://sri-india.110mb.com/documents/Farmersexperiences.pdf

Bindraban, P. S., H. Hengsdijk, W. Cao, Q. Shi, T. M. Thiyagarajan, W. Van der Krogt, et al. 2006. Transforming inundated rice cultivation. Int. J. Water Resour. Dev. 22:87-100. doi:10.1080/07900620500405338

Birch, H.F., 1958, The effect of soil drying on humus decomposition and nitrogen, Plant and Soil, 10, 9-31.

Bommayasamy, N., N. Ravisankar and T. Subramani. 2010. Influence of non-monetary inputs on growth and yield of rice (Oryza sativa) under system of rice intensification (SRI). Indian Journal of Agronomy. 55(2):95-99.

Bonlieu, F.. 1999. Summary of findings from thesis research on SRI in Madagascar. University of Angers, France.

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

Borkar, L. S., V. S. Khawale, P. B. Raut, T. S. Patil and H. S. Kolte. 2008. Studies on spacing and nitrogen management under system of rice intensification (SRI). Journal of Soils and Crops. 18:438-441.

Borromeo, E and D. Deb. 2006. Future of Rice. Green Peace International. 20p.

Bulandi, J., Adlaba, P.B. and Rodriguez, V.C. 1964. Three years of rice irrigation research in the Maligaya Experiment Station. J.Soil Sci.Soc.Philippines 11: 25-37.

Cai, X., and M.W. Rosegrant. 2003. World Water Productivity: Current Situation and Future Options. In : Water Productivity in Agriculture: Limits and Opportunities for Improvement (eds J.W. Kijne, R. Barker and D. Molden). CAB International. p 163 – 178.

Ceesay, M. 2004. Management of rice production systems to increase productivity in The Gambia, West Africa. Ph.D. Dissertation. Cornell University (178 p., 744KB pdf)

Ceesay, M. C., W.S. Reid, E.C.M. Fernandes, and N. Uphoff. 2006. The effects of repeated soil wetting and drying on lowland rice yield with System of Rice Intensification (SRI) methods. International Journal of Agricultural Sustainability 4(1):5–14.

Ceesay, M. 2011. An opportunity for increasing factor productivity for rice cultivation in The Gambia through SRI. Paddy and Water Environment 9:129-135. doi:10.1007/s10333-010-0235-1

Chadwick, D.T. 1914. Agricultural Department and its aims. The Agriculturist, 6 : 87

Chandramani, P., K. Mahender Kumar, S. Kumarand N.S. Venkataraman. 2008. Managing pest manifestation in SRI : OFT and FFS results. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policiev.js, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore.p 100-101.

Chandramohan, N. and Jayaraj, S., 1977, Effect of different levels of nitrogen and granular insecticides in the control of rice leaf roller Cnophalocrocis medinalis (Guenee), Madras Agric. J., 64, 544 – 548.

Chandrapala, A. G., M. Yakadri, R. Mahender Kumar and G. Bhupal Raj. 2010. Productivity and economics of rice (Oryza sativa)-maize (Zea mays) as influenced by methods of crop establishment, Zn and S application in rice. Indian Journal of Agronomy. 55(3):171-176.

Chapagain, T. and E. Yamaji. 2010. The effects of irrigation method, age of seedling and spacing on crop performance, productivity and water-wise rice production in Japan. Paddy and Water Environment. 8(1):81-90. doi:10.1007/s10333-009-0187-5

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

Chen, Z. and S. T. Yen. 2006. Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farms: A comment. Am.J.Agric.Econ. 88:763-766.

Chienyun, C., 1985, Stem borer infestation in hybrid rice, Int. Rice Res. Newsl.,
10, 21.

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

Choudhary, R. L., D. Kumar, Y. S. Shivay, Lata, G. Singh and N. Singh. 2010. Performance of rice (Oryza saliva) hybrids grown by the system of rice intensification with plant growth-promoting rhizobacteria. Indian Journal of Agricultural Sciences 80(10):917-920.

Choudhury, B.U., A.K. Singh and B.A.M. Bouman. 2005 Effect of establishment techniques on yield, crop water relationship in rice and wheat. In: T.M. Thiyagarajan, H. Hengsdijk, and P.S. Bindraban (eds). Transitions in Agriculture for Enhancing Water Productivity: Proceedings of an International Symposium held in Killikulam, Tamil Nadu, India, September 23-25, 2003, pp 19 - 38. Tamil Nadu Agricultural University, Coimbatore, and Plant Research International, Wageningen, Netherlands.

Chuan, H., Chen, L.Q.Chang, C.Y.Meng, L.G. Lin and J. X. Bin. 2009. Analysis on system of rice intensification (SRI) localization and dry matter production characteristics of high-quality rice. Guangxi Agricultural Sciences. 40:1418-1423.

Comprehensive Assessment of Water management in Agriculture. 2007. Water for Food, Water for Life: A comprehensive Assessment of Water Management in Agriculture. London : Earthscan, and Colombo : International Water Management Institute.

Das, N. M. and M.J. Thomas. 1977, Effect of water level in rice fields on the population build up of the brown planthopper, Nilaparvata lugens and on the incidence of hopper burn., Agric. Res. J. Kerala, 15, 104 – 105

David, P. M. M., K. Ezhilrani and T. M. Thiyagarajan. 2005. Relative abundance of insects in SRI and conventional rice. Paper presented at the National Symposium on Biodiversity and Insect Pest Management held on 3-4, February, 2005 at Entomology Research Institute, Loyola College, Chennai.

De Data, S.K. 1981. Principles and practices of rice production. International Rice Research Institute, Los Baños.

de Laulanie´, H., 1993. Le syste`me de riziculture intensive malgache. Tropicultura 11, 110–114.

De Feng, Z., C.H. Zhe, Z. Xiu Fu, L.X. Qing and Z. Yu Ping. 2007. Evolvement of rice cropping system and planting zonation in Zhejiang province. Acta Agriculturae Zhejiangensis. 19:423-426.

Dharmarangaraju, J. 1913. Paddy irrigation. Practical Life. 5 (3) : 132 – 135.

Din, M., P. S. Deshmukh, N. Ravisankar, R. C. Srivastava, S. G. Chaudhuri and M. Kumar. 2008. Influence of tillage and planting methods on productivity and energetic of rice (Oryza sativa) under Island ecosystem. Indian J.Agric.Sci. 78:702-705.

Doberman, A. 2004. A critical assessment of the system of rice intensification (SRI). Agricultural Systems 79(3):261-281. doi:10.1016/S0308-521X(03)00087-8

Dumas, J. and M. Krisof. 2009. Effect of the System of Rice Intensification (SRI) on livelihood strategies for Cambodian farmers and possible carbon storage and mitigation possibilities for greenhouse gas emissions. Master's thesis. University of Copenhagen. (4.06 MB)

Dung, N.T. 2007. SRI application in rice production in northern ecological areas of Vietnam. Report of National IPM Program to Council of Science & Technology, Ministry of Agriculture and Rural Development, Hanoi.

http://sri.ciifad.cornell.edu/countries/vietnem/vnMARDdecree07.pdf

Dutta, A and T.K. Pati. 2008. SRI: a Promising methodology for rice farmers of Orissa. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 172-173.

Escasinas, R.O. and O. B. Zamora. 2011. Agronomic response of lowland rice PSB Rc 18 (Oryza sativa L.) to different water, spacing and nutrient management. Philippine Journal of Crop Science. 36(1):37-46.

Fang, T.L. 1977, On the effect and cause of rice borer control by drainage of the rice field. Acta Entomol. Sin.,. 20, 426 - 430.

FAO (Food and Agriculture Organization). 2006. Prospects for food, nutrition, agriculture, and major commodity groups. World agriculture: toward 2030-2050, Interim report. Global Perspective Studies Unit, Food and Agriculture Organization of the United Nations, Rome.

Farooq, M., N. Kobayashi, A. Wahid, O. Ito and S. M. A. Basra. 2009. Strategies for Producing More Rice with Less Water. Advances in Agronomy, Vol 101. 101:351-388. doi:10.1016/S0065-2113(08)00806-7

FengYing, X., Ma Jun, W. H. Zheng, L.H. Yuan, H.Q. Long, Ma WenBo, 2005. Rice quality under the cultivation of SRI. Acta Agronomica Sinica. 31:577-582

Fu Xian, Xu, Xiong Hong, Zhu Yong Chuan and Wang Gui Xiong. 2004. Effect of system of rice intensification on grain plumpness in association with source-sink ratio in mid-season hybrid rice. Rice Science. 11:269-273.

Fu Xian, Xu, Xong Hong, Zhu Yong Chuan and Wang Gui Xiong. 2006. Preliminary analysis of the hybrids with smaller panicle in the system of rice intensification. Southwest China Journal of Agricultural Sciences. 19:395-399.

Garcia, U., Arlene and Sanchez Fernando, 1994, Influence of variety and plant spacing on the incidence of major insects pest and predators of low land rice, Philipp. Ent, 9, 399-405.

Gardjito, Budi Indra Setiawan, Arief Sabdo Yuwono, I Wayan Astika, and Tasuku Kato. 2010. Analysis on the productivity of organic rice farming in intensification (Analisis produktivitas pada intensifikasi budidaya padi organik). Jurnal Irigasi 5: 24-33. (English abstract only available through Perpustakaan Universitas Indonesia)

Gayathry, G. 2002. Studies on dynamics of soil microbes in rice rhizosphere with water saving irrigation and in-situ weed incorporation. Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India

Geethalakshmi, V., T. Ramesh and A.Palamuthirsolai. 2011. Agronomic evaluation of rice cultivation systems for water and grain productivity. Archives of Agronomy & Soil Science. 57(2):159-166. doi:10.1080/03650340903286422

Ghosh, R. K., L. Sharma, S. Barman and A. K. Dolai. 2009. System of intensification: the alternate approach for increasing production of field crops. Journal of Crop and Weed. 5(2):63-67.

Ginigaddara, G. A. S. and S. L. Ranamukhaarachchi. 2009. Effect of conventional, SRI and modified water management on growth, yield and water productivity of direct-seeded and transplanted rice in central Thailand. Australian Journal of Crop Science. 3:278-286.

Glover, D. 2011. A System Designed for Rice? Materiality and the Invention/Discovery of the System of Rice Intensification. East Asian Science, Technology and Society 5(2), pp.217-237.

Glover, D. 2011. Science, practice and the System of Rice Intensification in Indian agriculture (in press). Food Policy. doi:10.1016/j.foodpol.2011.07.008

Glover, D. 2011. The System of Rice Intensification: Time for an empirical turn'. NJAS-Wageningen Journal of Life Sciences 57(1), pp.217-224.

Gui Ping, Zhu, Yu Ai Ying, Zhang Pei Yan, Zhou Ze Hua, Ying Yun Xian and Chen Dong Lian. 2004. A preliminary study on suitable transplanting density in system of rice intensification (SRI). Hybrid Rice. 19:45-46.

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

Gujja, B. and T.M. Thiyagarajan. 2010. Producing more with less: exploring farm-based approaches to improve productivity and providing options to farmers in adapting to climate change. In : Wassmann R, (ed). Advanced technologies of rice production for coping with climate change: 'no regret' options for adaptation and mitigation and their potential uptake. Proceedings of the Workshop Advanced Technologies of Rice Production for Coping withClimate Change: 'No Regret' Options for Adaptation and Mitigation and their Potential Uptake held on 23-25 June 2010 in Los Baños, Philippines.IRRI Limited Proceedings No. 16. Los Baños (Philippines): InternationalRice Research Institute. 81 p

Guo Hua, Liu, Chen Li Yun, Xiao Ying Hui, Tang Wen Bang, Cai Yi Dong, Deng Hua Bing, et al. 2003. Comparison of the yield differences between rice hybrids under SRI and TCM. Journal of Hunan Agricultural University. 29:89-91.

Gupta, R.K., R.K. Naresh, P.R. Hobbs, Z. Jiaguo and J.K. Ladha. 2002. Sustainability of Post-Green Revolution Agriculture: The Rice-Wheat Cropping Systems of the Indo-Gangetic Plains and China. In: Ladha, J.K. et al. (eds). Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts. Special Publication, ASA. Madison, Wisconsin, USA.

Haden, Van R. J. M. Duxbury, A. DiTommaso, and J. E. Losey. 2007. Weed community dynamics in the System of Rice Intensification (SRI) and the efficacy of mechanical cultivation and competitive rice cultivars for weed control in Indonesia. Journal of Sustainable Agriculture. 30(4):5-26. doi: 10.1300/J064v30n04_03.

Halweil, B and D. Nierenberg. 2010. State of the World 2011: Innovations that nourish the planet. World Watch Institute.(http://blogs.worldwatch.org/nourishingtheplanet/sneak-preview-state-of-the-world-2011/)

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

Hasan, M., and S.Sato. 2007. Water saving for paddy cultivation under the System of Rice Intensification (SRI) in Eastern Indonesia. Jurnal Tanah dan Lingkungan 9(2):57-62.

He, Yang-Dong, and Ma Jun. 2005. Effect of different kinds of fertilizer on the yield and physical and chemical status of soil in SRI. Southwest China Journal of Agricultural Sciences. 18:315-320.

Hengsdijk, H. and & P. Bindraban. 2004. Rice: Location is vital in crop management. Nature 429: 803

Horie, T., T. Shiraiwa, K. Homma, K. Katsura, S. Maeda and H. Yoshida. 2005. Can yields of lowland rice resume the increases that they showed in the 1980s? Plant Production Science. 8:259-274.

Hossain, M. Z., S. M. A. Hossain, M. P. Anwar, M. R. A. Sarker and A. A. Mamun. 2003. Performance of BRRI Dhan 32 in SRI and conventional methods and their technology mixes. Pakistan Journal of Agronomy. 2:195-200.

Hossain, M., and K.S. Fischer. 1995. "Rice Research for Food Security and Sustainable Agricultural Development in Asia: Achievements and Future Challenges." Geo Journal 35 (3): 286–98.

Hua, Lin, Wu Chun Zan, Chen Ai Liu, Ding Yu Yun and Liao Chuan Shuang. 2006. Yield-increasing mechanism of system of rice intensification (SRI) and its key techniques. Hybrid Rice. 21:42-43.

Hugar, A. Y., H. Chandrappa, H. M. Jayadeva, A. Sathish, and G. B. Mallikarjun. 2009. Comparative performance of different rice establishment methods in Bhadra command area. Karnataka Journal of Agricultural Sciences 22(5): 992-994.

Hussain, A., M. A. Bhat, M. A. Ganai and T. Hussain. 2009. Comparative performance of system of rice intensification and conventional methods of rice cultivation under Kashmir valley conditions. Environmental Ecology 27:399-402. doi:10.1111/j.1439-037X.2009.00406.x

ICAR. 2010. Handbook of Agriculture. Indian Council of Agriculture, New Delhi. p 817- 844.

IRRI. 2009. Good Agricultural Practices for irrigated and rainfed rice. Cereal Knowledge Bank. (IRRI-CIMMYT). http://www.knowledgebank.irri.org/ipm/index.php/weeds-crop-health-2743/482-directshort-term-options

Islam, A. K. M. R., N. Islam, M. M. Hossain, K. M. R. Karim and K. M. Alam. 2005. Performance of growth contributing characters through spacing and variety under the system of rice intensification (SRI) technique. International Journal of Sustainable Agricultural Technology. 1:21-29.

Islam, M. S., G. J. U. Ahmed and A. W. Julfiquar. 2005. Effect of the system of rice intensification on hybrid rice performance and yield. International Rice Research Notes. 30:43-45.

Jain, A. and V. B. Upadhyay. 2008. Effect of planting geometry and age of seedlings on the performance of inbred and hybrid rice under system of rice intensification (SRI). Haryana Journal of Agronomy. 24:16-18.

Jayadeva, H.M., T.K. Prabhakara settee, and A.G. Bandi. 2008. Performance of SRI method of rice establishment under Bhada Command of Karnataka. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 33 – 35.

Jayadeva, H. M., T. K. P. Setty, M. T. Sanjay and G. B. Mallikarjuna. 2009. Studies on crop management practices for maintaining optimum tiller production under crop establishment techniques. Mysore Journal of Agricultural Sciences. 43:181-188.

Jayadeva, H. M., T. K. P. Setty, R. C. Gowda, R. Devendra, G. B. Mallikarjun and A. G. Bandi. 2009. Methane emission as influenced by different crop establishment techniques and organic manures. Agricultural Science Digest. 29:241-245.

Jayakumar, B., C. Subatra, V. Velu and S. Ramanathan. 2005. Effect of integrated crop management practices on rice root volume and rhizosphere redox potential. Journal of Agronomy, 4:311-315.

Jia Guo, Zheng, Lu Xian Jun, Jiang Xin Lu and Li Chong De. 2004. Testing modifications for the system of rice intensification (SRI) to achieve super-high-yield in the Sichuan basin. Southwest China Journal of Agricultural Sciences. 17:169-173.

Jian Long, Qian, Min Chang Yu and Zhang Jian Ping. 2006. Study on the intensification of rice cultivation. Acta Agriculturae Shanghai. 22:63-65.

Ji Ming, Peng and Wang Xue Hua. 2003. Use of Chinese hybrid rice with modified SRI in Guinea. Hunan Agricultural Science & Technology Newsletter. 4:13-15.

Jothimani, S. 2004. Studies on the controlled-release nitrogen fertilizers in rainfed and irrigated rice. Ph.D Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India

Kabir, H. 2006. Adaptation and adoption of the System of Rice Intensification (SRI) in Myanmar using the Farmer Field School (FFS) approach. Ph.D. dissertation. University of Honolulu. (124 p, 2.47MB pdf)

Kabir, H. and N. Uphoff. 2007. Results of disseminating the System of Rice Intensification with Farmer Field School methods in northern Myanmar. Experimental Agriculture 43(4):463-476.

Kalyanasundaram, D., R. Vijayabaskar and G. Kuppuswamy. 2005. Weed management under system of rice intensification. Proceedings of the 13th EWRS Symposium, Bari, Italy, 19-23 June 2005. unpaginated.

Kar, S., S.B. Varade, T.K. Subramanyam, and B.P. Ghildyal. 1974. Nature and growth pattern of rice root system under submerged and unsaturated conditions. Il Riso (Italy) 23:173-179.

Karki, K.B.. 2009. Productivity and economic viability of rice under different planting pattern and age of seedlings through System of Rice Intensification (SRI). Master's thesis. Tribhuvan University, Nepal. (107p., 446KB pdf)

Karki, S. 2010. System of Rice Intensification: An analysis of adoption and potential environmental benefits. Master's thesis. Norwegian University of Life Sciences. (80p., 8.65MB)

Karthikeyan, K., Sosamma Jacob and M. Puvaraj. 2008. Incidences of pests in the SRI and normal system of rice cultivation. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore.p 90-91.

Karthikeyan, K., Jacob Sosamma, S.M. Purushothaman. 2010. Incidence of insect pests and natural enemies under SRI method of rice cultivation. Oryza 47 (2) ; 154 - 157

Karuppusamy, P. and Uthamasamy, S., 1984, Influence of flooding, fertilizer and plant spacing on insect pest incidence, Int. Rice Res. Newsl., 9, 17.

Kassam, A., W. Stoop and N. Uphoff. 2011. Review of SRI modifications in rice crop and water management and research issues for making further improvements in agricultural and water productivity. Paddy and Water Environment 9:163-180. doi: 10.1007/s10333-011-0259-1

Katti, G., I.C., Pasalu, T. Ratna Sudhakar, P. rama Mohan Rao, G. Anitha and B.P. Katlam. 2008. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 178-179.

Kazunobu Toriyama & Ho Ando. 2011. Towards an understanding of the high productivity of rice with System of Rice Intensification (SRI) management from the perspectives of soil and plant physiological processes, Soil Science and Plant Nutrition, 57:5, 636-649

Kirk, G. J. D. and Solivas J. L., 1997, On the extent to which root properties and transport through the soil limit nitrogen uptake by lowland rice, Eur. J. Soil Sci, 48, 613-621.

Kokate, K. D., A. K. Singh and Lakhan Singh. 2010. Drought mitigation through knowledge advisory. Indian Research Journal of Extension Education. 10(1):1-7.

Krishna, A., N. K. B. Patil and B. B. Channappagoudar. 2008. Influence of system of rice intensification (SRI) cultivation on seed yield and quality. Karnataka Journal of Agricultural Sciences. 21:369-372.

Krishna, A., N. K. Biradarpatil, K. Manjappa and B. B. Channappagoudar. 2008. Evaluation of system of rice intensification cultivation, seedling age and spacing on seed yield and quality in Samba Masuhri (BPT-5204) rice. Karnataka Journal of Agricultural Sciences. 21:20-25.

Krishna, A., and N. K. Biradarpatil, K. Manjappa and B. B. Channappagoudar. 2009. Influence of methods of cultivation and nutrition on seed storability of BPT-5204 rice variety. Karnataka Journal of Agricultural Sciences. 22:192-193.

Krishna, A., and N. K. Biradarpatil. 2009. Influence of seedling age and spacing on seed yield and quality of short duration rice under system of rice intensification cultivation. Karnataka Journal of Agricultural Sciences. 22:53-55.

Krishnamurthy, A. T., H. K. Basavaraju, V. B. S. Kumar and M. S. Nataraju. 2009. Training need assessment of extension functionaries of Chickmagalur district. Mysore J.Agric.Sci. 43:518-521.

Kulandai Veludaiyar. (1911). Experiments in single planting of paddy. Practical Life 3(2): 84 – 86.

Kumar, M. S., M. Yakadri and Shaik Mohammad. 2006. Evaluation of genotypic responses for system of rice intensification - a novel technology. Plant Archives. 6:329-331.

Kumar, R. M., C. Padmavathi, K. Surekha, P. C. Latha, P. Krishnamurthy and S. P. Singh. 2007. Influence of organic nutrient sources on insect pests and economics of rice production in India. Indian Journal of Plant Protection. 35:264-267.

Lafitte, H.R., and Bennett, J. 2002. 'Requirements for aerobic rice : physiological and molecular considerations', In : Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bindraban, P.S., Tuong, T.P., and Ladha, J.K, eds, Water-wise rice production, Proceedings of the International Workshop on Water-Wise Rice production, International Rice Research Institute, Los Baños, pp 259-274.

Lales, J., A. Corpuz and R. Cruz. 2010. The comparison of system of rice intensification, leaf color chart-based nitrogen management, and growth stage-based nitrogen for yield and ROI. PJCS. 35:50-56.

Latif, M. A., M. Y. Ali, M. R. Islam, M. A. Badshah and M. S. Hasan. 2009. Evaluation of management principles and performance of the System of Rice Intensification (SRI) in Bangladesh. Field Crops Res. 114:255-262. doi:10.1016/j.fcr.2009.08.006

Latif, M.A., M.R. Islam, M.Y. Ali, and M.A. Saleque. 2005. Validation of the system of rice intensification (SRI) in Bangladesh. Field Crops Research 93(2-3):281–292. doi:10.1016/j.fcr.2004.10.005

Li, X., Xu, X. and Li, H. 2005. A socio-economic assessment of the System of Rice Intensification (SRI) : A case study from Xiushang village, Jianyahng County, Sichuan Province, Center for Integrated Agricultural Development, China Agricultural University, Beijing.

Li Jun, Zhou, Zeng Xiang, Liu Yun Kai, Yang Xing Xia, Zhang Xing Huai, Xie Jian Hong, et al. 2005. Demonstrative performance of sparse direct seeding SRI (system of rice intensification) of Liangyou Peijiu. Hybrid Rice. 20:46-48.

Lin X.Q., D.F. Zhu, H.X. Chen, S.H. Cheng and N. Uphoff. 2009, Effect of plant density and nitrogen fertilizer rates on grain yield and nitrogen uptake of hybrid rice (Oryza sativa L.), Journal of Agricultural Biotechnology and Sustainable Development, 1: 44–53.

Lin, X, D. Zhu and X. Lin. 2011. Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics. Paddy and Water Environment 9:33-39. doi: 10.1007/s10333-010-0238-y

Lin, X.Q. 2010. Evaluation of key factors in SRI methods. China National Rice Research Institute workshop, Hangzhou, March (http://www.slideshare.net/SRI.CORNELL/1001-evaluation-of-key-factors-of-sri-method)

Maclean, J.L., D. Dawe, B. Hardy, B. and G.P. Hettel. 2002. Rice Almanac. 3rd Edition, CABI Publishing, Wallingford, UK.

Magdoff, F.R. and D.R. Bouldin. 1970. Nitrogen fixation in submerged soils and energy based on the oxygen flux component. Physiol. Plant, 23: 623-630.

Mahajan, G., and P.S. Sarao. 2009. Evaluation of System of Rice (Oryza sativa L.) Intensification (SRI) in irrigated agro-ecosystem of Punjab. Journal of Research ANGRAU 37(1&2):1-6.

Mahendrakumar, R. K. Surekha, Ch. Padmavathi , P.C. Latha, L.V. Subba Rao, V. Ravindra Babu, M.S. Prasad,. P.Muthu Raman, S. Ravichandran, O.P. Rupela, V.Vinod Goud, S.P. Singh, S.V. Subbiah and B.C. Viraktamath. 2007. Water saving technologies in integrated rice production in India—SRI a viable alternative. In: Gujja, B. et al. (eds). SRI India 2007. Second National Symposium on System of Rice Intensification (SRI) in India-Progress and Prospects. Papers and extended summaries. October 3-5, 2007. Agartala, India.

Mahender Kumar, R. K. Surekha, Ch. Padmavathi , M.S. Prasad,. L.V. Subba Rao, V. Ravindra Babu, P.R. Rao, P.C. Latha, N. Somashekar, B. Nirmala, S.P. Singh, and B.C. Viraktamath . 2008. Evaluation of principles of SRI and its influence on growth parameters and grain yield of rice. In: SRI India 2008. Third National Symposium on System of Rice Intensification in India: policies, institutions and strategies for scaling up. Extended Summaries. December 1-3, 2008. Coimbatore, India.

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

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

Manjunatha, B. N., A. S. P. Patil, J. V. Gowda and V. Paramesh. 2009. Effect of different system of rice intensification on yield, water requirement and water use efficiency (WUE). Journal of Crop and Weed. 5:310-312.

Manjunatha, B. N., A. S. Policepatil, K. N. Harsha and T. Ahmed. 2009. Effect of age of seedlings under different system of rice intensification (SRI). Journal of Crop and Weed. 5:277-280.

Manjunatha, B. N., R. Basavarajappa and B. T. Pujari. 2010. Effect of age of seedlings on growth, yield and water requirement by different system of rice intensification. Karnataka Journal of Agricultural Sciences. 23:231-234.

Mankotia, B. S., J. Shekhar and S. C. Negi. 2006. Performance of rice in SRI (system of rice intensification), ICM (integrated crop management) and conventional transplanting methods with common date of transplanting in the mid hills of HP. Haryana Journal of Agronomy. 22:68-70.

Manonmani, V. 2010. Quality seed production of paddy variety ADT 39 under system of rice intensification (SRI) method. Green Farming. 1:161-162.

Manzano, Virgilio Julius P., Masaru Mizoguchi, Shoichi Mitsuishi and Tetso Ito. 2010. IT field monitoring in a Japanese system of rice intensification (J-SRI). Paddy and Water Environment (SpringerLink Online First, 8 October). doi:10.1007/s10333-010-0226-2

Mao, M., P. Tongdeelert and P. Chumjai. 2008. The adoption of the system of rice intensification (SRI) in Tram Kak District, Takeo Province, Cambodial the case study of leading farmers. Kasetsart Journal, Social Sciences. 29:303-316.

Martí, Orlando. 2011. Evaluación de las modificaciones a la tecnología del Sistema Intensivo del Cultivo del Arroz (SICA) para la producción popular en el municipio Melena del Sur, Provincia Mayabeque. Universidad Agraria de la Habana. (34p., 417KB pdf) [see English language summary]

material media and the aerobic – anaerobic interface. Pl. Soil, 33: 49-61.

Mati, B. M., R. Wanjogu, B. Odongo and P. G. Home. 2011. Introduction of the System of Rice Intensification in Kenya: experiences from Mwea Irrigation Scheme. Paddy and Water Environment 9:145-154. doi:10.1007/s10333-010-0241-3

Matsunaka, S. 1983. Evolution of weed control practices and research : world perspective. Proceedings of the weed control in rice. 31 August-4 September, 1981. IRRI. Los Banos. p 5-18.

Matsushima, S. 1980. Rice Cultivation for the Millions. Japan Scientific Societies Press, Tokyo, 276 p.

Mausbach M., and A. Tugel. 1995: Decision document for establishing a Soil Quality Institute. White Pap. Nat.

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

Mc Hugh, Oloro V. 2002. Growing more rice with less water: Adaptive water management schemes utilized in the System of Rice Intensification (SRI). Master's thesis. Cornell University. (102p., 567KB pdf)

Menete, M.Z.L. 2005. Performance of the System of Rice Intensification (SRI) on salt-affected soils in southern Mozambique. Ph.D. dissertation, Cornell University.

Menete, M.Z.L., H. M. van Es, R.M.L. Brito, S.D. DeGloria and S. Fambab. 2008. Evaluation of system of rice intensification (SRI) component practices and their synergies on salt-affected soils. Field Crops Research 109(1-3):34-44. doi:10.1016/j.fcr.2008.06.003

Meyer, R. 2010. Low-input intensification in agriculture. Chances for small-scale farmers in developing countries. Gaia-Ecological Perspectives for Science and Society. 19:263-268.

Mishra, A. M. Whitten, J. W. Ketelaar and V. M. Salokhe. 2006. The System of Rice Intensification (SRI): a challenge for science, and an opportunity for farmer empowerment towards sustainable agriculture. International Journal of Agricultural Sustainability. 41:93-212.

Mishra, A. and V. M. Salokhe. 2008. Seedling characteristics and the early growth of transplanted rice under different water regimes. Exp. Agric. 44:365-383. doi:10.1017/S0014479708006388

Mishra, A. and V. M. Salokhe. 2010. Flooding stress: The effects of planting pattern and water regime on root morphology, physiology and grain yield of rice. Journal of Agronomy and Crop Science 196(5):368-378. doi:10.1111/j.1439-037X.2010.00421.x

Mishra, A. and V. M. Salokhe. 2011. Rice root growth and physiological responses to SRI water management and implications for crop productivity. Paddy and Water Environment 9:41-52. doi:10.1007/s 10333-010-0240-4

Misra, A.K., S.K. Chaudhary, N.K. Singh and B. Rai. 2007. Comparative studies on the population density of non-target organisms in the SRI and Non-SRI production systems in Bihar. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 102.

Miyazato, T., R. A. Mohammed, and R. C. Lazaro. 2009. Irrigation management transfer (IMT) and system of rice intensification (SRI) practice in the Philippines. Paddy and Water Environment 8(1):91-97. doi:10.1007/s10333-009-0188-4

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

Moser, C. M. and C. B. Barrett. 2006. The complex dynamics of smallholder technology adoption: the case of SRI in Madagascar. Agricultural Economics. 35:373-388.

Mukerji, N.G. 1907. Hand book of Indian Agriculture. Thacker, Spink and Co., Calcutta. 706p

Munda, G.C., Anup das and D.P. Patel. 2007. Performnce of lowland rice as influenced by stand establishment methods and nutrient management practices at mid altitude of Meghalaya. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 92 -93.

MWR. 2006. Report of Sub-Committee on More Crop and Income Per Drop, Advisory Council on Artificial Recharge of Groundwater, Ministry of Water Resources, New Delhi, October (http://www.pib.nic.in/release/release.asp?relid=21113).

NAAS (National Academy of Agricultural Sciences). 2006. Low and declining crop response to fertilizers. Policy Paper No. 35. New Delhi (India): National Academy of Agricultural Sciences. p 8.

NABARD. 2011. Report on System of Rice Intensification (SRI) in Jharkhand. Jharkhand Regional Office, Ranchi.42p.

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

Neung, T., S. N. Thanwalee, T. E. Janice and B. Nantakorn. 2005. Comparison of bacterial activities involved in nitrogen cycling between conventional rice cultivation and the system of rice intensification (SRI). Biological Nitrogen Fixation, Sustainable Agriculture and the Environment. 41:322-322.

Nisha, P.T .2002. Physiological responses of rice hybrids CORH2 and ADTRH1 to integrated crop management techniques. Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Nojima, K. 1960. Studies on the intercultivation in rice field. A historical review and confirmation of the theories on the intercultivation. J. Kanto-Tosan Agric. Expt. Sta. 17:14-114.

Nyarko, K.A. and S.K. De Datta. 1991. A handbook of weed control. International Rice Research Institute, Los Banos, Lhilippines 113p.

Orr, S., J. Sumberg, O. Erenstein and A. Oswald. 2008. Funding international agricultural research and the need to be noticed A case study of NERICA rice. Outlook Agric. 37:159-168. doi:10.5367/000000008785915449

Padmavathi, Ch., R. Mahender Kumar, K. Surekha, P.C. Latha, L.V. Subba Rao, M.S. Prasad, V. Ravindra Babu, J.S. Prasad, O.P. Rupela, V. Vinod Goud, I.C. Pasalu and B.C. Viraktamath. 2007. Insect-pest dynamics and anthropod diversity in SRI and conventional methods of rice cultivation. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 89-91.

Padmavathi, Ch., R.Mahendrakumar, A. Ravindra and R. Lingaiah. 2008. Influence of SRI on pesticide in rice. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 1-2.

Padmavathi, Ch., R. Mahender Kumar, L.V. Subba Rao , K. Surekha, P.C. Latha, M.S. Prasad, V. Ravindra Babu, and I.C. Pasalu. 2009. Influence of SRI method of rice cultivation on insect pest incidence and arthropod diversity. Oryza 46(3): 227-230.

Padmavathi, Ch., and R. Mahender Kumar. 2011. Insect pest scenario in SRI method of rice cultivation and their management. Lecture Notes. Training on 'Rice Production with System of Rice Intensification, AgSri-NABARD. Hyderabad. June, 2011

Paggi, M.S. and F. Yamazaki. 2001. The WTO and International Trade Prospects : Rice. Executive Seminar On Agricultural Issues. University of California. December 10, 2001. (http://aic.ucdavis.edu/oa/paggi.pdf)

Panda, D. 2005. Chemistry of nitrogen transformation in submerged soil and scientific management of urea fertilizer for higher rice productivity. Journal of the Indian Society of Soil Science. 53:500-513.

Pandey, S. 2009. Effect of weed control methods on rice cultivars under the System of Rice Intensification (SRI). Master's thesis. Tribhuvan University, Nepal. (876 KB pdf)

Pandiselvi, T., R. Veeraputhiran, V. Ganesaraja, J. P. Priya and B. J. Pandian. 2010. Productivity, water use efficiency and economics of system of rice intensification in Sivagangai district of Tamil Nadu. International Journal of Agricultural Sciences. 6:138-140.

Parthasarathi, M. and N.S. Negi. 1977. Control of rice weeds with butachlor. In: Proceedings of Weed Science Conference. Indian Society of Weed Science, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad, India. pp. 179-180.

Parthasarathy, N.1963. 'Some facts about rice', IRC News Letter, Special issue, pp 1-16.

Pasuquin, E., T. Lafarge, and B. Tubana. 2008. Transplanting young seedlings in irrigated rice fields : early and high tiller production enhanced grain yield. Field Crops Res. 105 : 141-155.

Patwardhan, S.M., and S.M. Patel. 2008. Promotion of System of Rice Intensification (SRI) in rainfed rice cultivation amongst farmers of Dangs Distrcit of Gujarat. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 85-87.

Prasad, J.S., Ch. Padmavathi, R. Mahendrakumar and L.V. Subba Rao. 2007. Are nematodes in SRI. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 100-101.

Prasad J.S., Somasekher N. and Kumar R.M., 2008. Nematological considerations in SRI method of rice production. In: Extended summaries of 3rd National Symposium of Rice Intensification in India, December 1-3, 2008, Tamil Nadu Agricultural University, Coimbatore, India, pp.160-162.

Priya, J. P., R. Veeraputhiran, V. Ganesaraja, T. Pandiselvi and B. J. Pandian. 2010. Comparative study of system of rice intensification and conventional method of rice cultivation in Madurai district of Tamil Nadu. International Journal of Agricultural Sciences. 6:186-188.

Radha, T.M., Rajendra Hegde and M. Ram Prasad. 2007. An improving resource use efficiency through RI – A CASE OF Madanapalli. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 158 – 161.

Rahman, A. B. M. Z., M. A. Haque, M. A. Hoque, M. S. Pervin and Q. A. Alam. 2006. Evaluation of System of Rice Intensification (SRI) practice for boro rice cultivation in some selected areas of Bangladesh. International Journal of Sustainable Agricultural Technology. 2:24-27.

Rajaonarison, Jean de Dieu. 2000. Contribution a l'amelioration des redements de 2ème saison de la double riziculture par SRI sous experimentations multifactorielles. Memoire de Fin d'Etudes (thesis). University of Antananarivo, Madagascar. (French)

Rajendran, R., V. Ravi, S. Ramanathan, B. Chandrasekaran, T. Jayaraj and V. Balasubramanian. 2005. Evalaution of selected crop management components for enhancing rice productivity and profitability in Tamil Nadu, India. In : pages 39-44. T.M. Thiyagarajan, H. Hengsdijk and P.S. Bindraban (eds). Transitions in agriculture for enhancing water productivity. Proceedings of an International symposium held in Killikulam, Tamil Nadu, India, September 23-25, 2003,, Killikulam, Tamil Nadu, India.

Rajeshwar, M. and M. A. A. Khan. 2008. Comparison of System of Rice Intensification (SRI) and conventional method of rice planting under Nagarjuna Sagar project left canal command area of Andhra Pradesh, India. Asian Journal of Soil Science. 3:53-57.

Rakesh Sharma, R.D. Singh and K.D. Sharma. 2005. Water resources of India. Current Science. 89 : 794-811

Ramamoorthy. K., 2004. Effect of square planting and mechanical weeding on the growth and yield of rice. M.Sc.(Ag.) Thesis submitted to the Tamil Nadu Agricultural University, Coimbatore.

Ramasamy, S., H.F.M. ten Berge and S. Purushothaman, 1997. Yield formation in rice in response to drainage and nitrogen application. Field crops Res., 51: 65-82.

Ramiah, R. V. 1954. Weed your rice with these weeders. Indian Farming 4(18):7-30.

Randriamiharisoa, R., J. Barison and N. Uphoff. 2006. Soil biological contributions to the system of rice intensification. Biological Approaches to Sustainable Soil Systems. 113:409-424.

Rao, K.S., Annie poonam, A. Ghosh, P.C. MOhapatra, and M.P. Pandey. 2007. Present status of SRI research at CRRI, Cuttack, India. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 35 – 37.

Ravi, G., R. Rajendran, N. Raju, K. Chozhan and V. Muralidharan. 2007. Insect pest scenario in irrigated rice grown under SRI method of cultivation. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 94-95.

Ravindra, A, and S. Bhagya Laxmi. 2011. Potential of the system of rice intensification for systemic improvement in rice production and water use: the case of Andhra Pradesh, India. Paddy and Water Environment 9:89-97. doi: 10.1111/j.1439-037X.2010.00421.x [NOTE: Erratum to this article have been published during Feb. 2011 at DOI:10.1007/s10333-011-0255-5]

Reddy, G. K., M. Yakadri and Shaik Mohammad. 2007. Grain yield of cultivars as influenced by different spacing under SRI (System of Rice Intensification). Journal of Research ANGRAU. 35:74-77.

Reddy, V. R., P. P. Reddy, M. S. Reddy and D. S. R. Raju. 2005. Water use efficiency: a study of system of rice intensification (SRI) adoption in Andhra Pradesh. Indian J.Agric.Econ. 60:458-472.

Reddy, Y. R., Tariq Sultan, Shijhat Hussain and S. S. Singh. 2008. Effect of age and number of seedlings per hill on growth and yield of rice grown under system of rice intensification and traditional methods. Environmental Ecology 26:859-861.

Reissig W. H., Heinrichs E. R.A., Litsinger J. A., Moody K., Fiedler, L., Mew, T. W. and Barrion, A.T., 1986, Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia, International Rice Research Institute, Philippines. 411 pp.

Rupela, O.P., S.P. Wani, M. Kranthi, P. Humayun, A. Satyanarayana, V. Goud, B. Gujja, P. Punnarao, V. Shashibhushan, D.J. Raju and P.L. Reddy. 2006. Comparing soil properties of farmers' fields growing rice by SRI and conventional methods. In Proceedings of 1st National SRI Symposium, Worldwide Fund for Nature-ICRISAT, Patancheru, Hyderabad, 17-18 November.

Saha, Anuradha and Vijay Bharti. 2010. Effect of different crop establishment methods on growth, yield and economics of rice (Oryza sativa L.). Environmental Ecology 28(1B):519-522.

Saina, T. and N. Uphoff. 2001. More rice with less water. Appropriate Technology. 28:8-11.

Sandhu, B.S., Khera, K.L., Prihar, S.S. and Singh, B. (1980). Irrigation needs and yield of rice on a sandy-loam soil as affected by continuous and intermittent submergence. Ind. J. Agric. Sci. 50: 492-496.

Sasaki, Ryouji. 2004. Caracteristics and Seedling Establishment of Rice Nursling Seedlings. Japan Agricultural Research Quarterly (JARQ) 38 (1): 7-13.

Sato, S. and N. Uphoff. 2007. A review of on-farm evaluations of system of rice intensification methods in Eastern Indonesia. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. 212 pp.

Sato, S., E.Yamaji, and T. Kuroda. 2011. Strategies and engineering adaptions to disseminate SRI methods in large-scale irrigation systems in Eastern Indonesia. Paddy and Water Environment 9:79-88. doi:10.1007/s10333-010-0242-2

Satyanarayana, A. 2004. Rice, research and real life in the field. Nature 429: 803

Satyanarayana, A., T. M. Thiyagarajan and Norman Uphoff. 2007. Opportunities for water saving with higher yield from the system of rice intensification. Irrigation Science 25(2):99-11. doi:10.1007/s00271-006-0038-8

Seenivasan, N., P. M. M. David and P. Vivekanandan. 2010. Population dynamics of rice nematodes under a System of Rice Intensification. Nematologia Mediterranea. 38:159-163.

Seenivasan, N. 2011. Efficacy of Pseudomonas fluorescens and Paecilomyces lilacinus against Meloidogyne graminicola infecting rice under system of rice intensification. Archives Of Phytopathology And Plant Protection.44(15):1467-1482

Seko, H. and M. Kuki. 1956. Studies on the effects of intercultivation in paddy fields. 1. On the plant growth and yield of paddy rice affected by intercultivation. B. Div. Plant Breeding Cult. Tokai-Kinki Nat. Agric. Expt. Sta. 3:31-55.

Sen, D., S.P. Chaturvedi, H. Bharti, and R. Bansal. 2007. Promoting System of Rice Intensification among marginal farmers of Uttrarakhand and Himachal Pradesh. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p147 -150.

Senthilkumar, K., P. Bindraban and T. M. Thiyagarajan. 2008. 'Modified rice cultivation in Tamil Nadu, India: Yield gains and farmers (lack of) acceptance. Agricultural Systems 98:82-94.

Shaik, Mohammad. 2009. Modern concepts of agricultural research: ripples and options for conservation agriculture and resource use efficiency. Indian Journal of Agronomy. 54:149-158.

Shambu Prasad, C. 2006. System of Rice Intensification in India: Innovation History and Institutional Challenges. WWF Project 'Dialogue on water, Food and Environment', ICRISAT, Hyderabad & Xavier Institute of Management, Bhubaneswar. 75p.

Shambu Prasad, C. 2007. Rethinking innovation and development: Insights from the System of Rice Intensification (SRI) in India. The Public Sector Innovation Journal, Volume 12(2), 2007, article 3, http://www.innovation.cc/peer-reviewed/prasad_p2rethinking_innovat3.pdf

Shambu Prasad, C. 2008. Jai Sri: Celebrating civil society involvement in SRI in India. Presentation at the 3rd National Symposium on SRI held at Tamil Nadu Agricultural University, Coimbatore, December 3-5.

Shambu Prasad, C., D. Mohapatra and P. Mishra. 2008. Strengthening the Learning Alliance : Scaling up options for SRI in Orissa. Xavier Institute of Management, Bhubaneswar, Orissa. 57p

Sharif, Asif. 2011. Technical adaptations for mechanized SRI production to achieve water saving and increased profitability in Punjab, Pakistan. Paddy and Water Environment 9:111-119.doi:10.1007/s10333-010-0223-5

Sheehy, J. E., S. Peng, A. Dobermann, P. L. Mitchell, A. Ferrer, J. C. Yang, et al. 2004. Fantastic yields in the system of rice intensification: fact or fallacy? Field Crops Res. 88:1-8.

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

Shekhar, J., B. S. Mankotia and S. P. Dev. 2009. Productivity and economics of rice (Oryza sativa) in system of rice intensification in North-Western Himalayas. Indian Journal of Agronomy. 54:423-427.

Shui Xiao, Chen (et al). 2006. The effects of plant density on the yield of Yongyou6 using the System of Rice Intensification (SRI). China Rice. 22.

Shukla, V. D. and Anjaneyulu, A., 1981, Plant spacing to reduce rice tungro incidence. Plant Dis., 65, 58 -586.

Sinclair, T. R. and K. G. Cassman. 2004. Agronomic UFOs. Field Crops Res. 88:9-10.

Singh, V.P. and Singh, R.K. 2000. Rainfed rice: a sourcebook of best practices and strategies in eastern India. IRRI, Los Baños, Laguna. 292 p.

Singh, A.K., A.K. Singh, C.S. Singh, and Rabindra Prasad. 2008. Agronomic evaluation of different methods of rice establishment under medium land situation of Jharkhand. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 141 – 143.

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

Singh, S. S. and Pandey, V., 1997, Integrated approach for management of rice yellow stem borer, Scirpophaga incertulas. Indian J. Ent., 59, 164-169.

Sinha, B.B.P., and A. Kumar. 2007. Less incidence of sheath blight disease and higher grain yield under SRI. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 98-99.

Sinha, S. K. and J. Talati. 2007. Productivity impacts of the system of rice intensification (SRI): A case study in West Bengal, India. Agricultural Water Management. 87:55-60.

Sivasubramanian, T. 1961. Agricultural trends in Tanjore district. Madras Agricultural Journal 48: 255-258.

Sooksa-nguan, T., J. E. Thies, P. Gypmantasiri, N. Boonkerd and N. Teaumroong. 2009. Effect of rice cultivation systems on nitrogen cycling and nitrifying bacterial community structure. Applied Soil Ecology. 43:139-149. doi:10.1016/j.apsoil.2009.06.013

Sooksa-Nguan, T., P. Gypmantasiri, N.rn Boonkerd, J.E. Thies, and N. Teaumroong. Changes in bacterial community composition in the System of Rice Intensification (SRI) in Chiang Mai, Thailand. Microbes and Environments 23(3):224-227. doi:10.1264/jsme2.ME09184

SRI Secretariat. 2011. Integrated Disease Pest management in SRI Paddy. SRI Secretariat, Bhubaneshwar. 24p.

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

Srinivasa Rao, I., P. Punna Rao and P. Gidda Reddy. 2007. Force field analysis in System of Rice Intensification in Andhra Pradesh. (eds) Gujja, B., Goud, V.V., Kumar, R.M., Rao, P.P., Prasad, C.S., and Shib, S. Second National Symposium on System of Rice Intensification (SRI) in India – Progress and prespects. Papers and Extended summaries. 3-5, October 2007. Agartala, India. p155.

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

Stoop, W. A. and A. H. Kassam. 2005. The SRI controversy: a response. Field Crops Research. 91(2-3):357-360. doi:10.1016/j.fcr.2004.07.023

Stoop, W. A., A. Adam and A. Kassam. 2009. Comparing rice production systems: A challenge for agronomic research and for the dissemination of knowledge-intensive farming practices. Agric.Water Manage. 96:1491-1501. doi:10.1016/j.agwat.2009.06.022

Stoop, W.A., A. Adam and A. Kassam. 2009. Comparing rice production systems: A challenge for agronomic research and for the dissemination of knowledge-intensive farming practices. Agricultural Water Management, 96: 1491-1501.

Stout, B.A. (1966), Equipment for rice cultivation. FAO. Rome. 169p.

Styger, E., G. Aboubacrine, M. Attaher, and N. Uphoff. 2011. The system of rice intensification as a sustainable agricultural innovation: introducing, adapting and scaling up a system of rice intensification practices in the Timbuktu region of Mali. International Journal of Agricultural Sustainability 9:67-75. doi:10.3763/ijas.2010.0549

Styger, E., M. Attaher, H. Guindo, H. Ibrahim, M. Diaty, I. Abba and M. Traore. 2011. Application of system of rice intensification practices in the arid environment of the Timbuktu region in Mali. Paddy and Water Environment 9:137-144. doi:10.1007/s10333-010-0237-z

Subba Rao L.V., R. Mahender Kumar, U. Chaitanta, Ch. Padmavathi, K. Surekha, P.C. Latha, M.S. Prasad, V. Ravindra Babu, J.S. Prasad, O.P. Rupela, V. Viod Goud, N. Shoba Rani, and B.C. Viraktamath. 2007. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 112 – 114.

Karki, S. 2010. System of Rice Intensification : an analysis of adoption and potential environmental benefits. Masters Thesis submitted to Norwegian University of Life Sciences, Norway.

Sudhalakshmi, C., V.Velu and T.M.Thiyagarajan. 2007. Redox potential in the rhizosphere soil of rice hybrids as mediated by crop management options. Research Journal of Agriculture and Biological Sciences. 3(4) : 299 -301

Sumathi, E., M. Gnanachitra, T.M. Thiyagarajan and V. Jayabal. 2008. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 176-177.

Surridge, C., 2004) Rice cultivation: Feast or famine? Nature 428:360-361

Surya Prabha, A.C., T.M. Thiyagarajan and M. Senthivelu. 2011. System of Rice Intensification principles on growth parameters, yield attributes and yields of rice (Oryza sativa L.). Journal of Agronomy. 10(1):27-33. doi:10.3923/ja.2011.27.33

Tanaka, A., 1958: Studies on the characteristics of physiological functions of the leaf at a definite position on a stem of the rice plant: accumulation of carbohydrate in the leaf at a definite position. J. Sci. Soil Manure 29, 291–294.

Tandon, H.L.S. 1996. Organic resources: an assessment of potential supplies, their contribution to agricultural productivity, and policy issues for Indian agriculture from 2000 to 2025. Kanwar, J.S. and Katyal, J.C. (Eds.) Proc. Symp. Plant Nutrient Needs, Supply, Efficiency and Policy Issues: 2000-2025. NAAS, New Delhi, pp.17.

Tao, L., Xi Wang and Min Shaokai, 2002, Physiological effects of SRI methods on the rice plant. In Assessment of the System of Rice Intensification (SRI), Uphoff, N., Fernandes, E., Long Pin, Y., Jiming, P., Sebastein, R. and Rabenanadrasana, J., (eds.) Proceedings of an International Conference, Sanya, China, April 1-4, 2002, Ithaca, NY, CIIFAD, pp 132-139.

Tewari, A. and B. Barai. 2007. System of Rice Intensification in Basmati. : A win-win situation for farmers and rice processors. In : Papers and extended Summaries. SRI India 2007-Second National Symposium on System of Rice Intensification in India –Progress and prospects. October 3-5, 2007. Agartala, Tripura, India. p 143 – 146.

Thakkar, H. 2008. Future water solutions for India. Development (London). 51:68-71. doi:10.1057/palgrave.development.1100463

Thakur, A. K., S. K. Chaudhari, R. Singh and A. Kumar. 2009. Performance of rice varieties at different spacing grown by the system of rice intensification in eastern India. Indian J.Agric.Sci. 79:443-447.

Thakur, A. K. , S. Rath, S. Roychowdhury, N. Uphoff. 2010. Comparative performance of rice with System of Rice Intensification (SRI) and conventional management using different plant spacings. Journal of Agronomy and Crop Science. 196(2):146-159. doi:10.1111/j.1439-037X.2009.00406.x

Thakur, A. K., N. Uphoff and E. Antony. 2010. An assessment of physiological effects of System of Rice Intensification (SRI) practices compared with recommended rice cultivation practices in India. Experimental Agriculture 46:77-98. doi:10.1017/S0014479709990548

Thakur, A.K., N. Uphoff and E. Antony. 2010. An assessment of physiological effects of System of Rice Intensification (SRI) practices compared with r3ecommended rice cultivation practices in India. Exptl. Agric. 46:77-98.

Thakur, A.K. 2010. Critiquing SRI criticism: beyond scepticism with empiricism. Current Science 98(10):1294-1299.

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

Thakur, A.K., S. Rath, D. U. Patil and A. Kumar. 2011. Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. Paddy and Water Environment 9:13-24. doi:10.1111/j.s10333-010-0236-0

Thakur, A.Kumar, S.Ratha and A. Kumara. 2011. Performance evaluation of rice varieties under the System of Rice Intensification compared with the conventional transplanting system. Archives of Agronomy and Soil Science 57(3):223-238 doi:10.1080/03650340903302302

Thies, J.E. 2006. Measuring and assessing soil biological properties. In : Norman Uphoff et al. (eds). Biological approaches to sustainable soil systems. Taylor & Francis. pp 655 – 670.

Thies, J.E., and J.M. Grossman. 2006. The soil habitat and soil ecology. In : Norman Uphoff et al. (eds). Biological approaches to sustainable soil systems. Taylor & Francis. pp 59 – 78.

Thiyagarajan, T.M., V. Velu, S. Ramasamy, D. Durgadevi, K. Govindarajan, R. Priyadardhini, C. Sudhalakshmi, K. Senthilkumar, P.T. Nisha, G. Gayathry, H. Hengsdijk and P.S. Bindraban. 2002. Effects of SRI practices on hybrid rice performance in Tamil Nadu, India. In: B.A.M. Bouman, H. Hengsdijk, H. Hardy, B. Bindraban, P.S. Tuong, and J.K. Ladha (Eds). Water-wise Rice Production: Proceedings of the International Workshop on Water-wise Rice Production, April 8-11, 2002, pp 119-127. IRRI, Los Baños, Philippines.

Thiyagarajan, T.M. 2004. On-Farm Evaluation of SRI in Tamiraparani Command Area, Tamil Nadu, India. Powerpoint presentation to World Rice Research Conference, Tsukuba, Japan, November (http://ciifad.cornell.edu/sri/wrrc/wrrcppts/wrintnseveraju.ppt).

Thiyagarajan, T.M., K. Senthilkumar, R. Priyadarshini, J. Sundarsingh, A. Muthusankara-narayanan, H. Hengsdijk and P.S. Bindraban. 2005. Evaluation of water saving irrigation and weeder use on the growth and yield of rice. In: T.M. Thiyagarajan, H. Hengsdijk, and P.S. Bindraban (eds). Transitions in Agriculture for Enhancing Water Productivity: Proceedings of an International Symposium held in Killikulam, Tamil Nadu, India, September 23-25, 2003, pp 3-18. Tamil Nadu Agricultural University, Coimbatore, and Plant Research International, Wageningen, Netherlands.

Thiyagarajan, T.M. and Biksham Gujja. 2009. Single Seedling Planting and Gaja Planting : Century Old Practices in Tamil Nadu, India and Similarity to the Principles of SRI. SRI Newsletter 6: 2-27. ICRISAT-WWF Project, ICRISAT, Patancheru, Andhra Pradesh.

Thiyagarajan, T.M., B.J. Pandian, and M. Ranghaswami. 2009. Principles and practices of SRI in Tamil Nadu. Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore. 44p.

Thomas, V. and A.M. Ramzi. 2011. SRI contributions to rice production dealing with water management constraints in northeastern Afghanistan. Paddy and Water Environment 9:101-109. doi:10.1007/s10333-010-0228-0

Thura, S. 2010. Evaluation of weed management practices in the System of Rice Intensification (SRI). Master's thesis. Yezin Agricultural University, Myanmar. (89p., 770KB)

TildaRicelands Pvt. Ltd. 2008. Promotion of SRI with Basmati Rice. PPT presented to 3rd National SRI Conference, Coimbatore (http://www.slideshare.net/SRI.CORNELL/0854-welcome-to-the-world-of-tilda-promotion-of-sri-with-basmati-rice-in-haryana)

Turmel, Marie-Soleil, Benjamin L. Turner, and Joann K. Whalen. 2011. Soil fertility and the yield response to the System of Rice Intensification. Renewable Agriculture and Food Systems 26(3):185–19. doi:10.1017/S174217051100007X

Turner, B. L. 2006. Organic phosphorus in Madagascan rice soils. Geoderma. 136:279-288.

Uma, A., S.C. Ahuja, T. Rashmi and R.K. Singh. 2008. Rice – A Nutraceutical. Asian Agri-History Vol. 12 : 93–108

University of Reading. 2007. Food crops in India in a changing climate. Walker Institute Research. http://www.walker-institute.ac.uk/publications/factsheets/walker_factsheet_crops.pdf

Uphoff, N.. 1999. Agroecological implications of the System of Rice Intensification (SRI) in Madagascar. Environment, Development and Sustainability 1(3/4):297-31.

Uphoff, N. 2001. Understanding SRI? Appr.Technol. 2811-11-13

Uphoff, N. 2002. System of Rice Intensification (SRI) for enhancing the productivity of land, labour and water. J. Agric. Res. Manage. 1: 43-49.

Uphoff, N. 2003. Higher yields with fewer external inputs? The system of rice intensification and potential contributions to agricultural sustainability. International Journal of Agricultural Sustainability. 1:38-50.

Uphoff, N. 2008.   What is SRI? Some considerations. Presentation at the 3rd National Symposium on SRI held at Tamil Nadu Agricultural University, Coimbatore, December 3-5, http://sri-india.110mb.com/documents/3rd_symposium_ppts/Uphoff.pdf.

Uphoff, N. and A. Kassam. 2009. Case Study: "The system of rice intensification" (IP/A/STOA/FWC/2005-28/SC42), Annex 3 in European Parliament: Science and Technology Options Assessment (STOA) Agricultural Technologies for Developing Countries. 57p.

Uphoff, N., A. Kassam and W. Stoop. 2008. A critical assessment of a desk study comparing crop production systems: The example of the 'system of rice intensification' versus 'best management practice'. Field Crops Research 108:109-114. doi:10.1016/j.fcr.2007.12.016

Uphoff, N., and A. Kassam. 2009. System of rice intensification. Agriculture for Development. 10-14.

Uphoff, N., I. Anas, O. P. Rupela, A. K. Thakur and T. M. Thiyagarajan. 2009. Learning about positive plant-microbial interactions from the System of Rice Intensification (SRI). Aspects of Applied Biology 98:29-53.

Uphoff, N. 2011. The System of Rice Intensification: An Alternate civil society innovation. Technikfolgenabschätzung – Theorie und Praxis 2:45-52

Uphoff, N., A. Kassam and R. Harwood. 2011. SRI as a methodology for raising crop and water productivity: productive adaptations in rice agronomy and irrigation water management. Paddy and Water Environment 9:3-11. doi:10.1007/s10333-010-0224-4

Uyloan, John Terrence M. 2008. Agronomic, morphological, and physiological differences of lowland rice grown under System of Rice Intensification (SRI) and conventional production system using three methods of fertilization. Master's thesis, University of the Philippines at Los Baños. [accessible from the International Rice Research Institute Library - SB218 .U59 2008]

Vaidyalingam Pillai. 1911. Row planting. Practical Life. 3 (7) : 347 – 349.

van der Maden, Edwin. 2006. Beyond technological solutions: Farmers, water and the introduction of the System of Rice Intensification in the Tambiraparani river basin, Tamil Nadu, India. MSc. thesis, Wageningen University. (114p., 3.24MB pdf)

Vannak Meas, Daniel Shon and Young Han Lee. 2011. Effects on Rice Growth of System of Rice Intensification under No-till Paddy in Korea. Korean Journal of Soil Fertility. 44(1):91-97.

Veeramani, P. 2011. Enhancement of mat nursery management and planting pattern (using rolling markers) in System of Rice Intensification (SRI) technique. Research Journal of Agricultural Sciences. 2(2):371-375. [Article by the same title published in the Libyan Agriculture Research Center Journal International 1(5): 279-283]

Veeramani, P. and R. D. Singh. 2010. System of rice intensification in hybrid rice - a review. Agricultural Reviews. 32(1):32-35.

Venkatasubramanian, M.K. 1958. Line planting and intercultivation rice. Madras Agric. J. 45(4):153-154.

Venugopal Rao, N. V, Prakasa Rao, L. V, Krishnamurthy Rao, B. H. and Subbarami Reddy, P., 1982, Note on the effect of cultural practice on the incidence of insect pests of rice, Indian J. Agric. Sci. 52, 48-50.

Vijayabaskaran, S. and A.K. Mani. 2008. System of Rice Intensification : A boon for saving on labour. In : Extended summaries of the Third National Symposiun on System of Rice Intensification in India-Policies, Institutions and Strategies for Scaling up. 1-3 December, 2008. Tamil Nadu Agricultural University, Coimbatore. p 148 - 150.

Vijayakumar M., S. D. Sundar Singh, N. K. Prabhakaran, and T. M. Thiyagarajan 2005. Effect of SRI (System of Rice Intensification) practices on the yield attributes, yield and water productivity of rice (Oryza sativa L.). Acta Agronomica Hungarica 52(4):399-408.

Vijayakumar, M., S. Ramesh, B. Chandrasekaran and T. M. Thiyagarajan. 2006. Effect of System of Rice Intensification (SRI) practices on yield attributes, yield and water productivity of rice (Oryza Sativa L .). Research Journal of Agriculture and Biological Sciences 2(6): 236-242.

Vijayakumar, M., S. Ramesh, N. K. Prabhakaran, P. Subbian and B. Chandrasekaran. 2006. Influence of system of rice intensification (SRI) practices on growth characters, days to flowering, growth analysis and labour productivity of rice. Asian Journal of Plant Sciences. 5:984-989.

Wijebandara, D. M. D. I., G. S. Dasog, P. L. Patil and M. Hebbar. 2009. Effect of nutrient levels and biofertilizer on growth and yield of paddy under System of Rice Intensification (SRI) and conventional methods of cultivation. Tropical Agricultural Research. 20:343-353.

Wijebandara, D. M. D. I., G. S. Dasog, P. L. Patil and Manjunath Hebbar. 2009. Response of rice to nutrients and bio fertilizers under conventional and system of rice intensification methods of cultivation in Tungabhadra command of Karnataka. Karnataka Journal of Agricultural Sciences. 22:741-750.

Weijabhandara, D.M.D.I, , G.S. Dasog, P.L. Patil, Manjunath Hebbar. 2011. Effect of nutrient levels on rice (Oryza sativa L.) under System of Rice Intensification (SRI) and traditional methods of cultivation. Journal of the Indian Society of Soil Science Year. 59(1).

Wolfe, D. 2006. Approaches to monitoring soil systems. In : Norman Uphoff et al. (eds). Biological approaches to sustainable soil systems. Taylor & Francis. pp 671 – 681

World Bank Institute. 2008. SRI, achieving more with less: a new way of rice cultivation. http://web.worldbank.org/WBSITE/EXTERNAL/WBI/WBIPROGRAMS/WBIWATER/0,,contentMDK:21953509~pagePK:64156158~piPK:64152884~theSitePK:443986,00.html

WWF (World Wildlife Fund). 2007. More rice with less water: System of Rice Intensification www.panda.org

Xin Lu, Jiang, Zheng Jia Guo, Chi Zhong Zhi, He Shu Lin and Wang Shao Hua. 2009. Study on nitrogen regulation of the system of rice intensification (SRI) of hybrid rice. Southwest China Journal of Agricultural Sciences. 22(4):996-1000.

Xiu Ming, Lu, Huang Qing, Liu Jun and Liu Huai Zhen. 2004. Research of the experiment on the system of rice intensification. Journal of South China Agricultural University. 25:5-8

Xu, Long, Wang Ren-quan, Sun Yong-jian and Ma Jun. 2010. Characteristics of population development and yield formation of rice under triangle-planted System of Rice Intensification at different nitrogen application amounts. Zhongguo Shuidao Kexue (Chinese Journal of Rice Science). 24:162-168. doi:10.3969/j.issn.1001-7216.2010.02.10

Xu Hui, Wang, Yang Xiang Tian, Luo San Zhuo, Mao Guo Juan and Tao Dong En. 2006. Application of system of rice intensification (SRI) to single cropping rice in Taizhou, Zhejiang. Hybrid Rice. 21:45-47.

Yadao, A. C. and O. B. Zamora. 2007. Responses of rice under the system of rice intensification and conventional production systems in Ilocos Norte, Philippines. Philippine Journal of Crop Science. 32:99-107.

Yuying, Wang, Zhu Bo, Wang Yanqiang, Gao Meirong and Ma Xiumei. 2006. N2O emission from paddy field under different rice planting modes. Wuhan Univ.J.Nat.Sci. 11:989-996.

Zeigler, R.S., Dobermann, A., and Mackill, D. (2008), 'Rice science: Key to food security and environmental health in a changing world', Website :
http://beta.irri.org/news/bulletin/2008.15/PDFs/ICSC%20ZeiglerPaper-Final_Feb-06.pdf

Zhao, L., L. Wu, Y. Li, X. Lu, D. Zhu and N. Uphoff. 2009. Influence of the System of Rice Intensification on rice yield and nitrogen and water use efficiency with different N application rates. Experimental Agriculture 45: 275–286. doi:10.1017/S0014479709007583

Zhao, L., L. Wu, Y. Li, S. Animesh, D. Zhu, and N. Uphoff. 2010. Comparisons of yield, water use efficiency, and soil microbial biomass as affected by the System of Rice Intensification. Communications in Soil Science and Plant Analysis 41(1):1-12. doi:10.1080/00103620903360247

Zhao, L., L. Wu, M. Wu and Y. Li. 2011. Nutrient uptake and water use efficiency as affected by modified rice cultivation methods with reduced irrigation. Paddy and Water Environment 9:25-32. doi:10.1007/s10333-011-0257-3

Zonde, N.G., V.V. Goud, M.K. Rathod. 2008. System of Rice Intensification Modified for Eastern Zone of Vidarbha. Annals of Plant Physiology. 22:140-141.

AgSri

AgSri is a social enterprise focused on providing solutions in the agriculture sector for improving the farm productivity and income, while reducing the inputs costs. We are working towards promoting industry-friendly policies favoring green technologies. Our concept of "More with Less" in Agriculture offers newer options for farmers and companies to adapt to simple, but integrated methods for improving the productivity while reducing the usage of seed, water, fertilizers and pesticides. The focus of our work is to support governments, farmer groups, companies and aid agencies - working on the global concern for food and water security and environment protection - on crop advisory, water management, irrigation, fertilizer and pest management, environment impact assessments and technology solutions in farm management. AgSri is significantly contributing to environment sustainability in the world through agri-business committed to sustainable agriculture.

AgSri Team Our strength is our highly experienced team who have previously worked with various International organizations and have significantly contributed in the areas of agriculture, water policy, rural development and social sector for more than three decades. Some of the members of our team have been duly credited for promoting sustainable methodologies in rice, sugarcane, wheat and other crops and for their significant contribution in other areas in the development sector. The team includes experts from the field of Agriculture, Agri-business, Forestry, Geology, GIS Hydrology, Human Resources, Soils Sciences, Rural Development and Social Sector.

What We Do AgSri offers services as consultants, as well as, on partnership basis for agriculture projects of various scope, size and resources. We offer consultancy for piloting innovative agriculture projects for governments, multilateral aid agencies and corporate companies, cutting across diverse crops and climate zones. Some of the areas AgSri can significantly contribute are:

- Optimize crop management systems in rice,sugarcane and others crops to produce more with custom inputs in diverse climatic zones
- Design large-scale interventions in collaboration with multilateral agencies to maximize economic benefits for farmers and industry
- Specifically provide solutions for water intensive crops without compromising on the yields
- Set-up process for traceability of the production process for the companies
- Provide guidelines and implementation of certification process for major crops such as sugarcane, cotton, rice, wheat, etc.
- Reduce the footprint of agriculture sector, while improving the income of the farmers and bringing profits to industry and providing quality products to the consumers

Knowledge Resources India's growing food industry is facing crisis of human resources owing to modern technological developments. AgSri School is working towards meeting the expertise required to meet the agriculture industry's human resources needs. In collaboration with NRMC (NABARD), AgSri is building a human resources pool who will work with farmers' cooperatives and agricultural industries in implementing the sustainable green technologies, successfully.

International Exposure AgSri's unique International experience and partnership has opened up new vistas for food industry in India and globally. AgSri with Nestle International will be soon designing and implementing Responsible Source Guidelines (RSG). With Cambodian industry, AgSri is promoting SSI in South East Asia. And, SSI has also found admirers among the Cuban Cane Cooperatives too. As part of South- South Cooperation's Initiative to address the global food crisis, AgSri made exploratory visits to Tanzania, Ethiopia and Sierra Leone at the request of Indian and Global companies for introducing sustainable crop and water saving technologies.

AgSri Partners AgSri has a long standing tradition of partnership with farmers for their prosperity. Globally and in India, AgSri has joined Nestle International, Solidaridad, Triveni Sugars, National Bank for Rural Development (NABARD), Driptech USA and National Sugarcane Breeding Institute (SBI, Coimbatore), for providing sustainable solutions in the agriculture sector.

We are currently working with India's third largest sugar company, Triveni Engineering in Uttar Pradesh and have collaborated with Krishi Vigyan Kendra (KVK, Latur) in Maharashtra. Our bud chip technology is changing the way sugarcane crop is raised impacting on profits and ecology. Our Sustainable Sugarcane Initiative (SSI), which reduces inputs costs and improves productivity of sugarcane by 30 percent is being implemented in Odisha, Andhra Pradesh, Uttar Pradesh and Maharashtra and is benefiting more than 5,000 farmers. By adopting SSI, the sugar mills are benefitting due to increased sugar recovery as well as improved supply of raw materials.

AgSri has partnered with Driptech USA and has introduced low cost drip systems that are easy to install and comes at one-fourth cost of the conventional drip system. AgSri aims to make drip irrigation easy and affordable to farmers and to achieve this, as a pilot project, AgSri Driptech has targeted to reach out to atleast 10,000 farmers in Andhra Pradesh in 2012-13.

AgSri in collaboration with NABARD and SBI (Coimbatore) hosted the first National Seminar on Sustainable Sugarcane Initiative (SSI) in the Tamil Nadu Agricultural University (Coimbatore) in 2011. Following AgSri's massive SSI promotion, the governments of Tamil Nadu and Andhra Pradesh have included the SSI promotion in the 12th five year plan. NABARD is extensively promoting SSI adoption and trainings in the various states of India.

NATIONAL CONSORTIUM OF SRI (NCS)

The National Consortium on SRI is a coalition of practitioners, policy makers, resource institutions, researchers, scientists and other individuals, who are keen to spread SRI on a large scale in the country. It is a think-tank and resource-pool in which the members have come together voluntarily and committed to understand the advancement of the science, strengthen practice and take up policy advocacy in favour of SRI. The NCS emphasizes on these three pivots:

1. Science of SRI: This includes identification of the enabling factors for the full expression of the genetic potential of the rice plant without intensive inputs; conservation of natural resources; reduction in cost of cultivation; and improvement of soil health, root system and sustainable nutrient management.

2. Practices of SRI: The adoption of SRI has witnessed very rapid growth within a short span of time. This has happened mostly under Civil Society initiatives and little State support. The following issues are of critical importance- clear insights and understanding the realities of adoption and dis-adoption along with an understanding of the tangible benefits of SRI; measuring the efficiency and efficacy of the use of inputs and conservation of resources such as seeds, water, fertilizers and labour as well as organic supplements; design and spread of suitable implements; and preparation of user friendly tools and knowledge resource materials.

3. Policy on SRI: This includes influencing mainstream programmes and strategies for scaling up SRI; advocating innovative institutional architecture of extension for wider adoption and impact; convergence of multiple programmes; and evolving new forms of partnerships.

Achievements: In a short time span, the NCS has created considerable impact among stakeholders and has sensitized many policy makers. The recent outputs are the following: series of interactive policy dialogues conducted, published multi-lingual brochures, brought out a compilation of major research works on SRI, and published a Resource Book on SRI. The NCS was closely associated with the 12th Five year Plan preparation process as well. The NCS continues to be regular touch with the policy makers in providing and inputs on mainstreaming the SRI discourse.

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 at the on-farm level in collaboration with scientists and practitioners including farmers, and to pilot new ideas.
3. Develop more clarity on the socio-economic impacts of SRI techniques at the family farms. Evolve strategies for capacity building of stakeholders on an ongoing basis.
4. Advocate for supportive policy and innovative communication strategies

NCS promote SRI research, bring out research documentation and engage in upscaling policy

For more Information about NCS (srincsindia@gmail.com), contact:

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