THE SYSTEM OF RICE INTENSIFICATION (SRI)

Responses to Frequently Asked Questions

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FOREWORD

Compared to a decade ago, many more persons – at least 10 million people, most of them farmers -- can now answer the question ***"What is SRI?"*** at least in general terms. However, most would probably not give very detailed answers, and many would like to know more about this strategy for raising the crop yield of rice, and now also other grains, legumes and vegetables, just by changing the way that these crops are managed, with minimal reliance on purchased inputs.

Also by now, many more persons will at least have heard something about SRI and about its benefits for producers, for consumers, and for the environment. They may well be interested in a systematic introduction to this phenomenon which has demonstrated positive results in more than 50 countries around the world (http://sri.ciifad.cornell.edu/countries/index.html).

So this book is written for both groups of potential readers, bringing together in one place much of the accumulated field experience and scientific research that makes the **System of Rice Intensification** and its derivations grouped under the broad heading of the **System of Crop Intensification** an unprecedented opportunity for enabling people to improve their lives in this 21st century.

Two publications previously assembled such information with primary reference to India (Pandian et al. 2011; Thiyagarajan and Gujja 2012). This presentation complements those books, but can be read separately and is intended for a worldwide readership. It is organized to address in a simple, organized way any interests, curiosities and concerns that people may have about this phenomenon which is now widely known just as 'SRI.'

What is referred to as 'modern agriculture' has been very productive and significant in the 20th century, but it is going to have to change considerably for the 21st century. Our *land and water resources* are diminishing in quantity, quality and reliability -- certainly in per-capita terms, but in many places also absolutely. With the added complications and compulsions of *climate change*, there is ever more reason to rethink and revise our agricultural practices, even practices that have served many if not all of the world's people reasonably well in the past.

We face the triple imperative of ensuring *food security* for all of the households in our respective countries; raising our crop productivity so that *food needs can be met with fewer rather than more of our resources*; while maintaining the health-fulness of our food supply and the robustness and quality of our environment.

We know that meeting these objectives will not solve all of the world's problems. But we also know that unless the essential requirement of food for everyone can be satisfied, resolving the many other major problems that now confront us will become much more difficult and surely much less likely.

In this Foreword, not much needs to be written about SRI since this book addresses the subject systematically and reasonably thoroughly. The book starts out with a listing of ***frequently asked questions*** (FAQs) regarding SRI on pages 1-2, followed by ***short summary answers*** on pages 3-19, with the remainder of the book then providing ***more complete responses*** to each question, offering more extended explanations on pages 20-184. There will be necessarily a little overlap in some of the longer responses as each answer was constructed to be self-standing. However, the whole presentation is constructed in such a way as to provide readers with an efficient way to get a good understanding of SRI. Responses to the questions are like transects through the growing body of SRI knowledge and experience.

Farmers' and Others' Contributions

In this Foreword, I will comment briefly on two pictures that have shaped my own understanding of SRI. Each picture is worth more than the proverbial 'thousand words' because each makes the subject of SRI both vivid and concrete, combining both the human and the biological aspects of the SRI phenomenon. This book contains many pictures because SRI is such a visual subject, and I have learned almost as much from the pictures that I have received or taken as I have from others' reports and from my own field visits. This book shares the most instructive pictures in my files as providing part of the answers to many questions.

Below is seen **Mey Som** of Tropaing Raing village in Kandal province of Cambodia, who was the first farmer in his country to agree to use and evaluate SRI methods. In his hands he is holding two rice plants of the same variety. The plant in his left hand was grown with his former usual practices, while the one in his right hand he grew by using the new SRI methods.

In 2000, 28 farmers including Mey Som tried out the proposed new methods on their own fields, having learned about SRI from CEDAC, the Cambodian Center for Study and Development of Agriculture, based in Phnom Penh. CEDAC's director Dr. Y.S. Koma had tried the methods out on his own farm the previous year before recommending them. Within 15 years, over 200,000 Cambodian farmers were working with SRI concepts and methods. Because few of them have access to irrigation facilities, most farmers have developed unirrigated versions of SRI for rainfed production. Their yields have averaged 3.2 to 3.9 tons of paddy rice per hectare, which is 25 to 50% more than the national average of 2.6 tons.

Mey Som's own yields have doubled, increasing from 1.75 tons per hectare to 3.5 tons with reduced use of agrochemicals and with lower costs of production. This has meant that his income like that of other SRI farmers has risen by more than the value of the increased grain that they produce using SRI's alternative methods.

As a kind of community service, Mey has visited dozens of villages in his district and beyond to share his SRI experiences with other farmers. As visual aids he carries contrasting rice plants like those shown in the picture. When he walks into a village, he engages farmers like himself in conversation, encouraging them to use SRI ideas and practices to benefit their families, their communities, and their environments just as he has done. This is an example of the way that SRI has proceeded with farmer buy-in and effort. While government agencies, NGOs and other organizations have all engaged in SRI extension efforts, an important factor in the spread of SRI has been this kind of farmer initiative.

The picture at the top of the next page 'speaks volumes' about SRI. It was sent to me in 2003 by Dr. Rena Perez, who began supporting the evaluation and spread of SRI in Cuba as a volunteer SRI *promotore* there in 2000. This picture has helped me and subsequently thousands of others to understand better the phenomenon of SRI which I had first learned about in Madagascar some 10 years earlier.

In 2002, Rena got **Luis Romero**, a Cuban farmer in San Antonio de los Baños, to try out SRI methods for himself. She knew him from her previous work as an advisor on animal nutrition in the Ministry of Sugar. He prepared a traditional nursery and when all of its seedlings were 9 days old, he took out some of them to plant in an experimental SRI plot. In Cuba, a common age for transplanting rice seedlings is 50-55 days after sowing, considerably later than anyone now advises.

When Rena visited Luis 52 days after he had sown his nursery, he was starting to transplant his main field. She had a camera with her, so she took a picture to compare an SRI plant already growing in an SRI plot with a typical rice seedling being pulled up from Luis' nursery. The plant on the right which had been transplanted as a young single seedling, widely spaced with organic matter

added to the soil, and with some soil-aerating weeding, had become quite obviously much larger and more vigorous.

It can be hard to believe that these two rice plants are the ***same variety*** (VN2084, locally known as *Bollito*) and the ***same age***, both 52 days old. The plant on the left with only 5 tillers (stalks) and a meager root system was affected by the crowding and flooding of a conventional nursery. Its SRI 'twin sister' on the right has 43 tillers and a large, healthy root system, stimulated by having space and aeration. The same *genotype* produced quite different *phenotypes*. The differences were attributable simply to the modifications that Luis had made in his management of the rice plants.

In his first season, Luis, seen on the left, got a yield of 14 tons per hectare from this SRI plot with good growing conditions. In a subsequent water-short season with late planting because of delayed rains, he got a yield of only 4.5 tons per hectare. But his neighbor's yield was just 3 tons when using conventional cultivation methods.

The picture above of the contrasting tillering and root growth quickly became iconic for the whole SRI movement. It has been reproduced countless times around the world. Knowing that people can be suspicious of any still picture in this era of Photoshop, I sent a digital movie camera to Rena so that in the next year she could visit Luis every week during the growing season and could record consecutive images of the plants' growth. With this camera and Luis' cooperation, Rena documented with pictures and his weekly commentary the divergent growth trajectories of his SRI plants compared to more typical rice plants of the same variety.

This was before the advent of YouTube, which has become such a helpful medium for SRI communication around the world. Rena's videos were posted on CIIFAD's SRI website for anyone to see: a short, 14-minute version with Spanish narration at http://sri.cals.cornell.edu/countries/cuba/SICA4web.wmv (35.2 MB), and a longer, more complete version, 36 minutes with English subtitles, at http://ciifad.cornell.edu/sri/countries/cuba/SICA4web.wmv (72.6 MB).

That this was an 'amateur' video production was itself iconic. It reflects how much of the effort to disseminate SRI knowledge and experience has been done by volunteers -- by persons who moved outside their disciplines and professions and who contributed their time, energy and personal resources generously and effectively. Using an American metaphor, we say that most of the SRI work done all around the world thus far has been accomplished with ‘a lot of shoestrings.'

What has carried the SRI effort forward, with relatively few professionals and specialists involved, and with very modest funding, has been most importantly the merits and productivity of SRI methodology itself. However, this potency has been amplified by the imagination, improvisation and unceasing work of dozens, then hundreds, and now thousands of people from many walks of life, from farmers to ministers, both a government minister in Sri Lanka and a religious one in Liberia.

The farmer pictured on this book’s cover, **Miyatty Jannah** from Crawuk village in East Java, Indonesia, has become ‘the farmer face of SRI.’ Her picture graced a story on SRI in the Science section of the *New York Times* (Broad 2008), and it is seen on packages of organic SRI rice that is imported from Indonesia, Cambodia and Madagascar by Lotus Foods for sale in stores across the U.S.

When Miyatty first learned about SRI in 2004, she invited SRI trainers to her village and personally covered the costs of their stay to provide four days of training. Of the 25 farmers they trained, only 10 were willing to try out the methods; and there was a lot of resistance initially, even abuse. When we first met in 2008, she told me: “The whole village was against us at first. ‘You are stupid,’ they said when they saw the tiny transplanted SRI seedlings: ‘You will get nothing.’”

“There was really a strain,” Miyatty recollected. “It was really, really hard. People were talking bad things about SRI.” She had to convene many meetings among the 10 SRI farmers, to discuss among themselves and to keep them all continuing. “One husband and wife were not talking to each other. They almost divorced.”

“But when harvesting was done, people came and said, ‘Wow. How did that happen from such small seedlings?’ All the people were surprised. With less water and less money, we had 40-50% more paddy. People from other villages came and asked us how we did this. So I went to other villages to tell them. Always there were lots of tensions and problems at first. Still, these problems go away once farmers see the results.”

It was gratifying to hear this by-then-familiar account from Miyatty. Subsequently she traveled to the Solomon Islands in 2010 as a guest of that Pacific nation’s government to train farmers and extension personnel on SRI methods there. When we met again in 2011, she gave me a picture of her organic SRI field compared to her neighbor’s conventionally-managed field (page 14). Both crops had been attacked by brown planthopper pests and were then hit by a tropical storm. Her yield was 8 tons/ha, while his yield with higher production costs was practically nil.

The SRI Community of Practice and Knowledge

What the diverse voluntary assemblage of SRI colleagues in many countries has shared is an understanding of what SRI ideas and methods can do to improve the lives of food producers, the diet of food consumers (i.e., all of us), and the natural environment on which we all depend. It is this shared understanding that has motivated such broad-scale efforts around the world.

So, this book is dedicated to the dozens, then hundreds, and now thousands of SRI colleagues who have shown, once again, the wisdom of an observation made by the esteemed American anthropologist, Margaret Mead: “Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has.” This book is dedicated also to the millions of farm households who have grasped the opportunities of SRI and have made it a force for refashioning agricultural practices for the 21st century.

SRI brings together in productive ways the realms of biology and sociology, plus economics, political science and many other disciplines. It also connects the realm of *material* relationships, on the one hand, with that of *mental* and *moral* engagement, on the other.

The story of SRI, practically a saga, is not yet finished. Indeed it is far from ended. The elements of SRI were first assembled by Fr. Henri de Laulanié three decades ago in Madagascar; and it is two decades since I first learned about SRI from his Malagasy colleagues in the NGO that they founded together, *Association Tefy Saina*. It has been just a decade and a half since I first felt comfortable with the conclusion that SRI is ‘for real’ and began to share SRI knowledge as widely as possible, to encourage its testing and evaluation in other countries.

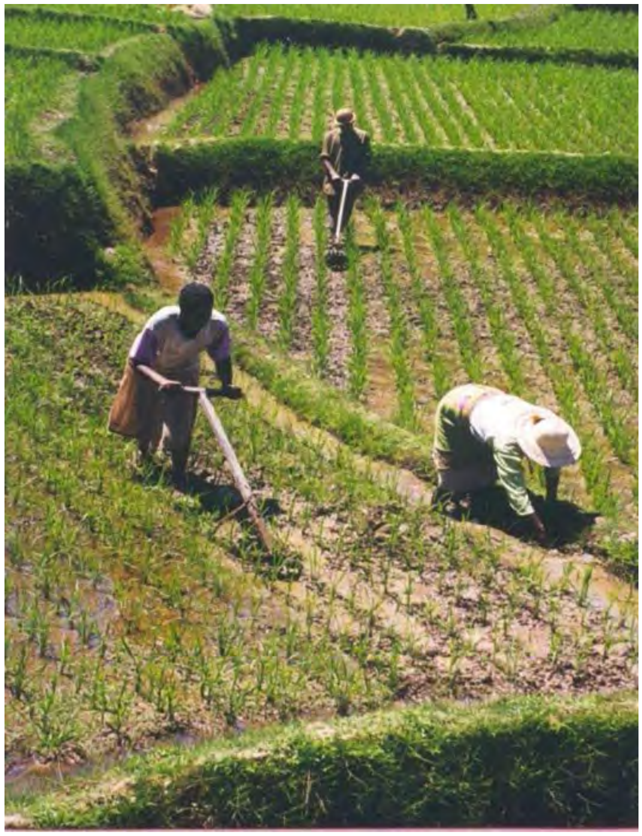
SRI began spreading seriously in Asia, Africa and Latin America about a dozen years ago, after an international conference held in China in 2002. Its proceedings are available at: http://sri.ciifad.cornell.edu/proc1/index.html. On the next page, there is a picture of the conference participants, a truly international gathering from all over the world. The accumulation of knowledge about SRI and its application have been accelerating ever since, year by year.

This book is best regarded as an interim report on SRI, bringing together what I have learned about it thus far from working together with colleagues in many countries. It is not a scientific document, although it includes references to extensive research findings that support its statements (pages 185-201). It is intended to inform a wide range of interested persons. The references provide the most inclusive bibliography available on SRI. It is certain that this knowledge base as well as its application will keep on growing considerably in the years to come.

Norman Uphoff
Ithaca, NY
July 22, 2015

Participants in the first, and so far only, international conference on SRI, held in Sanya, China, April 1-4, 2002. This event was organized by the Cornell International Institute for Food, Agriculture & Development (CIIFAD), hosted by the China National Hybrid Rice Research and Development Center (CNHRRDC), and co-sponsored by Association Tefy Saina (ATS) and the China National Rice Research Institute (CNRRI), with some travel support provided by the Rockefeller Foundation and the World Bank.

Fifty international participants came from 15 countries, plus Chinese rice scientists invited by the host, Prof. Yuan Long-ping. He is seated in the center of the first row, with Tefy Saina president Sebastien Rafaralahy seated to his left and the author sitting to his right. The director-general of the China National Rice Research Institute, Dr. Shihua Cheng, also a conference co-sponsor, is seated in the first row 4th from the right. Rena Perez (Cuba) and Y.S. Koma (Cambodia), who are mentioned in this Foreword as early SRI protagonists, are standing in the second row: 3rd from the left and 5th from the right.



Madagascar farmers who could not produce enough rice to meet household needs from their small available landholdings found that they had to encroach upon fragile rainforest ecosystems as a means of survival. However with SRI methods that modified their management of plants, soil, water and nutrients and gave them more yield per unit of land, water, seed, labor and capital, farmers could reduce their need to expand their cultivated land area for food security. These methods are being used now in a wide variety of agroecosystems in over 50 countries, also with a range of other crops in addition to rice, thereby serving both human and environmental needs.

FREQUENTLY ASKED QUESTIONS ABOUT SRI

A young farmer trained by The Green Foundation in Karnataka state of India carrying young SRI seedlings in a basket, ready for transplanting.

The questions below cover matters of interest and concern that have been most often expressed regarding the System of Rice Intensification (SRI). Short answers are given to each question on pages 3-19, and then more detailed information is given in the longer answers that follow.

SRI farmer-activists in Burundi, Mathilde Nibigira and Isidonie Hiboniyo, who have spread SRI within their communities, as seen in a video on the movement of SRI ideas and practices from Madagascar to Rwanda to Burundi, produced for the International Fund for Agricultural Development (IFAD) by Flooded Cellar Productions, Sussex, UK: http://www.ifad.org/english/sri/documents.htm

SHORT ANSWERS

Moghanraj Yadhav, a young Indian farmer, counting grains on the panicles of rice in his SRI field near Nagipattinam in Tamil Nadu state. He subsequently established a local NGO, VAANGAI, that disseminates SRI methods and other agroecological practices.

1. What is SRI?

The System of Rice Intensification, widely known as SRI and called *SICA* in Latin America, is **a management strategy for crop improvement** (Stoop et al. 2002). It is a set of ideas and insights for beneficially modifying agronomic practices that are based on validated knowledge for increasing the production of irrigated rice – and also now for many other crops. SRI does not require or depend on the use of improved or new varieties or on use of synthetic fertilizers and agrochemical crop protection to get higher output. These inputs can be used with SRI management practices, but they are not necessary to improve crop productivity and vigor.

By reducing farmers' needs for seeds and water, and often even for labor, SRI gives them greater returns from their available resources of land, labor and capital. This raises their incomes while also being beneficial for the environment. SRI plants are less affected by water stress, storm damage, and pests and diseases as they demonstrate a resilience that is increasingly needed with the *growing hazards of climate change*. This capability is likely to become more important. However, getting acceptance and use of SRI it not easy because some of the SRI methods are counter-intuitive, like getting more yield from many fewer plants.

1.1 What are its key practices?

SRI is based on certain *principles* that justify particular practices which are expected to be adapted empirically to local conditions. While SRI is most clearly and concretely explained in terms of *certain recommended changes that alter standard rice-growing practices*, it is the *principles* that underlie these practices which should always be kept in mind since SRI is much more than just a set of recommended practices. These practices are very concrete, however, and can be summarized as follows. To get the best results when growing irrigated rice:

- **Transplant young seedlings**, preferably *8-12 days old* and as a rule less than 15 days old. These small plants should be grown in an *unflooded nursery* and then *removed gently*, with minimum trauma to their roots, being replanted in the main field *carefully, quickly and shallow* (1-2 cm).

- **Wider spacing between plants**, with seedlings planted *singly*, one per hill instead of 3-6, and in a *square pattern*, usually 25 x 25 cm. Plant densities in the field are reduced by 70-90%. This gives plants' roots and canopies more room to grow and spread, acquiring more nutrients and sunlight.

- **Soil in the field is kept moist but not continuously flooded,** intermittently wetted and dried, so that the soil is mostly aerobic, never hypoxic. Good drainage of the soil can be almost as important as the provision of irrigation water. A lack of oxygen in the soil will suffocate the plants' roots and also the aerobic soil organisms that can provide many beneficial services to the plants.

SRI starts with young seedlings, transplanted singly in a square pattern in soil that is moist but not flooded, as shown in this picture from Eastern Indonesia.

- **Control weeds with repeated use of a mechanical hand weeder.** This will aerate the soil better than possible with hand weeding or use of herbicides. Active soil aeration can enhance paddy yields by 1-2 tons per hectare.

- **Enhance soil organic matter as much as possible,** adding compost or other biomass to the soil. This will improve the soil's structure and functioning as well as provide the plants with more complete and balanced nutrition.

1.2 Why isn't SRI considered as a new technology?

Unlike most current agricultural technologies, *SRI is not based on material inputs*. Instead it involves *mostly mental changes and new thinking*. Also, SRI is *a work in progress*, continuing to evolve. Promoting something as a technology makes the innovation seem static, with farmers becoming *adopters* rather than *adapters*. SRI emphasizes *adaptation and continuing improvement* by farmers and others.

2. What are the origins of SRI?

SRI was developed in Madagascar by a remarkable French priest/agronomist, ***Father Henri de Laulanié, S.J.***, who spent 34 years (1961-1995) working with farmers there to help them improve their rice productivity and their livelihoods without having to rely on purchased inputs. Most of its practices were assembled and synthesized into this system by the 1983-84 main season, some 30 years ago.

With Malagasy friends, Laulanié established in 1990 a local NGO, ***Association Tefy Saina***. ATS has promoted SRI knowledge and use as part of a holistic rural development strategy (Laulanié 2003). Progress with SRI dissemination was at first very slow because SRI goes against strongly-held traditional beliefs that enjoin Malagasy people to 'follow the ways of the ancestors.' Adopting SRI practices is a very visible and public departure from those ways, risking the ancestors' wrath. Still, SRI use has become wider in Madagascar and is now accelerating there.

Malagasy children standing in front of an SRI field in Madagascar.

2.1 How has SRI spread around the world?

In 1994, Tefy Saina and the Cornell International Institute for Food, Agriculture and Development (CIIFAD) began working together in a USAID-funded project to conserve the rainforest ecosystems in Ranomafana Park. With SRI methods, farmers cultivating rice around the Park whose yields were usually ~2 tons/ha got yields averaging 8 tons/ha; and some had even higher yields. This was with the *same varieties on the same poor soils, using less water, and not needing chemical fertilizer or other inputs*, instead relying on compost to improve soil fertility.

After three years of such results, CIIFAD began trying to get rice scientists and farmers in other countries to try out SRI methods. However, it took 2 years before this began. The higher productivity attainable with SRI management practices was first validated outside Madagascar in China and Indonesia in 1999-2000. Then similar results were reported from Cambodia, Philippines, Cuba, Sri Lanka, India, Myanmar, Gambia, Sierra Leone, and other countries. By 2002, SRI methods had been further validated in 15 countries. Now 13 years later, this number is 55.

2.2 Does SRI spread require favorable political and other conditions?

The introduction of SRI knowledge and methods can proceed best in a supportive political and social environment. But because SRI depends upon knowledge and skill rather than on purchased inputs, we have seen SRI start up under conditions of armed conflict (Afghanistan, Indonesia, Iraq, Mali, Nepal, Myanmar, Sri Lanka) and in post-conflict situations such as Sierra Leone and Timor Leste.

An Aga Khan Foundation technician making a field visit with farmer protection In Baghlan province of northeastern Afghanistan, where there was opposition from Taliban forces to this and other development programs.

3. How can SRI benefit poor, resource-limited households?

Poor households have usually very little access to land, so raising their *yield per hectare* is of great importance. As they have relatively more family labor, initial labor-intensity is not as much of a problem for them as it is for larger-scale farmers. However, very poor households with a hand-to-mouth existence may encounter difficulties for adopting SRI (Moser and Barrett 2003).

As discussed below, many farmers find that SRI is or can become ***labor-saving***. This is good for most farmers, although it can reduce employment opportunities for those who depend on wage labor for their household income. Keeping rice prices lower because of a more abundant rice supply is available, and not having staple food supply sharply reduced in seasons with a poor harvest, is one of the most important boons that poor households will have from wider use of SRI.

Indian farmer Raju who learned SRI methods from the AME Foundation in Karnataka state showing the author the difference that he has observed between the root systems of an SRI-grown plant, on left, and a conventionally-grown rice plant, on right.

3.1 Can SRI also benefit larger farmers?

Yes, because SRI is capitalizing on biological processes and potentials that already exist in the genomes of rice and in plant-soil-microbial interactions. Its application is thus ***scale-neutral*** and its benefits are available to any producers who make appropriate adaptations in practices to suit their own conditions. Efforts to ***mechanize*** various operations in SRI practice are underway (Sharif 2011). We expect that SRI ideas will soon be utilized across a full range of scales as they are now being applied within a wide variety of agroecosystems. ***SRI effects on labor and on households of different classes*** (3.2) are varied, best addressed not with a short answer but with some more detailed discussion (pages 57-58, 88-89).

4. How can SRI benefit the natural environment?

By reducing irrigated rice crops' requirement for water, SRI relieves pressure from agriculture on ecosystems' water resources. Moreover, raising crop yields reduces need to expand cultivated area at the expense of natural areas. By reducing or eliminating farmers' dependence on chemical fertilizers and agrochemicals, both soil health and water quality can be improved compared to what results now from input-intensive agriculture. Reversing the build-up of reactive nitrogen (N) in our soil and water supplies will improve the natural environment’s sustainability.

4.1 What impact can SRI have on greenhouse gas emissions?

Because SRI stops the continuous flooding of rice paddies, there is no disagreement that it will significantly reduce the emission of methane (CH_4) from rice fields, which constitutes 5-19% of the global total (Rajkishore et al. 2015). When there is no flooding, on the other hand, according to current thinking, emissions of nitrous oxide (N_2O), a more potent greenhouse gas, are expected to increase. However, when soil is fertilized with organic materials rather than with nitrogen fertilizers, there will be less excess N available for microbes to convert to N_2O.

Evaluations in Nepal, India, Indonesia, Vietnam and Korea have found that with SRI management, there was no significant increase in N_2O to offset the expected and measured decreases in CH_4 emissions. Sometimes there is even *some reduction in* N_2O with SRI. These studies should be continued and replicated. Little evaluation has not been done so far on SRI impacts on the 'carbon footprint' of rice production. But with less production, transport and use of inorganic fertilizers, the emission of the CO_2 associated with rice-growing should be considerably less.

4.2 Does SRI have anything to do with genetically-modified crops?

SRI gains achieved through modifications made in crop management do not derive from any particular genetic traits or potentials. However, it is clear that *some genotypes perform better than others* under SRI management. Genes are central, indeed essential factors in crop productivity. But by themselves they are not deterministic. The growing environment can have as much or more influence.

The performance of GM crops would probably be enhanced if they were grown with adapted SRI methods. SRI yield improvements and other benefits have been greater than are being achieved by altering rice plants' genetic potentials through GM techniques. In any case, SRI's benefits are available without needing further research; they entail little cost and raise no evident environmental issues. SRI opportunities now available make the development and use of GMOs less urgent than often said to be necessary to meet world food needs.

5. Can SRI outperform what are called 'best management practices'?

Yes. Some have argued that SRI can only improve upon 'traditional' farmer practices, but not upon the 'best practices' that rice scientists propose. A meta-analysis of comparative evaluations by Chinese researchers has found a 20% yield advantage over BMP from 'good,' not even full use of SRI methods (Wu and Uphoff 2015). The idea that SRI offers 'nothing new' is no longer tenable. SRI is increasingly becoming understood as being itself 'best management practice.'

5.1 Why is there so much variability in SRI yields?

With basic SRI practices, one can expect yields in the range of 6-8 tons per hectare, 50-100% above the world average. But sometimes there are yields of 10, 15, even 20 tons per hectare, well above what some scientists have considered as a 'biological maximum.' Since yield gains from SRI do not come from a certain genetic blueprint or from the application of external inputs, results are not fixed or proportional. SRI practices influence beneficial soil organisms (Anas et al. 2011). These can vary by orders of magnitude, so we expect variability in SRI results.

5.2 Are the super-yields reported with SRI practices credible?

SRI has been dismissed as not worth considering or even evaluating (Sinclair 2004) because the very high yields occasionally reported with SRI management are beyond what scientists have been able to produce in their on-station trials. This ignored the effects that their management practices and agrochemical inputs will have had on the soil biota and deflected attention away from the large average increases. Actually, the super-yields reported have shown what potential exists within rice genomes if given optimizing growing conditions. But we are always more interested in increases in average yields than in outliers because *it is averages that feed people and make their lives better.* This said, I have confidence in the high yields reported, being measured with standard methods.

6. What are the requirements for practicing SRI?

As noted already, SRI does not require any change in rice varieties or purchase of fertilizers or agrochemical protectants. It does require enough **water control** so that *smaller amounts* of water can be provided *reliably* during the growing season; all crops require at least some water. There must also be **sufficient, motivated labor** available for skilled crop management, and enough **access to biomass** starting with rice straw to make compost or do mulching to maintain soil organic matter. Fertilizer can be used if there is not enough biomass for compost.

Although SRI plants are usually more resistant to pests and diseases, some **crop protection** measures may be needed, preferably IPM or organic pesticides. Having access to **weeding implements** that aerate the soil while they control weeds will enhance crop yield, but they are not absolutely necessary. The most important requirement is **motivation and aptitude for careful crop management** given that *SRI is more of a mental innovation than a material one*.

6.1 Isn't it true that SRI requires more labor?

Not necessarily. More time is needed to complete the operations while the new methods of management are being learned. So SRI is often considered to be more labor-intensive. However, as experience and confidence are gained, the labor requirements per hectare usually decline. The length and steepness of the learning curve varies. In countries where rice farmers are accustomed to making adaptations in practices, such as India and China, or where rice production is already relatively labor-intensive, farmers already in their first season report *reductions* in the number of days of labor per hectare required for the use of SRI.

Using a simple mechanical weeder like this actively aerates the soil as it uproots weeds and churns them into the soil to decompose. As it can enhance yields by 1 or more tons per hectare, this kind of weeding becomes a benefit *for farmers rather than just a* cost.

6.2 Can SRI practices be utilized without irrigation?

Yes. Although SRI was developed to improve the production of irrigated rice, NGOs and farmers have adapted SRI methods also to upland or rainfed cultivation in the southern Philippines, northern Myanmar, eastern India, and southern Mali. In some places, rainfed SRI yields are as high as 7 tons/ha. Water management, timing, and spacing need to be adjusted, of course. But SRI concepts and methods are adaptable to producing rice without irrigation.

6.3 Do farmers need to use new or special varieties of rice with SRI?

No. SRI methods have been found to enhance yields from practically all rice varieties -- high-yielding or traditional, improved or unimproved, hybrids or landraces. Some varieties respond better than do others to the modifications that are made with SRI crop management. The best SRI results have been with HYVs or hybrids, but most local varieties also perform well with SRI management.

6.4 Is SRI an organic system of production?

Not necessarily. SRI was initially developed with chemical fertilizer, but when subsidies for fertilizer were withdrawn and poor farmers could no longer afford it, Fr. Laulanié switched to recommending the use of compost. Factorial trials have shown that organic fertilization used with the other SRI practices can outperform the use of inorganic fertilizer (Uphoff and Randriamiharisoa 2002). However, the highest yields often come with some optimizing combination of *both sources* of nutrients for the soil, in what is called *integrated nutrient management* (INM). Farmers can decide for themselves whether to grow their SRI rice organically or not, depending on labor availability and on cost relationships, e.g., prevailing costs of fertilizer and the market price offered for 'organic' rice. SRI is intended to expand farmers' range of choices rather than to dictate certain practices.

7. What limitations are there for utilizing SRI methods?

Where there is **not sufficient water and enough water control** to maintain moist but aerobic soil conditions, best SRI results will not be obtained, although the water control need not be perfect. **Insufficient labor time and skill** will also be a constraint. Certain **crop pests** can limit the utility of SRI, e.g., yield will be reduced if root-feeding nematodes are endemic and thrive in unflooded soils. **Temperatures** must be within an appropriate range for growing a rice crop. Part of the SRI methodology is to make appropriate adjustments in practices to deal with limitations such as these, e.g., making raised beds within rice paddies where water control is limited, or modifying irrigation schedules to cope with and suppress nematodes.

7.1 Where would SRI methods be unlikely to succeed?

Following from the requirements enumerated under FAQ 7, we can say that:

- Where ***temperatures*** are too low for growing rice (or excessively hot), SRI will not be feasible. But SRI plants, once established, have been seen to tolerate more cold and more heat than conventionally-grown plants because of the more vigorous root systems promoted by SRI practices.

- At least some ***minimum of water*** must be reliably available, with ***enough water control*** to prevent standing water and plant inundation that will suffocate the roots. Rice can *survive* under flooding, but it does not *thrive*.

- Results have often been better on ***acid or neutral soils*** than on alkaline soils. But in a meta-analysis, SRI methods were found to raise production across the full range of soil pH (Jagannath et al. 2013). ***Saline soils*** are problematic for all rice crops, but compost can often neutralize the effects of salinity.

- Where there are serious **labor constraints** so that farmers cannot afford to invest enough time (household labor or hired labor) in the learning process to master SRI methods, these methods will not be successful.

- Where there are **negative attitudes** toward trying new methods or adopting practices, either from the farmer side or from the scientists, extension personnel and administrators who work with them, success will be problematic. As SRI is more a mental than a material innovation, it requires open minds and a willingness to experiment with and evaluate new ideas.

Average SRI yields of 9 tons/ha are reported from the cold climate and high elevations of northeastern Afghanistan as well as from the Timbuktu region of Mali, on the edge of the Sahara Desert. SRI methods are thus adaptable to a wide range of growing environments even if not to all circumstances.

7.2 Do all of the SRI methods need to be used fully and precisely?

Best results can be obtained by using the recommended practices all together, and as close as possible to what is recommended. The recommended practices represent an 'ideal type' of SRI. The more closely this is approximated, the better. Each practice makes a contribution to improving the growing environment for rice plants. If really young plants are used, there needs to be enough water control so that they will not be submerged and suffocated. SRI should be understood and practiced as a matter of degree – cumulatively giving plants the best growing conditions possible under the farmer’s circumstances.

7.3 Are there significant problems of disadoption of SRI?

A 2003 paper by Moser and Barrett identified disadoption among very poor households in Madagascar as a constraint on the spread of SRI. Some households were so dependent on earning immediate income that they could not afford to invest more labor in SRI even when they knew that this could give them more yield at the end of the season. This constraint derives more from the usurious credit markets in rural Madagascar, however, than inherently from SRI.

Some disadoption has been reported in certain states of India where irrigation water or rainfall is not reliable enough to risk starting a crop with young seedlings. In Southeast Asia, snails have been a deterrent to continuing with SRI practices; but some farmers have found water-management solutions to control this pest while others are not successful. Where data have been systematically gathered on disadoption, in most cases this has been at most a few percent, and usually attributable to factors beyond farmers' control.

8. Why change current rice-growing practices?

There are good agronomic justifications for each of the recommended SRI practices. Farmers should learn and understand the principles that justify the practices rather than just learn the practices themselves. For example, crowding rice plants together prevents leaves that are shaded from getting enough sunlight to maintain photosynthesis. Also, it is the lower leaves that supply most of the carbohydrates (energy) to the roots for carrying on their metabolic processes, and these leaves are the most shaded by close spacing. Crowding of plants thus reduces their production of energy to support growth and to create grain. It especially deprives the roots of the energy that they need for effective functioning. This is simple agronomy. Many scientifically-sound reasons can be given for SRI practices.

9. What are SRI's main economic, social and other benefits?

The simplest and most evident benefit is *increased yield per hectare*, but more important for spurring development is the *greater factor productivity* that SRI methods elicit from the land, labor, water and capital invested in growing rice.

- For farmers, *water saving* and *lower costs of production* are among the most important SRI benefits.
- Also, there is *no need to purchase new seeds or chemical fertilizer* if farmers are able to make and apply sufficient compost of their own. This can be an important consideration especially for the poorest households.
- *Higher returns to labor* per hour or per day are also important, as is *reduction in labor requirements*, including for women, once SRI methods are learned.
- *Increased net farmer income* and *greater profitability of rice production* are quantifiable economic benefits, as is a *reduced risk of economic loss* (Anthofer 2004; Namara et al. 2003).

Because rice plants are more robust, there are *reduced losses to pest and disease* and also *greater resistance to climate hazards* such as drought and storm damage, which are becoming more frequent and severe with *climate change*.

Two adjacent paddy fields in Crawak village, East Java, Indonesia, after the village had been hit by a brown planthopper attack in summer 2011, and also by a tropical storm. Field on left was planted with a modern variety (Ciherang) and had synthetic fertilizer applications; field on right has a traditional aromatic variety (Sinantur) being raised with organic SRI methods. The field on left gave little yield because of 'hopper burn' and lodging; SRI field produced 800 kg from 1,000 m^2, i.e., 8 tons per hectare.

Greater resistance to *lodging*, i.e., being knocked down by wind and/or rain, is an important consideration for rice farmers as extreme weather events become more frequent. Reductions in *greenhouse gas emissions* were discussed above.

Other environmental benefits include *lower water requirements* which reduce the agriculture sector's competition for water with natural ecosystems; and *better soil and water quality* from less use of agrochemical inputs. These effects improve environmental quality and also contribute to conservation of some biodiversity.

Other benefits that farmers are able to receive from SRI management:

- SRI management can *shorten the crop cycle* by 1-2 weeks, while also giving higher yield. This frees up land for other uses and reduces rice crops' exposure to biotic and abiotic stresses at the end of the growing season.

- When SRI paddy (unmilled) rice is milled, there is usually a *higher outturn of polished (edible) rice*, by at least 10% and up to 20% because of fewer unfilled grains and less breakage of grains during milling. This adds to food production beyond higher paddy yields. *Grain quality* is commonly enhanced by SRI management, with reduced chalkiness of rice grains, an undesirable quality.

That SRI offers so many benefits has suggested to some persons the conclusion that SRI is 'too good to be true.' However, this inference is itself untrue. All of the benefits listed here are documented and demonstrable.

9.1 What are the gender implications of SRI?

This will depend on whatever is the prevailing gender division of labor for rice production in the local situation. Most reports have found that women's labor burdens are reduced when SRI is introduced, because rice transplanting becomes quicker once the new methods are learned; plant populations are reduced by 70-90% and the seedlings are smaller and lighter. Also, when mechanical weeding is introduced, men often take over the task of weeding, which in many places is culturally classified as 'women's work,' with men expected to carry out any operations with machines. There have also been some health benefits particularly for women reported from India and the Philippines.

Abeline Razanamamy, an elderly widow in Madagascar, has described vividly how her life has been improved through her adoption of SRI methods in a video produced by Flooded Cellar Productions: https://www.youtube.com/watch?v=uSaKgaQMdzc

10. Can SRI ideas and practices be applied to other crops?

One of the most promising developments is the extension or extrapolation of SRI concepts and methods to a wide range of other crops by making appropriate modifications in practices according to SRI principles, e.g., wheat, finger millet, tef, sugarcane, mustard, legumes (various grams and soya), and vegetables (tomatoes, chilies, eggplant), even rhizome crops like turmeric and ginger.

A huge potato yield in Bihar state of India (over 100 tons/ha)has been 'inspired' by SRI experience in the farmer's village (NDTV 2013); and farmers in Cambodia and in Jharkhand state of India have adapted SRI concepts to improve their production of chickens and of lac (SRI-Rice 2014). That lac is an entomological crop shows what can happen when farmers and others 'think outside the box,' seeking to raise productivity by making modifications in management.

Comparison of the root systems of finger millet plants in Jharkhand state of India. The plant on the left was grown with adapted SRI practices (transplanting young seedlings, widely spaced, with enhanced soil organic matter, and active soil aeration) as tried out by farmers under the guidance of the NGO PRADAN. The plant on right is a typical millet plant established by the farmer practice of broadcasting. This shows the same differential effects as seen with SRI practices that are used for producing rice.

11. What is the role of phyllochrons in SRI performance?

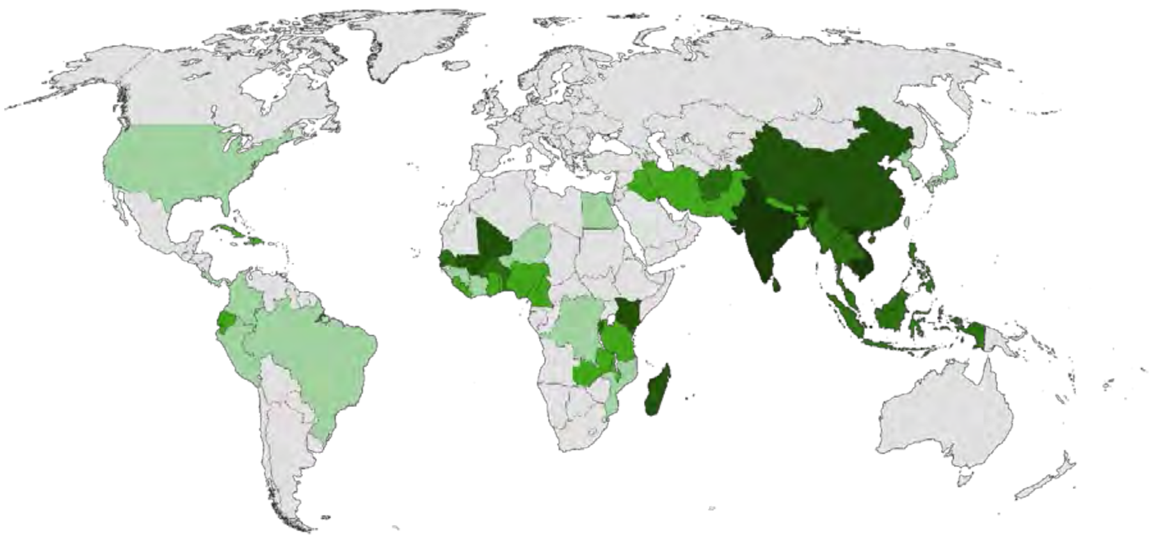
The profuse tillering of SRI rice plants can be explained in part by understanding the *pattern and extent* of tiller and root emergence in rice plants that is similar to what is observable in other grass-family crops (wheat, barley). The *phyllochron* concept, developed in Japan before World War II, has had little explanation in English language, so it has received little attention from non-Japanese scientists.

The periodicity of tiller emergence helps to explain why transplanting 'young seedlings' leads to much more profuse tillering and root development. Other SRI practices also help to shorten the length of phyllochrons and thereby promote the achievement of more tillering (and root growth) before the plants begin their flowering, grain formation, and grain filling.

12. How has SRI been disseminated among and within countries?

For the most part, SRI has been spread by a growing network of interested persons and institutions, from NGOs, from universities and research institutions, sometimes from government agencies or the private sector, and most of all, at the grassroots involving farmers themselves.

The SRI website maintained at Cornell University by ***SRI-Rice***, the SRI International Network and Resources Center (http://sri.cals.cornell.edu), has supported the widespread distribution of information on SRI – experience, problems, solutions, innovations, etc. – amplified by voluminous e-mail communication among members of an informal SRI international network. SRI-Rice was established in 2010 with a gift from the *Better U Foundation* (http://www.betterufoundation.org/) to catalyze the worldwide spread of SRI ideas and practice. Other sources of support have been found, but more are needed. Within many countries, networks of SRI users and proponents have been formed, with their own list-serves or websites or blogs. All SRI information is made available freely, with no IPR, patents, or other restrictions.



Map indicating the spread of SRI use, with extent of spread within countries suggested by darkness of color. The following dates indicate when the effectiveness of SRI methods was validated in each country to our knowledge at Cornell. Given the nature of SRI, it is difficult to determine precise dates and numbers, so these are indicative, not definitive.

- *Before 1999 – Madagascar*
- *1999-2000 – China, Indonesia*
- *2000-01 – Bangladesh, Cambodia, Cuba, Laos, Gambia, India, Myanmar, Nepal, Philippines, Sierra Leone, Sri Lanka, Thailand*
- *2002-03 – Benin, Guinea, Mozambique, Peru*
- *2004-05 – Senegal, Pakistan, Vietnam*
- *2006-07 – Bhutan, Burkina Faso, Iran, Iraq, Zambia; Afghanistan, Brazil, Mali*
- *2008 –Costa Rica, Ecuador, Egypt, Ghana, Japan, Rwanda*
- *2009-10 – Malaysia, Timor Leste, DPRK; Haiti, Kenya, Panama*
- *2011-12 – Colombia, Korea, Taiwan, Tanzania; Burundi, Dominican Republic, Niger, Nigeria, Togo*
- *2013-14 – Cameroon, Liberia, Malawi; Congo DR, Ivory Coast, US*

By 2005, the 'proof of concept' for SRI's beneficial effects on rice production had been demonstrated in 22 countries that produce about 88% of the world's rice. By 2015, this percentage had reached about 98%.

13. What has been the response of scientists and policy makers?

Initially there was skepticism regarding the higher yields reported with a reduction in inputs and with no use of new or improved varieties. A number of critical articles were published in the mid-2000s, but the push-back against SRI has diminished since then as more and more agricultural scientists have taken an interest in SRI, particularly in China (Zhu et al. 2006) and India (Pandian et al. 2011; Thiyagarajan and Gujja 2012), documenting the effects of SRI management and the merits of its component practices. Over 600 published scientific articles on SRI are available on the SRI-Rice website at: http://sri.cals.cornell.edu/research/index.html

SRI has been praised by the presidents of the World Bank and the International Fund for Agricultural Development (IFAD) and by the administrator of USAID, among others. The World Bank Institute has produced a *toolkit* for SRI: http://info.worldbank.org/etools/docs/library/245848/overview.html

Governments in China, India, Indonesia, Vietnam and Cambodia – where two-thirds of the world's rice is produced – are supporting SRI dissemination, having been encouraged by their farmers' good results. There should not be much controversy about SRI any more, although more research still needs to be done to understand better the potentials and limitations of SRI.

14. What do you see as future directions for SRI?

The ideas that created SRI and their applications will continue to evolve, already being applied to many crops beyond rice. We anticipate a convergence between SRI practice and *conservation agriculture* (Sharif 2011; Lu et al. 2013).

Initiative and innovation to modify farmers' crop management practices should continue and increase, with productive cooperation among farmers, researchers, extensionists, government agencies, and the private sector. This could transform the current one-way, linear model of agricultural research and development, going from research to extension to adoption, to establish more interactive and reciprocating relationships, describe by ISNAR as ‘triangular,’ where researchers, farmers and extension personnel interact and jointly undertake problem-solving for agricultural improvement.

It is anticipated that the impact of SRI will contribute to a *‘rebiologization’ of agriculture* as soil biology and ecology and plant physiology become more important in investigation relative to the present emphasis on soil chemistry and various kinds of mechanical and genetic engineering, The present, rather DNA-deterministic approach to genetics is being modified and superseded by more attention to epigenetics and to the factors that affect gene expression rather than simply to the genes themselves. SRI makes clear how much plasticity and potential there is in the rice genome. Learning how to produce ‘more from less’ will be essential for having a sustainable agricultural sector in this 21st century (see FAO 2015, and its section on SRI).

Ecuadorian farmers participating in a comparison trial organized by the NGO FUNDEC in 2010 showing the difference in crop stands.

Trial plots at Al-Mishkhab Rice Research Station near Najaf in southern Iraq evaluating different varieties in terms of their response to SRI management methods. The rice plants on the left side of each pair of plots were grown with SRI methods: young seedlings, wide spacing, etc., but differences in water control (AWD) could not be fully maintained. In each pair of trials, plants on the right are the same variety being grown with recommended on-station management methods.

MORE IN-DEPTH ANSWERS

Farmers in Baghlan province of northern Afghanistan learning SRI concepts and methods under a program initiated by the Aga Khan Foundation in 2007.

1. What is SRI?

The System of Rice Intensification (SRI) was developed as a set of insights and practices that beneficially change the management of the plants, soil, water and nutrients which are used for growing irrigated rice crops. These concepts and practices have been adapted also for raising rice that is not irrigated and for growing a number of other crops. So SRI is no longer just relevant for growing irrigated rice. As noted below, SRI is not just another kind of technology.

SRI methods by promoting the growth of plants that are more productive and more robust can give farmers *higher yield* (more kg or tons of rice per hectare) with the *use of less seed and less water* because the number of rice plants per m^2 is greatly reduced, and paddy fields are not kept continuously flooded. Each individual plant becomes much more productive. Significantly, SRI methods do *not require farmers to purchase new seeds or chemical inputs*, since inorganic fertilizer and agrochemical protection are not as necessary as with standard practice, although they can be used along with the other SRI practices.

Practically all rice varieties have given higher yield with these methods, although some varieties respond better than others. ‘Improved' varieties have usually given the highest yields with SRI management; but the yields of so-called 'unimproved varieties’ can also be greatly increased by SRI practices, quite commonly reaching 5 tons/ha and often more.

After a summary response to the very broad question *"what is SRI?"* more information is provided on each of the respective elements of SRI practice, followed by responses to certain related questions for which we have details.

- SRI methods are particularly accessible to and beneficial for poor households who need to get the maximum benefit from their limited land, labor, seeds. water, and capital. However, SRI concepts and practices can be adapted and used with *any scale of production*, from small-scale to large-scale, and they are amenable to considerable mechanization. So the methods can have and are having broad applicability.

- In an unprecedented way, SRI methods raise the *productivity of land, of labor, of water, of seeds, and of capital* all at the same time. Because the methods make soil systems more fertile, through biodiversity and biological activity, there is not the same requirement for 'tradeoffs' among the factors of production (land, labor, capital, etc.) as is the rule with improvements made in conventional agricultural technology.

- Because SRI's higher productivity will make more rice available in markets, it is hoped that over time the methods will lower food prices and will have widely distributed benefits. Everyone benefits when a country can meet its needs for staple food for its population with *less* of its land, labor, water and capital resources. Countries can then devote their freed-up resources (land, labor, capital, water) to meeting other needs of their people.

Juarez and his wife, the first farmers in Rio Grande do Sul state of Brazil to use SRI methods in their country, were able to get a doubled yield in their first attempt.

There is no secret and no magic with SRI. All of its results must be -- and are -- explainable with solid, scientifically-validated, verifiable *knowledge*. From what we know so far, the management practices recommended under the rubric of SRI are successful in large part because they promote two crucial things:

- **Better growth and health of rice plant roots.** With SRI practices, roots grow larger and deeper and do not degenerate for lack of oxygen in the soil as occurs when rice fields are kept continuously flooded (Barison and Uphoff 2011); and

- **The abundance, diversity and activity of beneficial soil organisms** – bacteria, fungi, earthworms, and other soil biota. These can improve the soil's structure, functioning and fertility and thereby contribute to the growth and health of rice plants (Anas et al. 2011; Zhao et al. 2010). How these two factors – roots and soil organisms -- interact positively is discussed on pages 33-34 below.

In practice, SRI involves some combination of the following simple changes in rice-cultivation practices. These practices are reviewed in the section that follows. Reasons for why they are recommended are discussed on pages 122-132.

- If the rice crop is being established by transplanting, the seedlings should be *transplanted at a very young age* – 8 to 12 days old, at most 15 days old – instead of when they are 3 or 4 weeks old or more.

- Seedlings are raised in *unflooded nurseries*, sowing the seeds sparsely rather than densely and supplying the soil with organic matter. It is possible to establish an SRI crop with direct seeding, but transplanting is still the most common method for crop establishment. This will likely change in the future.

- Seedlings are transplanted *quickly, carefully and shallow,* taking care so that there is minimum trauma to roots. *Plant root tips should not be inverted upward* as this will delay their resumption of growth. Deep transplanting inhibits tillering.

- Seedlings are transplanted at a *wider distance and singly*, not in clumps of 3 to 6 plants, and also planted in a *square pattern*, usually 25x25 cm for most soils. This gives the plants' roots and leaves more space to grow. In more fertile soils, even wider spacing, say 30x30 cm, gives better yields; conversely, in less fertile soils, better yields come with closer spacing, e.g., 20x20 cm.

- *No continuous flooding of the soil* since inundating the soil causes the roots to degenerate and suppresses soil organisms that require oxygen. So (a) *apply small amounts of water daily* to keep the soil moist if not saturated; or (b) *alternately flood and dry the soil* for short periods, a few days at a time.

- Use a simple mechanical *hand weeder* for weed control if available. This *aerates the soil* at the same time that it eliminates weeds, leading to better yield than with weed control either by manual weeding or by herbicides.

- Provide the soil with *as much organic matter as possible*. Although chemical fertilizer gives positive results with SRI practices, most of the best yields have come with organic fertilization. Organic matter does more than just 'feed the plant.' *Organic matter 'feeds the soil system' so that it can feed the plant.*

SRI methods were assembled in the early 1980s, as explained on pages 38-39. Only after 2000 did SRI begin to receive any attention around the world, and it was not very visible until after the first (and so far only) international conference on SRI, held in China in 2002. So, SRI has not been on the world scene for much more than a decade. During this time, SRI methods have been validated in over 50 countries across a wide range of agroecosystems – from equatorial to temperate climates, and from sea level to 2,700 meters above sea level.

The number of countries where SRI merits have been demonstrated, and where SRI is expanding, has been increasing year by year. Recent additions to 'the SRI club' include countries as diverse as Benin, Cameroon, Colombia, DPRK, DR Congo, the Dominican Republic, Liberia, Malawi, Taiwan, Tanzania, and the U.S.

An SRI field in the Democratic People's Republic of Korea in 2009 where the American Friends Service Committee (AFSC) introduced trials on four cooperatives (250 ha of trial plots) near Pyongyang. Even partial use of SRI methods added 0.5-1.0 t/ha to yield.

- The most rapid spread of SRI has been in **Vietnam**, where fewer than 10,000 Vietnamese farmers were using the methods in 2007, when the Ministry of Agriculture and Rural Development issued a formal decision that declared SRI to be *"a technical advance."* Within four years, the Ministry reported that there were over 1 million Vietnamese farmers using most or all of the SRI methods (http://qdnd.vn/qdndsite/en-US/75/72/182/156/189/164012/Default.aspx). By 2014, the number of farmers using SRI methods had reached 1.8 million.

- The Indian state of Tamil Nadu reported in 2012 having *over 1 million farmers* using SRI methods there on 850,000 hectares. This spread has been supported by Tamil Nadu Agricultural University under the World Bank-funded IAMWARM project, with the state government also promoting SRI utilization through its extension service (Pandian et al. 2011).

- In the Indian state of Bihar, SRI was introduced in 2007 with 128 farmers on 30 hectares. Within five years, the Ministry of Agriculture reported that SRI use has expanded to *335,000 hectares*, with yields of 5 to 8 tons/ha, 2-3x the usual paddy yield there. Given the small holdings in Bihar, the number of farmers was *about 1.3 million* (Verma 2013).

SRI is considered *as a methodology* rather than *as a technology* because it consists of concepts and practices that are to be applied by farmers to their local conditions and adapted for best results. As discussed on page 37, SRI is not a fixed set of things that farmers must do; it is more like working from a *menu* than from a *recipe*. Using SRI methods requires no material inputs beyond what farmers already have. Mostly it requires making changes in thinking and in practices.

- For simplicity's sake, SRI is usually spoken of as a *thing,* i.e., as a noun. But the term SRI is better utilized as a *description,* i.e., as an adjective. Most concretely, SRI refers to the use of certain *practices* that reflect specific *insights* into crop management dynamics but these are based on well-defined *principles* that can help farmers to provide their rice plants with an optimum growing environment both above- and below-ground.

- By altering plants' growing environments, SRI practices can elicit from any rice genotype or variety *a more productive plant phenotype* (Thakur et al. 2010; Uphoff et al. 2015). All effects of SRI practices can be explained with well-established scientific knowledge, usually referring to simple, even elementary relationships, like not crowding plants together to avoid inhibiting their roots' growth. When SRI is sometimes called, dismissively, 'just good agronomy,' this is taken as a compliment rather than as a criticism or implied refutation of SRI.

- Because some varieties (genotypes) respond to SRI practices better than do others, it is clear that *genetic potentials are important*. Many traditional or 'unimproved' varieties have given very good responses to SRI methods (5-10 tons/ha), and it can be more profitable for farmers to grow these when their market price is high because of consumer preferences. New varieties are not a necessary or the only way to grow rice more productively and profitably.

- Because SRI results depend on the realization of biological potentials, the results with SRI can be quite variable, more variable than if results are due to fulfilling some fixed genetic blueprint, or if the crop outputs are primarily due to (and thus proportional to) external inputs such as fertilizer. This variability may be disconcerting to some persons, but it is this *plasticity* that offers great opportunities to farmers who can, through better management practices, learn to capitalize on and utilize these biological potentials.

1.1 What are the key practices?

SRI is most easily visualized and operationalized in terms of certain practices that farmers are advised to try out on their own rice fields, to see if they can improve the productivity of their rice crop. These practices are based upon a suite of insights and principles that constitute the core of SRI. These particular *practices* recommended for SRI and discussed below are in effect the *signature* of SRI.

SRI's recommendations for more successful rice production markedly change what are usually age-old methods for growing irrigated rice. Even though the changes in practice are simple, they may not be readily or quickly adopted, being counterintuitive. It is important to emphasize with farmers the *reasons* for making the suggested changes in practice: to promote bigger, healthier root systems that can support larger, more productive plants, growing in biologically active soil systems that are or will become more fertile and more biodiverse.

- When establishing a rice crop by transplanting, use *very young seedlings*, less than 15 days old and preferably 8-12 days old in warm tropical climates. In biophysical (phenological) terms, 'young seedlings' should be in their 2-leaf to 3-leaf stage. The usual age of seedlings that farmers now use is 3 to 4 weeks, and up to 6 or 7 weeks in some countries. Seedlings which are older than about 15 days lose much of their potential for profuse growth of roots and tillers, as discussed in the section on phyllochrons (pages 154-162).

4-day-old seedlings being transplanted by Miyatty Jannah in her SRI fields in Crawuk in East Java, Indonesia. These are younger than necessary; but Miyatty found them easy to manage, contradicting the idea that farmers cannot handle such small seedlings.

- *In colder climates,* somewhat older seedlings, even up to 20 days, can still be physiologically equivalent to 'young seedlings' of 12-15 days grown in warmer climates. Why? Because at lower temperatures, plants grow more slowly. Plants' calendar age and physiological age are not the same.

- Note that farmers in several countries have begun experimenting successfully with *direct seeding* which can reduce their labor requirement for SRI. For now, however, SRI is focused mostly on reducing the age at which rice seedlings are transplanted.

Drum seeder for direct-seeding SRI, developed at the RASS-Acharya Ranga KVK In Tirupati, Andhra Pradesh state of India (Hussain Reddy et al. 2011).

Three-row direct-seeder fabricated by Cuban farmer Luis Romero for 40x40 cm SRI spacing. This implement was not successful because this spacing was too wide, and weeds became too dominant. His neighbor built an ox-drawn 12-row seeder; but it also was not effective because it proved to be too awkward to be managed with oxen.

- Seedlings for transplanting should be *grown in an unflooded, garden-like nursery,* watered by hand, and with a rather low seeding rate, 2-3 cm apart, so that the roots of all the seedlings have plenty of room to grow and are easily separated. The soil in nurseries should be loose and rich in organic matter, so that removing seedlings is easy and with little trauma to the roots.

SRI nursery seedbeds established by tribal farmers in Madhya Pradesh state of India who are working with the Madhya Pradesh Rural Livelihoods Program.

Young rice seedlings being lifted out of an SRI seedbed on a trowel, keeping the earth intact around their roots.

- When taking seedlings out of the nursery, they should be removed *very carefully*, lifted with a trowel, unless being grown on small plastic or metal trays for easy transport to the field as see on the next page, so that there is no trauma for the roots. The *seed sac* should be kept attached to the root, and the soil that is attached to the seedlings' roots *should not be knocked off.*

SRI seedlings being grown on plastic trays, an increasingly popular practice in Lombok, Indonesia. With SRI dramatically reducing the number of seedlings needed, this method for growing seedlings makes it easy to take them to the field and move them within it.

- Seedlings should be *transplanted soon after being removed* from the nursery, within 15-30 minutes, so that their roots do not dry out. They should be *transplanted gently and carefully*, to avoid any trauma to the roots.

- When transplanting, rather than pushing the seedlings down into the soil, they should be *put into the soil very shallow,* just 1-2 cm deep. If pushed straight downward into the soil, the *tips of their roots will invert upward*.

- When seedlings' root tips point upward, the roots can take a week or more to reorient their tips downward, so they that they resume growth. *Transplanting shock* can be minimized by handling SRI seedlings carefully and by getting them replanted quickly and precisely in the main field.

Example of careful SRI transplanting from Sri Lanka.

Seedlings should be transplanted in the field with wider spacing than is usual now. This reduces rice plant populations per square meter by 70 to 90%.

- *Single seedlings* are put in each hill, instead of the usual number of 3 to 6 plants clumped together in a hill. At the same time,

- Hills are located *in a square pattern*, 25 x 25 cm – or even wider if the soil's fertility is very good. By planting seedlings in a square grid, farmers can to do their crop weeding with a mechanical implement in perpendicular directions as soon in the picture on page 32 from Indonesia.

25x25 cm spacing gives a plant density of 16 plants per m^2 compared to the more common density of 50 -100 plants per m^2, even up to 200 plants per m^2.

A farmer in Madagascar transplanting with her spacing of plants guided by marks on strings stretched across the field between posts that are moved 25 cm at a time.

An SRI farmer in Eastern Indonesia marking lines on his paddy field for precision transplanting of seedlings by using a simple wooden rake.

An SRI farmer in Punjab state of India using a metal roller-marker to imprint a grid pattern on his muddy field, impressing lines for a geometric pattern of transplanting.

- Paddy fields should be given *just enough water* to meet the needs of the plants and of soil organisms. *When the soil is kept continuously flooded*, this creates hypoxic conditions (no oxygen) in the soil. This inhibits root growth and prevents the flourishing of aerobic soil organisms, that is, ones which require oxygen.

  - Either small amounts of water should be applied daily to *keep the soil moist but with no standing water*; or fields can be *alternately flooded and dried out*, which requires less labor time. Either method can keep the soil system supplied with *both water and oxygen* to support the growth of the rice plants and of large populations of beneficial, aerobic soil organisms.

- When paddy soils are not continuously flooded, *weed control* becomes a greater problem. Weeds can be removed by hand or with herbicides, but the best results come with use of a *simple mechanical weeding implement* – a rotating hoe or a conoweeder – starting 10-12 days after transplanting.

  - Additional weedings are then done every 10 to 12 days until shading of the soil from the rice plants' growth inhibits further weed growth, and crop growth makes further weeding difficult because the leaves' canopy fills in all of the space between plants.

  - *Active soil aeration* from use of a mechanical weeder enhances both root growth and plant vigor. This makes the plants better able to withstand climatic stresses and pest and disease attacks.

Use of mechanical weeders in perpendicular directions in Eastern Indonesia.

- SRI was initially developed using chemical fertilizers to enhance soil nutrient supplies. But fertilizer requires cash expenditure by farmers, and it has been seen that with SRI management, rice plants' performance can be good -- and sometimes even better -- with *organic fertilization.*

  - We recommend the *application of compost, as much as possible.* This can be made from any decomposed biomass: rice straw, weeds, crop residues, loppings from shrubs and trees, kitchen wastes, and any available animal manure. Organic matter is valuable not just for its *nutrient content* but also for how well it can *improve the structure and the functioning of soil systems*.

  - Compost stimulates the growth and services of *soil organisms*, whose benefits include better aggregation and porosity of the soil, nutrient cycling, nitrogen fixation, phosphorus solubilization, better water absorption and retention, induced systemic resistance to pathogens, etc.

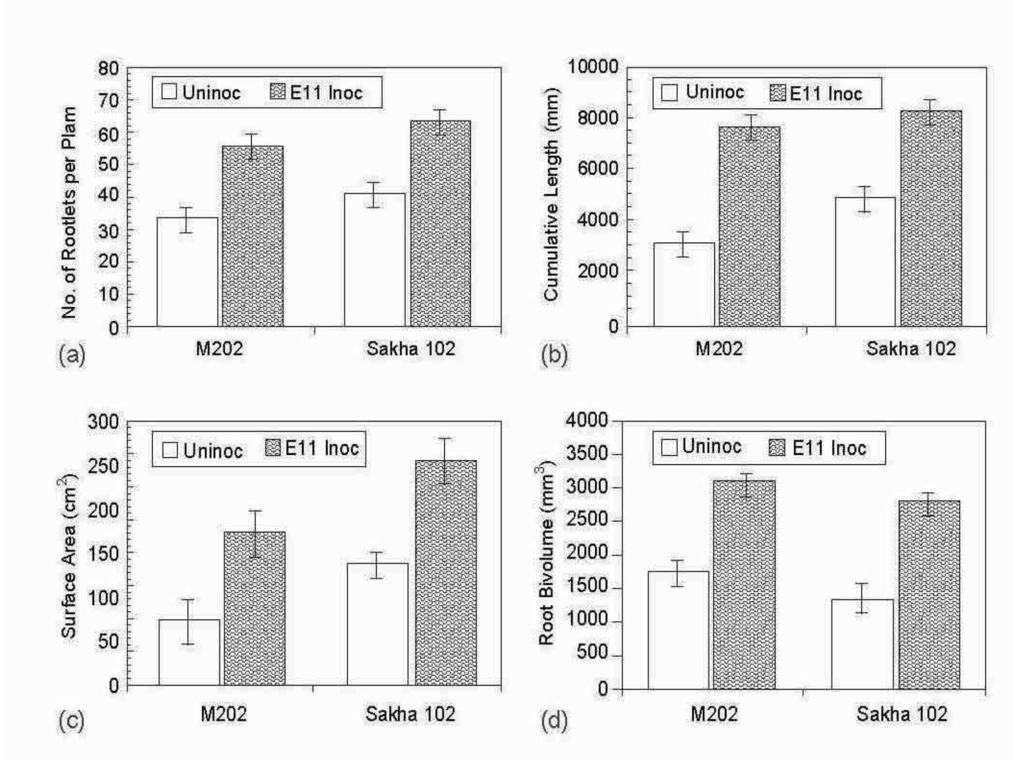
These practices are mutually reinforcing, nurturing the growth of plants' roots, leaves and tillers. Better nutrient acquisition by roots together with more photosynthesis in the leaves creates what analysts call a *positive feedback loop*. The roots help to nourish the canopy, at the same time that the canopy through its photosynthesis helps to nourish the roots. *The growth of each supports the growth of the other*. This is one of the basic explanations for SRI success.

Bourema, the first farmer in Burkina Faso to use SRI methods successfully, showing the root and canopy growth on one of his SRI rice plants. His first SRI yield was 7 tons per hectare, several times the average rice yield in Burkina Faso.

Another interactive effect is between the roots and soil biota which have positive feedback that is only starting to be studied. The kind of massive root growth seen in the picture above and on pages iv and 122, appears to be more than just a result of the plants all by themselves expressing greater growth potential.

There is some evidence that microorganisms, around, on or even in the plant, affect this expression of growth potential. When residing in the rhizospshere they benefit from sugars, amino acids and other exudates from plant roots; also they can access these when living within plant tissues and cells as symbiotic endophytes. Further, microbes produce many of the same phytohormones (growth-promoting or growth–regulating compounds) that the plant roots and shoots do (Khalid et al. 2006). So there are many intimate and essential nutrient and other biochemical connections between microorganisms and the roots and shoots of plants.

- Research in Egypt has shown positive feedback between the presence of certain rhizobacteria and the growth of rice plant roots (Yanni et al. 2001). When evaluating the root architecture of two different varieties of rice, it was found that the inoculation of rice plants with *Rhizobium leguminosarum* had significant and beneficial effects on (a) the *number of rootlets* per plant, (b) *cumulative root length* (in mm), (c) the *surface* area of the root systems (in cm^2), and (d) the root systems' *biovolume* (in cm^3). These effects are seen in the figure reproduced on the next page.



Source: Yanni et al. (2001).

Unfortunately there is still not much research on these kinds of symbiotic relationships where plants' roots and shoots and soil organisms benefit each other. For decades, most of the microbiological research associated with plants has been on microbial pathogens, 'the bad guys,' rather than with symbionts, 'the good guys.' This has been changing in the past 10-15 years, however. SRI experience and pictures such as those shared here should accelerate this trend.

Complementary Practices

There are a number of *other practices* that are beneficial when used together with any rice cultivation methods. However, they are not described as part of SRI because they are not unique to SRI. All rice farmers should take them seriously.

- **Land preparation**: Paddy soil should be well-worked and well-leveled, so that there is good soil structure, and so that the plants' roots can spread easily through the soil. *Proper leveling* helps farmers to achieve uniform wetting of all the soil on their fields just by making small applications of irrigation water.

  We should note that many farmers are now combining SRI methods with *conservation agriculture* (CA). This is based on no-tillage or minimal soil disturbance, combined with keeping the soil covered with organic matter (mulch) and rotation of crops (no monoculture). SRI methods of crop and water management can work well with *permanent raised beds*. Irrigation is provided in small amounts through the ditches that run between the beds, and the beds are mulched with organic matter, or covered with plastic film as in Sichuan province of China, thereby suppressing weeds and conserving soil moisture (Lu et al. 2013). Soil aeration, achieved in most SRI practice through mechanical weeding, can be accomplished by abundant and active populations of soil organisms, particularly earthworms, which enhance the soil's porosity and its 'breathing,' as seen in pictures on pages 82 and 109.

- **Varietal selection**: Farmers should choose a variety, either improved or local, that is well-suited to their own conditions (soil, climate, drainage, etc.), that is resistant to anticipated problems like certain pests or irregular water supply, and that has desired grain characteristics with a good market value.

- **Seed selection**: Only the best, heaviest seeds, ones that have good density and are fully-formed, should be used when starting an SRI nursery or any other.

  - One method to facilitate seed selection is to submerge all the seeds in a pail of water with enough salt dissolved in it to make a solution in which an egg or potato will float. When farmers put seed grains into this salty water, inferior seeds will float on the water's surface, while good seeds will sink to the bottom of the pail. These heavier ones will produce more vigorous seedlings and better plants; all the grains that float are thrown away.

  - This same separation of the better, denser seeds from less well-developed seeds can be accomplished just by soaking all the seeds in a pail of water for 24 hours, and then using only those that sink to the bottom.

  - Farmer experimentation in Cambodia has shown that grains taken from the branches in the *middle* of a rice panicle -- rather than from the top or the bottom branches – are better seeds, producing more vigorous and more productive plants. Yield enhancement of 10-20% makes the extra effort to select only seeds from the middle of rice panicles worthwhile.

Demonstration of seed-soaking to select just the most viable seeds in Afghanistan.

- **Seed priming**: This practice of soaking seeds in a solution before planting has been found to enhance the rate of germination and seedling emergence. Details on seed priming can be obtained on the web at: http://www.gaia-movement.org/files/Booklet%2029%20Priming.pdf. A study in Pakistan found that while priming seeds with a 1.5% solution of calcium chloride enhanced the yield of conventionally-grown rice plants by 13%, this practice increased the yield of SRI rice plants by 21% (Khalid 2013).

- **Nursery solarization**: Where farmers have soil-health problems to deal with, such as fungal pathogens or root-feeding nematodes, they may find it wise to *solarize their nursery soil* before sowing. This is done by covering the soil for the nursery area on which they plan to grow seedlings with *clear plastic* for 2 to 8 weeks before the seeds are going to be sown in the nursery. This can raise the soil temperature by as much as 10^{o} C. An example of seedbed solarization in Nepal is shown on page 132.

  Higher soil temperatures eliminate most of the organisms that have adverse impacts on young seedlings and subsequently on the mature plants. This practice enables nurseries to produce seedlings that have greater health and vigor, thereby improving the crop's performance (Banu et al. 2005).

Moses Kareithi, an innovative farmer in the Mwea Irrigation Scheme in Kenya, examining his SRI field, which he planted just by using simple notes on SRI after viewing the World Bank Institute's video on SRI. He understood the methods quickly and was impatient to try them, not waiting for the planned formal farmer training. Despite poor leveling of his field, his yield increase was 38%. So impressed by his results, Moses began promoting SRI among fellow farmers and was subsequently hired by the National Irrigation Board to do SRI extension work in the Mwea Scheme.

1.2 Why isn't SRI considered as a new technology?

SRI is referred to as a *system* or as a *methodology* rather than as a *technology*. SRI is a system of practices that are based on a number of concepts and principles which can produce better results. So why not call SRI a technology?

Because this term generally implies something that is *fixed and final*, something that is *finished and ready to be transferred*, something for farmers to use as instructed -- rather than something which is evolving and to be improved, season by season, as more experience is gained.

SRI evolves and improves as more farmers, scientists and others apply their intelligence and insights to making rice production more efficient and sustainable. For some people in India, SRI stands for the System of Root Improvement. In any case, SRI is *a work in progress*.

By not presenting SRI as a technology – as something to be *adopted* -- but instead as an *innovation* based on certain ideas about how to provide rice plants with an optimal growing environment, farmers can better understand SRI as *something to which they can and should contribute*.

Our terminology suggests to farmers that they should be making *adaptations* of SRI methods to suit their own conditions. We expect that farmers can and will be making further *improvements* in SRI and also further *innovations.* Farmers are expected and encouraged to engage in *participatory technology development* contributing to this process as *active partners* rather than as *compliant adopters*.

Also, technologies are usually associated with something *material* -- like a new implement, a better seed, an agrochemical, or a specific fertilizer -- whereas SRI is something more in the mind. The name which Fr. Laulanié and his associates agreed on for the NGO that they formed in 1990 to give impetus to developing and promoting SRI in Madagascar was *Association Tefy Saina*. This name refers to human development rather than to growing more rice. The best French translation of the Malagasy words *Tefy Saina* is '*formation de l'homme*.'

The fact that there are no material requirements for practicing SRI puts it in a different category from the kinds of technologies that have been prevalent in the agricultural sector for many decades. The benefits of SRI can be achieved essentially by farmers changing their thinking and their practices, rather than by buying prescribed inputs and depending on these more than upon themselves.

2. What are the origins of SRI?

Father Laulanié at his desk in his Antananarivo home.

SRI was developed in Madagascar through half-a-lifetime of effort by a French priest, Henri de Laulanié, who spent the last 34 years of his life working with traditional farmers in that country. He sought to help them reduce their poverty and hunger by improving their production of rice, the source of more than half of the calories consumed daily by typical Malagasies. His approach was to rely on simple methods that would not require farmers to purchase external inputs. Few Malagasy farmers could afford these, and these were generally not very available in much of the country even if farmers had the money to buy them.

Born in 1920, Laulanié attended France's leading agricultural college before the start of World War II. After graduating with a baccalaureate degree in 1939, he decided, given the terrible suffering spreading throughout in Europe, to change careers, and he entered a Jesuit seminary in 1941. After graduating in 1945, he worked in France for the next 16 years, among other things teaching in the agricultural college at Angers. In 1961, he was sent by the Jesuit order to Madagascar as an agricultural advisor. Although he knew little about rice when he arrived, he had been trained in general agriculture, so he decided to focus on raising the productivity of this crop that was important to all Malagasy households.

Over the next two decades, he observed and experimented with various practices. Two practices that contributed to SRI he learned from farmers who had departed from traditional cultivation methods. He found a few farmers who were transplanting *single seedlings* instead of 3-6 seedlings in clump, and some other farmers who were *not keeping their rice fields continuously flooded* – only moist enough to meet their crops' needs. To control weeds, which become a big problem when farmers did not keep their paddy fields always flooded, Laulanié started using a simple implement, the *rotating hoe* (called *hou rotative* in French), which aerated the topsoil at the same time that it eliminated weeds.

As his own unique contribution to SRI, Laulanié experimented with planting the single seedlings *in a square pattern*, 25x25 cm (10x10 inches). This permitted him to use the rotating hoe in two directions, perpendicularly, criss-crossing the field at right angles (90^{o}) as seen on page 32. This geometry of plant establishment reduced rice plant populations by 70-90%, giving every plant ample room for its roots and above-ground parts to grow freely. The roots had more volume of soil to access, and the leaves got better exposure to the sunlight and air (pages 123-124). Mechanical weeding enhanced both soil aeration and the growth of rice plants' canopies and roots, also reducing their susceptibility to pests and diseases.

The biggest step toward the development of SRI was Laulanié's serendipitous discovery in 1983 that transplanting *very young seedlings*, only 15 days after the rice seeds had been sown in the nursery, greatly increased their eventual yield (Laulanié, 1993). It turns out that transplanting young seedlings preserves the plants' potential for prolific growth of roots and tillers. This can be explained by an understanding of phyllochrons, discussed on pages 154-162.

SRI was developed with the use of chemical fertilizer. But when the government removed its fertilizer subsidy in the late 1980s – and small farmers could no longer afford to buy it – Laulanié modified SRI practice to *utilize compost*, which proved even more beneficial for plant growth (Uphoff and Randriamiharisoa 2002).

Fr. Laulanié making a field visit shortly before his death in 1995.

In 1990, together with some Malagasy friends and colleagues, Laulanié formed a local NGO called **Association Tefy Saina.** Its name, as noted above, means ‘human development’ rather than ‘grow more rice.’ The Association's mission was to promote broad-based agricultural and rural development in Madagascar as explained in a posthumous publication (Laulanié 2003).

In 1994, Tefy Saina began working with the **Cornell International Institute for Food, Agriculture and Development** (CIIFAD) on an integrated conservation and development project funded by USAID in and around Ranomafana National Park. This project was designed to protect endangered rainforest ecosystems in the country's central-eastern escarpment, in part by giving farmers productive alternatives to their illicit slash-and-burn cultivation practices.

The first president of Association Tefy Saina, Sebastien Rafaralahy, and its first general secretary, Justin Rabenandrasana, together on a field visit in Madagascar.

Over the next three cropping seasons, farmers trained by Tefy Saina field staff achieved, without changing varieties and without relying on chemical fertilizers, average yields of *8 tons/hectare* on fields where previously they had averaged only *2 tons/hectare*. Some of the farmers reached yields of 10, 12, even 14 tons. In 1997, CIIFAD started trying to get colleagues in other countries to try out SRI methods and evaluate these modifications of standard practice for themselves.

By this time, however, Fr. Laulanié had unfortunately passed away, dying in June 1995 at age 75, not knowing how successful his innovation could be and would be. (On his life, see: http://sri.cals.cornell.edu/aboutsri/LaulanieBiography.pdf, in French.) It fell to Association Tefy Saina and CIIFAD to carry on his work, building on his insights and trying to understand and share more widely the opportunities that his lifetime of selfless work had created by thinking ‘outside boxes.’

Laulanié would have been the first to insist that SRI should be an evolving farmer-centered phenomenon, a body of knowledge and practice to be enriched by new learning and by continuing experimentation and evaluation. In a technical article (1992), Laulanié suggested that SRI ideas could be extended to upland or rainfed rice production, for example.

Because SRI was not promoted as a fixed technology, many farmers and other individuals as well as non-governmental and governmental organizations around the world have since taken ‘ownership’ of the innovation, which has been extended and extrapolated also to other crops beyond rice.

An example is a direct-seeded, semi-mechanized version of SRI in Vietnam, in part for the purpose of reducing greenhouse gas emissions, with technical support from the Dutch development organization SNV and financing from Australian Aid; see this video on YouTube: https://www.youtube.com/watch?v=51uNFQL1zMw. Surely Fr. Laulanié would have been quite pleased with this extension of his ideas in labor-saving, environmentally-beneficial ways.

An SRI paddy field in Madagascar whose yield from a traditional rice variety was calculated by a government agricultural technician to be 17 tons per hectare. This yield could not be verified. But in any case, compared with the usual rice yields in this country, this crop is quite remarkable and a great improvement. Even a yield of 8 or 9 tons is a great boon for farmers and families in this or any country.

2.1 How has SRI spread around the world?

Before drawing any conclusions about SRI's efficacy, CIIFAD followed the normal practice for agricultural science of waiting for three years of results (until 1997) to be satisfied that the remarkable results were not a fluke. After seeing farmers get *four-fold increases in their rice yields for 3 years in a row*, using the same varieties and less water, and without relying on chemical fertilizer to enhance the fertility of the nutrient-deficient, acidic soils around Ranomafana (Johnson 1994), CIIFAD started trying to get SRI methods tested and validated outside Madagascar.

Because SRI sounded 'too good to be true,' however, it took two years to get researchers elsewhere to take any interest in SRI. Most people rejected the innovation as too counter-intuitive to warrant empirical testing. In 1999, Chinese researchers at **Nanjing Agricultural University** and Indonesian rice researchers in the Ministry of Agriculture's **Agency for Agricultural Research and Development** (AARD) tried out SRI methods. Their results, along with evaluations from researchers at the **China National Rice Research Institute**, verified that more productive phenotypes of rice could indeed be produced by using these alternative methods (Wang et al. 2002; Gani et al. 2002; Zhu et al. 2002; Tao et al. 2002).

Signboard erected by the China National Rice Research Institute in the village of Bu Tou, Tien Tai township of Zhejiang province, where some of the first Chinese field trials of SRI were done. In the middle of the back row are Zhu Defeng (in white t-shirt), a senior rice scientist in CNRRI who initiated SRI evaluations and has served as volunteer coordinator for SRI work in China, and next to him the author. In the front row (in white shirt) is Nie Fuqu, a farmer whose harvested SRI yield in 2004 was 11.38 tons/ha despite three typhoons having hit his village and wiping out most of his neighbors' crops due to lodging. The next year, in 2005, Nie began experimenting with direct seeding and zero-tillage for SRI, and obtained a yield over 10 tons/ha as evaluated by CNRRI researchers.

Also, Prof. Yuan Long-ping, known worldwide as 'the father of hybrid rice' and director of the **China National Hybrid Rice Research and Development Center,** validated SRI methods at his research centers in Changsha and Sanya, and at a seed multiplication farm that he worked with in Meishan, Sichuan (Yuan 2002).

Prof. Yuan Long-ping, on left, in front of an SRI trial plot at the China National Rice Research and Development Center in Sanya, China, in April 2001. On right, Liu Zhibin, manager of a seed multiplication farm in Meishan, Sichuan province, who obtained a 16 tons/ha yield using SRI methods with Prof. Yuan's Super-1 hybrid rice in 2001 (Yuan 2002). Liu is standing in a plot where he used SRI methods on no-till raised beds which gave him a 13 ton/ha yield in 2005, alternating SRI rice crop with potato production.

- In June 1998, the secretary of Tefy Saina, Justin Rabenandrasana, made a presentation on SRI to an NGO meeting on rice held in the Philippines, co-sponsored by the **International Institute for Rural Reconstruction** (IIRR) and a Dutch NGO that promotes low-external-input sustainable agriculture, **LEISA**. The editors of LEISA's magazine invited an article on SRI for its worldwide readership especially among NGOs (Rabenandrasana 1999). This gave impetus to SRI trials in several countries, including Cambodia and Myanmar.

- in May 1998, the author, while director of CIIFAD, made a presentation on SRI at the **International Center for Agro-Forestry Research** (ICRAF) in Nairobi, and then another in March 1999 at the **International Rice Research Institute** (IRRI) at Los Baños, Philippines. As it turned out, little interest was expressed from either institution in learning more about SRI experience or its methods.

- In April 1999, the author presented a paper on SRI at a conference on agroecological innovations held at the Rockefeller Foundation's conference center in Bellagio, Italy which he had organized together with Miguel Altieri, (Uphoff 1999, 2002). This led to further diffusion of knowledge about the new methods and led to the first SRI demonstrations in Bangladesh, through CARE (Hussain 2002).

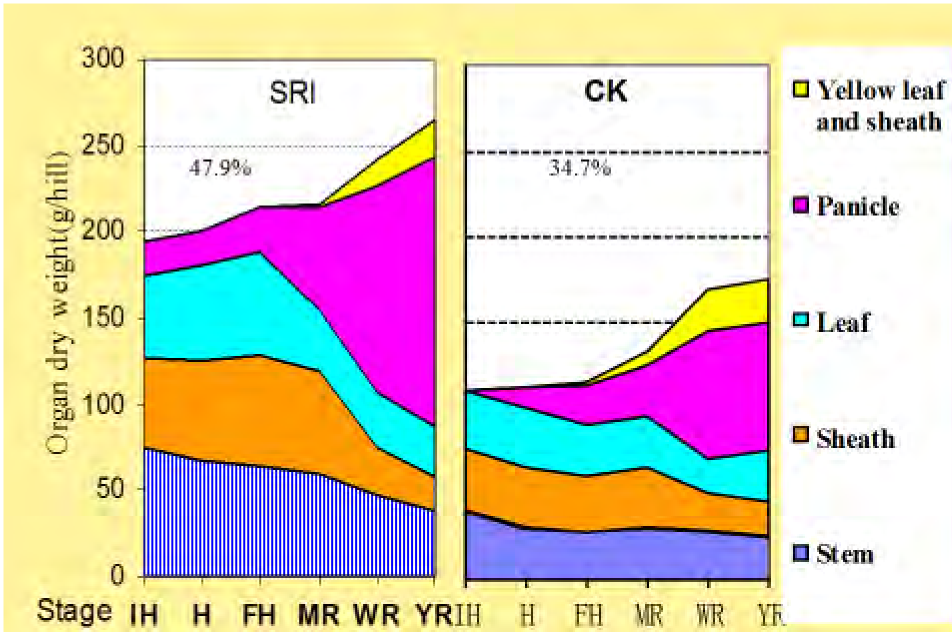
  - In Bangladesh, trials undertaken by staff of CARE, BRAC, and the Department of Agricultural Extension in 1999-2000 showed higher yields with reductions in irrigation cost. This was followed up by trials evaluating SRI methods conducted by three NGOs (BRAC, POSD and SAFE) working together with Syngenta Bangladesh Ltd., with funding from IRRI's PETRRA project. A total of 1,171 on-farm comparison trials over two years showed SRI methods giving 30% higher yields on average, with 7% lower costs of production, and 58% higher net income per hectare (Husain et al. 2004).

- In October 2000, Tefy Saina's president, Sebastien Rafaralahy, made a presentation on SRI at an international symposium on sustainable agriculture in Baltimore, MD, organized by the World Bank in conjunction with the Agronomy Society of America meetings that year. Three months later, he made another presentation on SRI at an international conference on sustainable agriculture convened at St. James' Palace in London. However, little evident interest was elicited from participants in either of these events.

  - Also in January 2001, the Florida-based NGO **ECHO** published an article on SRI in its *ECHO Development Notes* (Berkelaar 2001). This spread SRI knowledge further and prompted trials in several countries, including Benin and Peru.

- A research project on 'water-saving rice production systems' was initiated by some faculty at **Wageningen University** in 2000 with Dutch government funding. The author was coopted as an informal advisor for the project, which involved rice researchers in China, India, Indonesia, and Madagascar. At a project workshop held in Nanjing in April 2001, he made a presentation on 'Scientific issues raised by the System of Rice Intensification' and there were also research reports on SRI trials presented from each of the four countries (Hengsdijk and Bindraban 2001). The results of these trials spurred further work on SRI in China, India and Indonesia, but not at Wageningen.

- After the Nanjing workshop, the author and Prof. Robert Randriamiharisoa, the director of research for the Faculty of Agriculture of the University of Antananarivo, visited the China National Hybrid Rice Research and Development Center in Sanya, at the invitation of its director Prof. Yuan Long-ping to share our knowledge about SRI with Chinese rice scientists. Considerable interest was expressed there in the new ideas, and many initiatives were started in China, especially at the China National Rice Research Institute in Hangzhou.



Slide from presentation by Tao Longxing of CNRRI to International Year of Rice (2004) colloquium in Hangzhou, showing differences in average weights of rice plant organs (same variety) under SRI and conventional (CK) management, from initial heading (IH) to yellow rice (YR) stages of growth. 'Yellow leaf and sheath' refers to senescence. The large differences that Dr. Tao measured were evidence of the contrast in phenotypes.

From these various forums and from other contacts that CIIFAD and Tefy Saina were able to make on behalf of SRI, trials and demonstrations were begun from 2000 on also in Bangladesh, Cambodia, Cuba, Gambia, India, Laos, Myanmar, Nepal, Philippines, Sierra Leone, Sri Lanka, and Thailand.

- In April 2002, an international conference for SRI assessment was convened in Sanya, China, with support from CIIFAD, the Rockefeller Foundation, and the Rural Development Department of the World Bank. 45 participants from 15 countries shared SRI results and experience to date, with over 60 Chinese participants attending. The conference was hosted by the China National Hybrid Rice Center, with the China National Rice Research Institute and Association Tefy Saina as co-sponsors, as commented on in the Foreword. Proceedings were posted at: http://sri.cals.cornell.edu/proc1/index.html.

- Immediately after the Sanya conference, Randriamiharisoa and the author, along with several other SRI colleagues, participated in another workshop of the Wageningen project that was held at the International Rice Research

Institute in the Philippines. Data were presented from SRI trials in Madagascar, India, China and Indonesia and were published in the proceedings (Bouman et al. 2002). Following this workshop at IRRI, the author participated in additional workshops in Laos and Nepal organized respectively by IRRI's representative in Vientiane and by a CIMMYT staff member in Kathmandu.

Since the 2002 events at Sanya and Los Baños, reports from another 40 countries have shown that changing the management of plants, soil, water and nutrients as recommended for SRI can produce more productive, healthier rice plants in:

- **Asia:** Bhutan, DPRK, Japan, Korea, Malaysia, Pakistan, Taiwan, Timor Leste, Vietnam
- **Middle East:** Afghanistan, Egypt, Iran, Iraq
- **Sub-Saharan Africa:** Benin, Burkina Faso, Cameroon, Burundi, DR Congo, Ghana, Guinea, Ivory Coast, Kenya, Mali, Malawi, Mozambique, Niger, Nigeria, Rwanda, Senegal, Tanzania, Togo, Zambia
- **Latin America and the Caribbean:** Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Haiti, Panama, Peru

There has been little use of SRI methods in Europe, Canada and the U.S., although some SRI trials have been carried out in the latter by organic rice farmers. SRI use should spread into countries that are classified as 'more-developed.' The lack of interest there so far appears to stem from a belief that SRI is necessarily labor-intensive. This mistaken view may have deterred larger-scale producers from considering how SRI concepts and methods could be adapted and applied in their circumstances. Especially where water constraints are besetting agriculture, SRI ideas and practices should start receiving attention and evaluation.

An SWI wheat experiment conducted in 2009 by Mark Fulford, an organic farmer in Monroe, Maine, USA. The cap is shown to give a size comparison of the vigorous single plants at 28 days. Unfortunately, the crop's profuse growth before harvest attracted a hungry moose which devoured the plants, so there were no yield results to report. A video on Mark's applications of SRI ideas to a variety of other crops on his Maine farm is posted at: http://www.youtube.com/watch?v=ZUSXP7zVuxs

2.2 Does SRI spread require favorable political and other conditions?

One unexpected result of SRI's not depending upon material inputs and supplies to improve production – focusing instead on making more productive use of \farmers' available resources – is that its methods have been introduced successfully in a number of *conflict or post-conflict situations* where the usual extension and agricultural support activities are not feasible or are very difficult.

One of the first such experiences was in rural, post-civil war **Sierra Leone**. The World Vision program in that country sent an agricultural staff member to Madagascar in November 2000 to learn SRI methods from Association Tefy Saina (Yamah 2002). Twenty farmers in each of 8 villages were then trained in SRI methods and conducted their own evaluations, getting an average yield of 5.3 tons/ha compared to the 2.5 tons obtained on adjoining comparison plots. The results of an expanded program were reported in a USAID magazine in 2004. However, this initiative lost momentum after World Vision changed its director and its direction in Sierra Leone.

Report from a USAID publication describing yield increases with SRI methods in Sierra Leone. Some households produced 12 bushels of paddy where with broadcasting methods they had previously harvested only 2 bushels (Lartigue 2004).

Aceh Province of **Indonesia** is another disrupted area where SRI has been introduced. Shortly after the *tsunami* disaster in December 2004, the Catholic charity CARITAS started SRI work there, even though the area was also enflamed by a 30-year insurrection by the GAM guerilla movement seeking local autonomy. Use of SRI practices gave farmers in Aceh average yields of 8.5 tons/ha compared with usual yields of 2 tons using standard methods (Cook and O'Connor 2009).

ACEH UPDATE

Rice aplenty in Aceh

FOR THIRTY YEARS the people living in the conflict affected areas of Aceh were restricted to tending the fields and gardens adjacent to their homes. The productive rice fields and rubber plantations that were further away were left dormant for over a generation, untended and un-harvested.

themselves for a third of the year, due to their limited production.

Through the Caritas Czech livelihood program, local small holders have learnt the System of Rice Intensification (SRI): an innovative way of growing rice crops which has had incredible results.

Dr Ingvar Anda, Caritas Australia's Humanitarian Coordinator says that SRI

Rice Intensification at the same time as organic compost was introduced and it is proving a perfect combination," Dr Anda said.

Caritas Czech also saw that the increase in production could be improved upon with better irrigation infrastructure and a willingness of villagers to planting and harvesting two crops a year.

*Report from the Czech Republic branch CARITAS which introduced SRI methods as part of its post-*tsunami *relief efforts in Aceh province, Indonesia (Cook and O'Connor 2009).*

In **Sri Lanka** during the ethnic communal violence which plagued that country, the LTTE (Tamil Eelam) separatist administration in Batticaloa district permitted Oxfam Australia to carry out SRI training in some areas under its control. Once, a Sinhalese farmer-trainer was stopped and held for interrogation by armed soldiers who did not know about the permission. Some Tamil farmers who happened to be riding in a bus passing by the bunker in which the trainer was being held and questioned. Recognizing him, they stopped the bus, got out, and persuaded the soldiers to release Premarathne (seen below) so that he could conduct their SRI training session scheduled for that afternoon. Interest in raising rice productivity from both Tamils and Sinhalese transcended ethnic differences.

W.M. Premarathne at his farm in Mellawalana, Sri Lanka, holding up an SRI plant still in its vegetative growth phase. When the author visited his farm in 2004, Prema showed him one panicle of rice with 930 grains on it. Oxfam Australia employed Prema to develop its SRI program in Sri Lanka and to conduct training, even a separatist-held area.

Even during the height of the Maoist insurgency in **Nepal**, SRI extension activities there could proceed safely in the field even though guerilla violence kept other government agents from moving freely. Local farmers admonished the insurgents not to interfere with extension activities for SRI (Uprety 2006).

Research and extension on SRI has been conducted at the Al-Mishkhab Rice Research Station in southern **Iraq** even while armed conflict in the country was severe in the mid- 2000s. The station's library was burned down by insurgents in 2007, but SRI work went on (Hameed et al. 2011) as seen in picture on page 20.

After the end of armed conflict in **Timor Leste** (formerly East Timor) that had brought this country national independence from Indonesia in 2002, members of the Indonesian Association for SRI (Ina-SRI) began providing training on SRI methods for farmers and staff of Timor Leste (Oxfam/MCE-A 2014).

In Timor Leste, three SRI farmers, self-designated 'SRI militants,' standing on the left with the coordinator for the Indonesian Association for SRI, Iswandi Anas (third from left), with a GIZ staff member in the center, and three local extension personnel on the right.

In northern **Afghanistan**, the Aga Khan Foundation started introducing SRI in Baghlan district in 2006 (Thomas and Ramzi 2011). Considerable progress and spread has been achieved in spite of Taliban opposition (see the picture on page 6 of an armed farmer escorting a project technical advisor in the field). Some of the farmers who started SRI trials had to abandon them under Taliban threats, and subsequently AKF had to stop its operations in several districts because its staff there were in danger. However, use of SRI methods has continued, with much benefit to farmers. Now FAO includes SRI in its Integrated Pest Management program with support from the Norwegian government (Ramzi and Kabir, 2013).

The SRI spread and impact in **Myanmar** discussed below (page 53) was carried out in two northern states where there has been long-standing conflict between ethnic guerillas and the military. The NGO conducting farmer field schools for SRI dissemination had to continually maintain acceptance from both government and insurgent forces to conduct its work. But the improvements being achieved for tens of thousands of households in great economic need gave it substantial legitimacy and standing (Kabir and Uphoff 2007).

When jihadist forces took over parts of northern **Mali** in 2012, efforts to evaluate and spread SRI went on. Government services were halted in the Gao region in March, but a technician there who had been giving leadership for SRI extension, Hamidou Guindo, continued voluntary SRI work in his home area of Douentza.

- SRI-Rice and the NGO **SRI Global** were able to provide Hamidou with a small grant to assist the work. Despite the vigilance and suspicion of the jihadists who took over the Douentza area in the summer, 70 farmers who undertook SRI trials in seven villages were able to undertake on-farm comparison trials. Their SRI paddy yields averaged 8 tons/ha at the same time that their usual methods produced only 4.3 tons, an 86% increase (Cornell Chronicle 2013).

Farmers in Douentza, Mali, measuring SRI yields by harvesting ten 1-m^2 squares for each of 70 farmers, 700 samples in all. These results were evaluated during jihadist occupation of their area in 2012.

SRI extension and utilization can surely be easier and probably more successful under favorable political and social conditions. But in a number of countries, the new ideas have been disseminated under adverse circumstances, where the higher production with less need for expenditure and with less water has been of more benefit to vulnerable households than under conditions of 'normality.'

3. How can SRI benefit poor, resource-limited households?

SRI was developed initially to benefit households that are poor, resource-limited, and food-insecure – households needing to get the most production attainable from the small amounts of *land* that they have access to; and from available household *labor*, and if possible by using less *water* and without having to spend *money* to buy inputs (new seeds, fertilizer, agrochemicals) or to take out loans for buying inputs that would push them (further) into debt.

By raising the productivity of the land, labor, water and capital invested in the production of rice without requiring the purchase of certain inputs, SRI is unique among contemporary agricultural innovations. Poor households can take up SRI simply by changing their thinking and by modifying familiar practices.

SRI thus does not present the kind of barriers to adoption that have kept Green Revolution technologies from benefiting many of the world's poor households. The number of people in rice-producing areas of Asia, Africa and Latin America who are afflicted with chronic hunger has been estimated at 400 million (Surridge 2004), but this number may have increased in recent years.

How SRI can improve the lives of poor households has been vividly seen in Cambodia, India and Myanmar. See also report from Indonesia on pages 47-48.

- **Cambodia:** In 2002-03, the NGO **ADRA** persuaded 100 farmers in a village near Siem Riep, whose paddy yields averaged just *1 ton/ha,* to try SRI. ADRA offered to compensate any farmer who tried the proposed methods and whose yield fell below this average. According to Roland Bunch of World Neighbors, with SRI methods these 100 farmers averaged *2.5 tons/ha*, and not a single farmer had reason to ask ADRA for compensation for a lower crop yield (http://sri.cals.cornell.edu/countries/cambodia/cambadrepmay03.pdf).

- In 2006-07, a Family Food Production project of the NGO **LDS Charities** got 146 rainfed farmers in Kampong Chhnang province of Cambodia, whose paddy yields had averaged *1.06 ton/ha* in the previous year, to try out the new SRI methods. With these practices, their average yield that year was *4.02 tons/ha,* and all exceeded their previous yield with lower costs (Lyman et al. 2007). Such increases could transform the life chances of these poor households (http://sri.cals.cornell.edu/countries/cambodia/camldsrpt07.pdf).

Pictures from an LDS report on introducing SRI in central Cambodia (Lyman et al. 2007). On left, the three sons of Hang Hein who transplanted his SRI field in a day while many more person-days were required for conventional transplanting of a neighbor's field, on right. Hang Hein's SRI yield was 5 tons/ha compared to his previous yield of 1.25 tons/ha.

- **India:** When the NGO **PRADAN** introduced SRI into the poverty-stricken district of Purulia in West Bengal state in 2003, just 4 farmers were willing to try the new methods. The next year, 150 farmers practiced SRI, and almost 4,000 by 2007. An evaluation team from the India Programme of the International Water Management Institute (IWMI) assessed SRI use and impacts in two villages in 2004, one of which had been hit by severe drought.

    - With SRI methods, the average increase in yield was 32% (50% in the village with normal rainfall; 11% in the drought-stricken one). Evaluators found that average net household income per hectare went up by 67%, while households reduced their investment of labor per hectare by 8%. The labor saved was put to other remunerative uses. The IWMI team reported that one farmer had a yield of 15 tons/ha, measured and weighed personally by the team leader because he knew that such a yield would be controversial (personal communication). The IWMI report characterized SRI as a 'pro-poor' innovation (Sinha and Talati 2007).

- *The Hindu* newspaper reported in 2011 that by adopting SRI methods, whole villages in Damoh district of Madhya Pradesh state with mostly poor tribal populations were able to quadruple their paddy yields without having to purchase new inputs. Planting indigenous varieties and using locally-made compost, their average yields went from *2 tons/ha* to *8.5 tons/ha* (Singh 2011).

Comparison of panicle length between an indigenous rice variety grown with SRI methods, on top, and a high-yielding variety conventionally grown, below (Singh 2011).

- **Myanmar:** The NGO **Metta Development Foundation** began introducing SRI in the northern Kachin and Shan provinces in 2001 through farmer field schools (FFSs) for mostly ethnic-minority farmers cultivating rainfed rice. Over four years, Metta trained 5,200 men and women, providing hands-on FFS training which each lasted one season. In 2005, another 5,000 farmers received FFS training. With farmer-to-farmer spread, it was estimated that 50,000 households began using SRI methods (Kabir and Uphoff 2007).

    - On FFS plots (N=30) of 1-acre (0.4 ha), SRI yields averaged *6.5 tons/ha*, compared to farmers' usual yields of *2 tons/ha*. On farmers' own fields, after their training yields averaged over *4 tons/ha*, even without farmers using all of the SRI methods as recommended.

    - Because conventional rice growing has been little more than a break-even operation and since farmers' costs of production did not increase with SRI, households' *net income per hectare* from rice went up eight-fold – from 296 kg/ha net production of rice to 2,585 kg/ha.

A farmer field school session being conducted in the Kachin state in Myanmar by Metta Foundation.

SRI is one of the few innovations that offers *relatively greater benefits to poorer farmers*. But there is some indication that there can be greater benefits also in *absolute terms*. Poorer cultivators usually only have access to soils that are poorer than the more-fertile soils owned and cultivated by richer farmers.

- A study evaluating 70 comparisons from 15 countries of SRI vs. standard practice published in the agricultural literature found that average yield increases with SRI methods were *higher on moderate- and low-fertility soils than on high-fertility soils*, when soils were classified according to FAO criteria (Turmel et al. 2011). Thus, SRI methods could give poorer farmers absolutely as well as relatively greater gains.

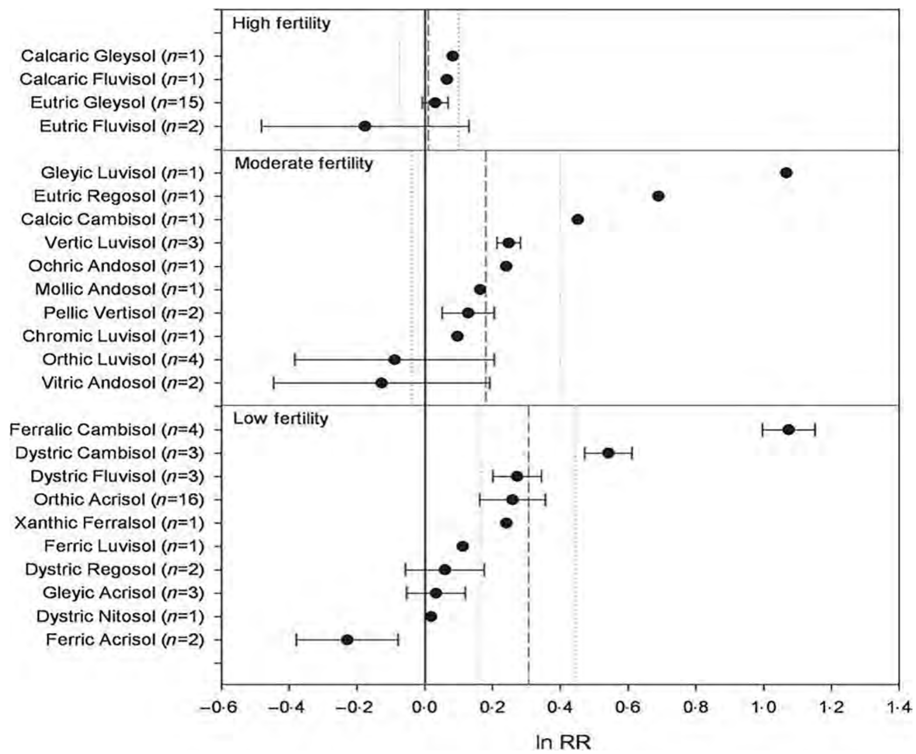


Figure showing response ratios (RRs) on different soil types classified as high (N=19), moderate (N=17) or low (N=36) fertility according FAO criteria, comparing paddy yields from SRI practices with conventional systems of management (Turmel et al. 2011).

- These differentials could have been achieved at least in part from SRI's water management practices. Alternate wetting and drying of paddy soils can mobilize ‘available’ phosphorus (P) from the soil's reserves of ‘unavailable’ P (Turner and Haygarth 2001). Many soils with currently low fertility have severe limitations of available P. The hypothesis that SRI's yield gains are achieved in part through the mobilization of otherwise-unavailable P in soils where there is little available P was supported by trials in Panama by Turmel (2011) which compared the productivity of SRI vs. conventional rice management.

3.1 Can SRI also benefit larger farmers?

SRI innovations, being biologically-based and scale-neutral, can be utilized by small, middle and large farmers. SRI is capitalizing upon potentials that already exist within rice plants, in their seeds and in soil systems properly managed. There are no patents and no intellectual property rights that limit its use. The insights and practices of SRI are available to anyone and everyone, free of charge.

Initially, SRI was considered to be *necessarily labor-intensive* – as requiring more labor input per hectare – so that richer farmers would not want, or would not be able, to use these methods on large holdings. This would make SRI appropriate and feasible only for small farmers who have relatively more labor supply. However, it turns out that SRI *can become labor-saving* once farmers and laborers gain skill and confidence with the new methods (pages 88-89).

The principles of SRI can be extrapolated, with adaptation of its practices, for larger-scale use, especially now that key labor-requiring SRI operations like weeding and transplanting are becoming mechanized, to be performed by machines (Sharif 2011). This, understandably, complicates the assessment of SRI's impacts on poorer relative to richer farmers.

With good instruction and supervision of laborers, given remuneration that reflects the contribution that their now-greater skill now makes to SRI results, and possibly with the mechanization of certain operations, SRI methods can be made beneficial for larger/richer farmers as well as for smaller/poorer ones.

To the extent that SRI gains from higher productivity and increased production have a big impact on rice supply and lower rice prices over time – making this staple food grain more readily and more cheaply available – this will certainly be of benefit to poor households, particularly those in urban areas.

- Already in 2004, one large progressive farmer operating in the Cauvery Delta of Andhra Pradesh state of India used SRI methods on a field >40 hectares. With good training and thoughtful supervision of labor, the harvested yield was 11.15 tons/ha, no sampling involved, double the previous yield (Uphoff 2005).

- In China in 2007, staff of the Departments of Agriculture in both Sichuan and Zhejiang provinces reported that they found larger farmers were taking up SRI methods more quickly than were smaller ones. Why? Because SRI methods enabled them to reduce not only seed, water and other costs, but also to reduce their labor requirements. The latter consideration was very attractive to larger Chinese farmers because rapid industrial development was reducing the supply of labor for China's agriculture (Uphoff 2007b).

We expect that over time, some key operations in SRI – transplanting or other means of crop establishment, as well as weeding – will become mechanized, e.g., with small 2-wheeled tractors. Direct-seeding is already being introduced with SRI methods in some places (https://www.youtube.com/watch?v=51uNFQL1zMw).

- In Pakistan, a large-scale trial evaluated fairly complete mechanization of SRI combining the principles of SRI with those of *conservation agriculture* (no-till) and *organic agriculture* (Sharif 2011). On an 8-hectare plot, laser-leveled to raise water-use efficiency, a paddy yield of 12 tons/ha was reached in the first season – with a 70% reduction in water and a similar reduction in labor, based on a raised-bed approach to land and water management. The machinery designed for SRI practice could be used by small farmers on a cooperative basis, so mechanization need not be limited to large farmers. Below are pictures of some of the equipment designed by Sharif for this innovation.

Mechanized SRI in Pakistan: on left, a machine makes permanent raised beds on a laser-leveled, 8-hectare test plot, also making precision application of small amounts of compost and fertilizer. On right, machine carrying laborers who drop 10-day-old seedlings into widely-spaced holes punched by the machine into the beds, with a water tank then filling the holes with water. A third machine not shown mechanically weeds the beds multiple times to keep the soil surface well-aerated (Sharif 2011).

As a rule, larger farmers shy away from labor-intensive production systems, preferring to mechanize production so that they do not have to hire and supervise labor. Having higher demand for labor will benefit poorer households in general by creating more employment opportunities for them, often also raising the wages paid to agricultural labor, and in any case raising household incomes.

It has been seen that SRI methods can benefit both richer and poorer households in absolute terms. However, because poor households have greater need and demand for more food, more income, and greater economic security, SRI will be *relatively more beneficial* for them. At the same time, richer households also can benefit from making changes in their production methods.

3.2 What are SRI's effects on labor and on household well-being?

The net impacts of SRI for the poor are somewhat complicated. To the extent that SRI is more labor-intensive, requiring more labor input per hectare, this favors its use by smaller farmers who have relatively more labor relative to land, and it also creates more employment opportunities for landless laborers.

However, SRI need not be or is not always more labor-intensive, as noted already. Reducing the amount of labor required per hectare to grow an SRI crop will reduce employment opportunities for hired workers to do transplanting and weeding, although there could be more employment opportunities created by the harvesting and threshing of higher SRI yields.

- To the extent that SRI is labor-saving rather than labor-intensive, this benefits small farmers because this will free up time that they previously had to devote to meeting their households' staple food needs. Labor saving will permit them to put some of their household labor to other, more remunerative uses. As reported above, this was appreciated by poor households in the Purulia district case in West Bengal, India, when evaluated by an IWMI team.

- Further, households that are food-deficit – not producing enough basic food grain for a year's consumption – will benefit greatly from the higher yields that SRI makes possible. Higher production can enable them to escape from the cycle of indebtedness that now keeps many of them in perpetual poverty.

    - Households that cannot feed themselves must borrow perennially from moneylenders who require them to sell their rice harvest at harvest time (when the price is low) to repay their high-interest debts contracted when their food supply ran out (and when the price of food is again high). Our expectation is that SRI can help such households, once they are better able to feed themselves, to break out of what amounts to debt bondage.

- In general terms, one can expect that by substantially increasing total food supply, SRI will bring down the price of basic food grains for hundreds of millions of poor people around the world. This would be a pervasive and efficient kind of poverty-reduction intervention by freeing up a significant portion of the meager incomes of the poor, leaving them with more money to spend for meeting more of their other needs beyond food.

- To the extent that larger farmers improve their efficiency and raise their production by utilizing SRI methods, they can earn more net income even if grain prices become lower due to increases in supply relative to demand because their costs of production will be lower. At the same time there can be more alleviation of the hunger and neediness of the urban poor.

There will be many further adjustments made in SRI applications; but we expect that improving basic-food production and freeing up land, water and other resources for other, more productive and remunerative operations will work broadly and sustainably to the benefit of poor households, both landless and those with limited landholdings. At the same time, we expect that SRI can be made beneficial also for larger farmers and for the society as a whole.

SRI concepts are being extrapolated and extended to *other crops*, as discussed on pages 149-154. The yields of finger millet, for example, have been doubled and even tripled with SRI concepts (PRADAN 2012). This is one of the main crops for the poor in India and eastern Africa. Similar gains have are being achieved in Ethiopia with *tef*, its national grain staple, being grown with adapted SRI methods.

The number of crops to which SRI ideas and methods can be productively applied keeps expanding, including oilseeds, legumes and vegetables (Abraham et al. 2013; Behera et al. 2013; SRI-Rice 2014). Boosting the production of sorghum, maize and other crops will be a boon to the poor families who rely on them. That richer farmers can benefit from SRI principles and practices will not subtract from the benefits that SRI concepts and methods can bring to the poor.

To the extent that SRI reduces labor requirements for rice production per hectare it will affect employment opportunities for the poor. But the effects of this could be offset or at least mitigated by lowering the market prices for staple foods on which the poor spend the largest share of their meager incomes. SRI has sometimes been dismissed as 'too labor-intensive,' and then when its practices are shown to *reduce* labor requirements, the objection is raised that this will hurt the poor, although admittedly benefiting smallholders and others quite directly.

These are complicated, interacting issues, with outcomes and resolutions varying according to the extent of crop productivity increases, prevailing wage levels, alternative employment opportunities, etc. There can be both increases and decreases in the demand for labor. Lower agricultural prices will disadvantage some producers and benefit others.

Probably the most important effects of SRI will be to raise the productivity of the land, labor, water, seeds and capital used in agricultural production, and to lower the real cost of food. Sorting out these effects requires general-equilibrium analysis, not *ceteris paribus* conclusions. All in all, higher productivity that frees up resources for meeting other needs and lowers the cost of food will benefit whole national economies, but with particular gains for the poor, who now must spend most of their meager incomes on food to meet this most basic of needs.

4. How can SRI benefit the natural environment?

SRI methods are beneficial not only for plants and people, but also for the *natural habitat* and for the maintenance and conservation of its *biodiversity.*

Water: The most direct environmental benefit of SRI is through its *reductions in the crop water requirements* for irrigated rice production. With continuous flooding of fields, rice is practically the 'thirstiest' crop there is. Producing 1 kg of rice consumes 2,000-5,000 liters of water. SRI's water management methods reduce this 'thirst' by 25 to 50% and sometimes by more, depending on soil type and on how excessive have been the previous practices of keeping fields flooded.

- The realization that *rice plants do not require flooding*, and do not produce their best when grown in standing water, comes as a surprise to many persons, who have accepted the conventional wisdom that flooding is beneficial, even necessary for growing rice, as stated several times by De Datta (1981). Research shows that this belief is simply wrong (Guerra et al. 1998).

- A *meta-analysis* has been done of 29 evaluations in the published literature which compared SRI with standard crop and water management practices for irrigated rice (Jagannath et al. 2013). The studies analyzed were ones that had sufficiently complete and comparable data for quantitative analysis. The studies reported results from 251 comparison trials (SRI N = 132; standard management N = 119). The trials had been done with standard and precise measurements, and the articles had gone through peer review. The findings can be summarized as follows. With SRI compared to standard practice:
  - ***Irrigation applications*** per hectare were 35% less, with higher yield.
  - ***Total water requirements*** (irrigation + rainfall) were 22% lower per hectare, again with higher yield. These measurements meant that:
  - ***Total water use efficiency*** (grams of grain produced per liter of water) was 52% higher – yield increased while water applications declined -- and
  - ***Irrigation water use efficiency*** (grams of grain per liter) was 78% higher.

- The benefits of SRI management in terms of water productivity held up across a series of disaggregated comparisons. SRI advantages were greater across different *climates*; between wet and dry *seasons*; for soils with different *pH* (acidity-alkalinity); with sandy, clay or loam *soil textures*; and for varieties of short, medium or long *duration* (Jagannath et al. 2013).

- Both *water saving* and *greater water productivity* (more crop per drop) within the irrigated-rice sector are important for environmental protection and conservation. Where water shortages and constraints become more severe, SRI's water-saving features may become sufficient justification for its spread.

Agrochemical Use: With SRI methods, by using compost and/or other organic inputs, farmers *can reduce their dependence on chemical fertilizers*, and they can often eliminate these agrochemicals altogether, producing yields that are as good as, or better than, when using such purchased inputs. This can contribute both to *better soil and water quality* and to *improved soil and human health*.

- Most farmers may not be willing or able to switch to fully organic fertilization, at least not right away. SRI training and experience encourage farmers to at least *reduce their use of chemical fertilizer*. For many soils, some combination of organic and inorganic nutrient sources (integrated nutrient management, or INM) may be optimizing for yield. INM may often give the highest yield with SRI; but when considering the costs of purchasing and applying inputs, it may not necessarily be the most profitable way to maintain soil fertility and profits.

- An early evaluation of 120 farmers in Cambodia who had used SRI methods for three years – with a doubling of their yields – documented that these farmers had reduced their fertilizer use by 43% and their use of agrochemical protection by 80% (Tech 2004).

- When SRI was introduced to farmers in eastern Indonesia under a Japanese-funded irrigation management improvement project, farmers were advised to cut their applications of fertilizer (NPK) by half, compared to what was being recommended by the government, and to increase their inputs of organic matter. While reducing their fertilizer use by 50% and at the same time reducing their irrigation applications by 40%, >12,000 farmers increased their paddy yields on average by 78%, by 3.3 tons/ha. These data are not from test-plot comparisons but from 12,133 on-farm comparison trials conducted over six seasons, covering a total area of 9,429 hectares (Sato and Uphoff 2007).

Comparison between SRI and non-SRI rice plants of the same variety grown by this farmer in Lombok province of Indonesia under the DISIMP project of the Ministry of Public Works, advised by a Nippon Koei technical assistance team.

Resource Quality: Wherever SRI raises paddy yields by reducing the use of fertilizer, especially inorganic nitrogen (N), this can *improve air, soil and water quality*. Commonly only about one-third of the nitrogen applied in rice paddies is taken up by the rice plants; 60-70% of what is applied thus accumulates in the groundwater or is volatilized into the atmosphere.

- A study of SRI effects conducted at Kangwon National University in Korea found significant *reductions in pollutants* in the water runoff from paddy fields. There were significant reductions in suspended solids (SS), chemical oxygen demand (COD), and total phosphorus (TP). Biochemical oxygen demand (BOD) and total nitrogen (TN) were also reduced, although not significantly. With SRI changes in management, the rice crop's water requirements were reduced by 56% as reported by Choi et al. (2012, 2014).

- In some rice-growing areas of China, the levels of *nitrate* (NO_3) in the groundwater supply are already many times higher than the maximum acceptable level established by the U.S. Environmental Protection Agency. In some areas of China already 10 years ago, nitrate levels in groundwater supply were measured as *300 parts per million* (ppm), with some as high as 500 ppm where N fertilizer as being heavily used (Hatfield and Prueger 2004). In the U.S., the EPA's allowable NO_3 concentration in groundwater is only *50 ppm*.

- A former chief executive of the U.K.'s Natural Environmental Research Council John Lawton, has described the rising use of N fertilizer as "the third major threat to our planet, after biodiversity loss and climate change" (*Nature*, 24 February 2005). He was referring just to the impacts that reactive N has on water quality and on aquatic ecosystems.

- An assessment of the *economic costs* to countries within the European Union from their (over)use of nitrogen fertilizers has concluded that these costs add up to between *70 and 320 billion euros* annually (Sutton et al. 2011). The opportunity with SRI to increase rice yields while reducing fertilizer use thus has great potential benefits beyond the direct advantages that it offers farmers.

The environment can thus benefit from SRI management by *extraction of less water from natural ecosystems* and by *reductions in the application of chemical fertilizers and sprays.* The latter benefits can also contribute to *human health*.

Biodiversity: Also, SRI methods can contribute to the *conservation of biodiversity*. This is most direct and obvious with respect to the biodiversity of rice species. SRI can make local or traditional varieties more productive, profitable, and thus competitive with high-yielding varieties and hybrids (pages 93-96).

The soil and water management practices of SRI, including the increase of soil organic matter, should have positive impacts of the *biodiversity of the soil biota*, a kind of biodiversity that receives little attention. Beyond this, farmers in Vietnam have reported that with SRI management they observe a revival of populations of fish, frogs and other fauna in their irrigation channels and canals (Castillo et al. 2012). This has economic as well as other benefits for communities.

SRI has been used in the peripheral zones of *national parks and protected areas* in Madagascar, Indonesia and Zambia. This can help save rain forest ecosystems by giving farmers an attractive alternative to their slash-and-burn cultivation, thereby preserving habitats for much-admired endangered species: lemurs, orangutans, rhinoceroses, storks, chameleons, and various other endemic birds, reptiles and amphibians. SRI-Rice is working the World Conservation Society's COMACO program to protect the Luangwa Valley national park, for example (http://www.itswild.org/itswild.html). By raising the productivity of rice farming in marginal areas, SRI can buffer the conflicts between parks and people, reducing human pressures to exploit the natural resources within vulnerable ecosystems.

Zambian farmers in establishing SRI nursery beds under a training program at Mfuwe supported by the World Conservation Society and its COMACO initiative to give them attractive alternatives to poaching wildlife in the Luangwa region, which has some of the richest and most diverse concentrations of fauna and flora in Africa.

4.1 What impact can SRI have on greenhouse gas emissions?

Evaluations have been made of this, but the subject is complicated enough that no strong claims are yet made about SRI's impact on the net emissions of greenhouse gases (GHGs) that contribute to global warming. However, there is an increasing amount of evidence that SRI practices can contribute to slowing the accumulation of GHGs so as to *reduce global warming potential* (GWP). By how much remains to be evaluated more thoroughly and precisely, and it will surely vary from place to place and by season.

Agriculture is a major contributor to the production and atmospheric accumulation of **methane** (CH_4). This GHG is produced by soil organisms (methanogens) that live under anaerobic soil conditions, i.e., where there is no oxygen. Per kg, CH_4 emissions contribute about 25 times more to GWP than those of CO_2. Continuous flooding of rice paddies to grow irrigated rice makes it one of the major sources of methane in the agricultural sector (Neue 1993). Flooded rice paddies account for 6 to 29% of the CH_4 for which humans are responsible (http://www.ciesin.columbia.edu/TG/AG/ricecult.html).

- The belief that rice requires continuous flooding for best results (DeDatta 1981) is contradicted by SRI experience and a number of scientific evaluations. That water stress on rice plants reduces their yield as reported in scientific literature has been concluded from *evaluations of plants that were being grown under continuous flooding*. These plants were different phenotypes from ones produced by SRI; their roots will not be large and healthy like those grown with SRI management. SRI plants with good root development, on the other hand, can obtain sufficient water from lower horizons in the soil even when surface soil horizons have dried out. So water shortages during the season create more serious stress for conventional rice plants that have been grown with flooding, because their roots are degenerated (Kar et al. 1974).

- Certainly rice plants perform better when they are not flooded continuously, and they perform even better when the other SRI practices are followed. SRI demonstrations are beginning to dissuade rice farmers from their long-held conviction that 'the more water, the better.' This benefits the environment not only by reducing the water applied to rice crops but *also by cutting methane emissions*. By making it profitable for farmers to stop keeping their rice fields always flooded, SRI can reduce their pumping methane into the atmosphere.

- Research has shown that SRI water management both reduces the soil population of methanogens, bacteria that synthesize methane, and at the same time increases the populations of methanotrophs, aerobic bacteria that consume methane (Rajkishore et al. 2013). These effects together reduce its emission from soils. Further, the soil-aerating weeding recommended for SRI adds to the effect of reducing methane production over and above keeping the soil aerobic (ibid.).

Everyone agrees that converting rice production from continuously-flooded to intermittently-flooded soil, or even to mostly-aerobic soil conditions, will reduce CH_4 production. However, could there be an offsetting increase in the generation of **nitrous oxide** (N_2O) from rice soils when they are no longer kept flooded and thus become aerobic? A good question.

- N_2O is an even more potent GHG than CH_4, produced by microbes (nitrifiers and denitrifiers) that live under aerobic soil conditions. N_2O molecules have almost 300 times more GWP effect on the atmosphere than CO_2 molecules. So we need to know whether and how much nitrous oxide is produced from alternately wetted-and-dried (AWD) SRI fields compared to the amount of methane emissions that emanate from flooded rice paddies.

- It has been expected that N_2O emissions will rise when soils are maintained under aerobic rather than anaerobic conditions. This may not apply with SRI crop management, however, because SRI reduces or eliminates the use of chemical N fertilizers, relying more on organic sources of N for plant and soil-microbial nutrition. If large amounts of inorganic N are not being applied to paddy soils, there is reason to expect that little if any additional N_2O will be produced as a by-product of SRI practices.

- The relationship between nitrous oxide and methane emissions is a complex one, affected in interactive ways by various factors, particularly soil *temperature, moisture, and pH*. There is no simple inverse relationship between these two GHGs as has been suggested by conventional predictions that look only at the aerobic vs. anaerobic status of the soil (Setiawan et al. 2014).

Various evaluations are now being done of the impact of SRI crop management on the emission of these greenhouse gases. Because they are volatile, emissions vary from season to season, week to week, even sometimes hour to hour; there will be no single effect to be reported, but rather a *range* of results, associated with different soil, climate and other conditions, and being dynamic over time.

- Trials done in Nepal in 2009 measuring the emissions from side-by-side paddy plots managed with SRI and conventional methods, respectively, found a 4-fold reduction in CH_4, along with a 5-fold reduction in N_2O (Karki 2010). The latter result was so unexpected that it may not be correct, but the measurements were carefully done.

- Several measurements in Indonesia have showed that while CH_4 is definitely reduced, the concurrent increase in N_2O is small enough so that the gains from reducing methane emissions from unflooded SRI paddy fields are not offset by greater emissions of nitrous oxide (Anas et al. 2008; Kimura 2009).

- Similar trials in Korea at Kangwon National University (Choi et al. 2012, 2014) found a *large reduction in methane with a miniscule increase in nitrous oxide.* Together the amount of net reduction in GHG emissions, evaluated in terms of CO_2 equivalence, was calculated to be more than two-thirds:

Treatment	Emissions (kg/ha)		CO_2 ton/ha equivalent
	CH_4	N_2O	
CT	840.1	0	17.6
SRI	237.6	0.074	5.0

- An assessment of SRI management impacts on CH_4 and N_2O emissions in the Mekong Delta of Vietnam sponsored by the German development agency (GIZ) also found a net reduction in global warming potential. A significant 20% reduction in methane emissions was accompanied by a small decrease also in nitrous oxide (not an increase as predicted) although the 1.4% reduction in N_2O was not statistically significant (Dill et al. 2013).

Variable	Plot Type	Observations	Mean	Std. Dev.
Methane emissions ($mg\ h^{-1}\ m^{-2}\ CO^2$ equiv.)	SRI	253	1.899[1]	1.869
	Control	255	2.376[1]	2.160
Nitrous oxide emissions ($mg\ h^{-1}\ m^{-2}\ CO^2$ equiv.)	SRI	246	1.411[2]	1.298
	Control	248	1.431[2]	1.320

[1] Two-sample t-test on equality of means, $p<0.01$ [2] Two-sample t-test on equality of means, $p>0.1$

- In Andhra Pradesh state of India, a Life Cycle Assessment (LCA) of the total GHG associated with rice production, by either SRI or conventional methods, was conducted by Gathorne-Hardy et al. (2013). They sought to assess all GHG emissions taken together, CO_2 as well as CH_4 and N_2O, considering the whole production and distribution process.

    - Their analysis found SRI management *reducing GHG emissions by >25% on a per-hectare basis*. With SRI practice, GWP was *reduced by >60% per kg of rice produced* because SRI methods raised crop yield while diminishing overall GHG emissions. While there was some increase in the N_2O emitted on an area basis, less N_2O was emitted per kg of rice produced.

Assessing the **'carbon footprint'** of SRI practices compared to conventional practice is a complicated matter, but it should be at least estimated. By reducing the use of chemical fertilizers, avoiding the CO_2 emissions associated with producing and transporting this commodity, SRI should diminish the amount of *carbon dioxide* that is generated in support of rice production. This change in agricultural practice alone could make a substantial contribution to abating GHG build-up.

Evaluating these relationships systematically and scientifically should be a priority for all those who are concerned about slowing and reversing the processes that currently contribute to GHG accumulation and to *global warming*. It would be fortunate if SRI not only can help farmers to adapt to global warming, but can also help them to mitigate this dire effect which endangers the sustainability of life on our planet.

Test plots shown on left at Kangwon National University in Korea set up to measure and compare GHG emissions from SRI and conventional management of rice cropping. On right, setting up measurement instruments in a farmer's SRI field in Orissa state of India, under an SRI program managed by the Centre for World Solidarity there.

4.2 Does SRI have anything to do with genetically-modified crops?

There is no direct connection between SRI practices and growing genetically-modified (GM) crops. SRI practices could presumably be used beneficially with GM rice crops (e.g., 'golden rice') as SRI's effectiveness is not associated with any particular kind of rice. Its methods are advantageous for practically all varieties (genotypes). To date, no GM varieties of rice are available for use; but some are under development. This question may become more salient in the future.

The productivity gains being achieved with best use of SRI methods have been somewhat greater than those projected with genetic modifications of rice plants. The availability of SRI methods makes arguments for development and approval of GM varieties less urgent at present. SRI methods can also give rice plants more resistance to pests and diseases and to other stresses such as lodging, so more than just yield effects should be considered when GM options are evaluated.

- The development of GM crops is likely to be a long and protracted process, as well as costly one. Also, GM is not without some risks to the environment, e.g., gene flow, impacts on biodiversity, and possibly to human health. There is much controversy over health risks reported from or attributed to GM crops, and SRI may get drawn into the debate. In my view, there is not sufficient evidence and experience at present to support the contention that there are inherent health hazards with all GM; but neither is there enough evidence to rule out the possibility of health problems. So, more evidence is needed before conclusions can be reliably drawn. The *precautionary principle* urges proceeding cautiously wherever there could be irreversible adverse effects.

- With SRI available, there is no imperative to hurry the development and release of GM rice varieties to meet some projected 'global food gap.' It weakens the economic justifications for making the large investments needed to develop and disseminate GM crops. SRI methods can presently enable farmers to increase their production and their incomes without any waiting time and with little if any additional cost (Uphoff 2007a).

- Indirect competition between SRI and GM rice may be one reason why there has been opposition to SRI from some scientists and some commercial interests. Some of the objections voiced to GM development are not based on very good scientific evidence, I believe. But at the same time, some of the claims made in support of GM are also questionable. The debate over GM crop development will benefit from everyone being more knowledgeable about claims and counterclaims and about the evidence on which these respective statements are based.

5. Can SRI outperform what are called 'best management practices'?

SRI was developed to benefit smaller, poorer farmers, to deal with their problems of poverty, hunger, and environmental degradation. It was not conceived to substitute for or compete with what rice scientists refer to as 'best management practices' (BMPs). Why not? Because these are heavily dependent on the use of purchased inputs and thus require considerable capital. Practically speaking, such inputs are commonly beyond the reach of those rural households which have the greatest need to achieve higher productivity and more income.

However, when SRI practices are used to best effect it has been found that *their results can match or even surpass* those associated with 'Green Revolution' technologies. This has ignited considerable controversy, as some rice scientists have insisted that however beneficial SRI might be for poor farmers, the results of using SRI's alternative practices are certainly inferior to what can be achieved by using the results of modern plant breeding and by applying synthetic fertilizers and other agrochemical inputs (Dobermann 2004; McDonald et al. 2006).

Reports of occasional 'super-yields' with SRI methods have been dismissed by skeptics or critics, saying that these are beyond what scientists have calculated to be the 'biological maximum' that can be attained from rice plants' current rice genetic potentials (Sheehy et al. 2004; Sinclair and Cassman 2004). Surprisingly, it has been argued that SRI *should not even be considered or evaluated* because this would be a waste of time and resources (Sinclair 2004). This is hardly a defensible scientific position and one that SRI results have shown to be mistaken.

Persons who have had direct acquaintance with SRI, having worked with it in the field and with farmers who have used the methods, are satisfied that yields over 15 tons per hectare have been and can be attained with SRI management (pages 76-81). But they are less concerned with super-yields than are many plant breeders and agronomists. Why? Because they are most concerned with overall and average effects, which have more impact on people's lives. Unfortunately, the controversy over super-yields has had the effect of distracting attention from the well-documented and widespread increases in *average yields* with SRI.

For the sake of both people and the environment, attention should be paid to:

a. ***Increases in average yields*** since it is these -- and not outliers -- that feed people and make them better off and more secure;
b. ***Comparisons*** between what farmers are now producing with their current methods and what they can achieve by using SRI practices; and
c. What can be achieved with ***methods that are neither costly for farmers nor have adverse impacts for the environment*.**

In addition, increasing importance should be attached also to:

d. ***Resistance to biotic and abiotic stresses**,* as this can give farmers greater assurance of food security under conditions of adverse climate changes (see pictures on pages 14 and 137-139). Studies have started to document the resistance to lodging which SRI-grown plants display (Chapagain and Yamaji 2009; Dastan et al. 2013).

An article which claimed that SRI does not produce better results than do 'best management practices' (McDonald et al. 2006) contained enough evident methodological and empirical flaws that it should not have been passed through peer review. These disqualifications are discussed in Uphoff et al. 2007. A preceding article that was similarly dismissive of SRI by Sheehy et al. (2004) also contained serious errors as pointed out by Stoop and Kassam (2005).

Unfortunately, the climate of controversy that has surrounded SRI has been a deterrence for most donor agencies and foundations to get involved with systematic evaluation of the new ideas and methods. It therefore has fallen to a variety of individuals around the world, based in NGOs, universities, research institutions, private firms and some government agencies, to do their own investigations and trials, to build up the extensive base of studies and evidence that now exists (http://sri.cals.cornell.edu/research/index.html).

The conclusion of McDonald et al. (2006) that SRI methods will give 11% lower yields than BMP has been contradicted by a more extensive study that employed a similar design with a more defensible data base (Turmel et al. 2011; discussed on pages 54 and 111). More recently, a meta-analysis by Wu and Uphoff (2015), evaluating published comparisons based on research by Chinese scientists who compared SRI yield results with those from what they considered BMPs, has shown how misconstrued were the previous dismissive evaluations.

The reasons why SRI methods produce plants that are so much more productive and more robust, i.e., better phenotypes, from a given variety (genotype) are still not fully understood. But claims that SRI management does not improve rice plants' growth and yield through synergistic interactions; that SRI can be at best only a 'niche' innovation; and that SRI methods cannot perform better than what scientists have proposed as best management practices (Dobermann 2004; Sheehy et al. 2004; McDonald et al. 2006) are contradicted on empirical grounds by analyses such as Lin et al. (2009), Thakur et al. (2010) and Wu and Uphoff (2015).

- Previous research on BMPs has paid little attention to either the growth and health of *plant roots* or to the abundance, diversity and activity of beneficial *soil organisms*, the plant-soil microbiota. These are key factors promoted by SRI management. Understanding them makes SRI more than a just an inductive, pragmatic innovation. SRI is not just some fortuitous but unexplained and unexplainable assemblage of practices; it has solid scientific foundations.

- The current concept of 'best management practices' assumes that for farmers to raise their crop yields, further improvements must be made in crops' genetic potential (new varieties) and farmers need to purchase and use agrochemical inputs (fertilizers, pesticides, etc.). There is no question that better crop genetic potentials can give farmers some benefit from higher factor productivity, and they surely can give farmers more options. Further, the application of well-chosen agrochemical inputs can be beneficial for raising crop production in appropriate places and at appropriate times.

- Experience with SRI management does not deny that benefits can be derived from the inputs of 'modern agriculture.' But it indicates that *these are not the only way to improve crop production*. It is also suggested that the strategy's economic costs to farmers and its environmental costs to soil and other ecosystems should be considered more thoroughly than at present. Net benefits from input-based agricultural production should be reckoned and demonstrated, rather than simply being assumed as they are now.

- One consideration to be further examined is the evidence from several studies (Zhao et al. 2009; Barison and Uphoff 2011; Thakur et al. 2013) that SRI plant phenotypes are *more efficient in the uptake and utilization of nitrogen*. Attention to phenotypical differences that result from modifications in the growing environment deserve more attention, rather than attributing all improvements in crop plant performance to manipulated differences in crop genotype (variety) (Uphoff et al. 2015).

On left, comparison of SRI and conventionally-grown rice plants of same variety grown in trial plots at the Haraz Extension and Technology Development Centre in Amol, Iran. There are evident differences in size and color of roots under the different management conditions; the blackened roots are dying back (necrosing) from lack of oxygen in the soil. On right, a similar comparison from Al-Mishkhab Rice Research station in Iraq.

Biksham Gujja, at the time director of a WWF-ICRISAT dialogue project on Food, Water and Environment, participating in a meeting in Punjab state of India, holding up a 'regular' rice plant on the left and an SRI rice plant on the right. Standing at left is Amrik Singh, ATMA-Gurdaspur, who pioneered the introduction of SRI methods in this 'Green Revolution' state. Note the difference in intensity of the green colors of the two plants, even though the 'regular' plant on left had received standard inorganic N fertilization.

Karma Lhendup, who introduced SRI trials into Bhutan, showing the Vice-Chancellor of the Royal University of Bhutan the impact that SRI methods can have on the phenotype of rice plants.

5.1 Why is there so much variability in SRI yields?

It has been frustrating for SRI proponents and skeptics alike to see that the yield results from using SRI methods are often quite variable. 'Replication' is a standard criterion for the acceptability of scientific studies, for good reason. But this criterion presumes that in agriculture one is dealing with fixed relationships such as one finds in physics and chemistry. In agriculture, we are dealing with biological phenomena with different dynamics and relationships than observed in these other realms of investigation (Uphoff 2008).

Despite so much effort to make agriculture into a kind of industrial enterprise, it remains intrinsically and necessarily biological. The realm of biology differs from its cognate realms of physics and chemistry in that its phenomena are more affected by -- and are more thoroughly interactive with -- their environments. Relationships in biology are more *contingent* than invariant, with many more interwoven strands of causation than are seen in chemistry or physics laboratory experiments, where *single invariant values* are expected and determined, rather than *quantitative ranges* that have more or less determinable distributions.

With the basic SRI practices as recommended, we find usually that yields of 6 to 8 tons per hectare are attainable, a typical increase of 50-100%. With traditional 'unimproved' varieties, yields will be somewhat lower with a usual range of 5 to 7 tons; but under ideal growing conditions, their SRI yields can go up to 10-12 tons. Modern 'improved' varieties can reach 15-20 tons per hectare, and even more, with SRI management, as discussed in the preceding and following sections.

Yields well beyond the norm depend particularly on having soil that is fertile not just in terms of its *soil chemistry*, but with an abundance and diversity of soil organisms. These range from almost limitless numbers of microbes to a plethora of invertebrate life. Achieving the greatest successes with SRI management thus depends on *the life in the soil*, most of it invisible to the unaided eye.

Soil biology has been given relatively little attention within our soil science, which has for decades been preoccupied with soil chemistry, having relatively simple and fairly unambiguous measurements. Any deficiencies that can be diagnosed this way are relatively easy to remediate (and commercially profitable). Soil physics has received attention because factors like soil compaction and water retention obviously influence crop performance. Probably 90% of soil science research over the past 50 years has been on soil chemistry or on soil physics.

Soil biology, on the other hand, has been given little positive attention within the agricultural sciences. For the most part it has been dealt with by the disciplines of entomology and plant pathology, which regard microbes and other organisms mostly as pests or as pathogens. Microbiology as a discipline has remained on the fringes of agricultural science. Research and writing in this area have focused mostly on 'the bad guys' rather than on 'the good guys.' However, the services and benefits of the latter are now becoming better understood.

This marginalization has been changing in the past decade or two (Uphoff et al. 2006). Research shows increasingly that plants are affected profoundly by the microorganisms that live around them, on them, and *within them*. All together they collectively constitute the *plant microbiota* or in terms of genetic resources the *plant-soil microbiome* (Schlaeppi and Bulgarelli 2015; Turner et al. 2013). Its significance for crop production is becoming clearer at the same time as people understand more about the importance of what is called the *human microbiome* for the growth and health of our own species (Uphoff 2012b; Uphoff et al. 2013).

The importance of the soil biota for SRI effects became evident early on from research in Madagascar (Randriamiharisoa 2002). It was seen that when SRI practices were followed, the abundance of a particular N–fixing bacterium (Azospirillum) living within rice plant roots increased by huge amounts, as much as 30-fold, along with a tripling of yield (Uphoff et al. 2009).

But the importance of the soil biota could also be inferred from the disparity seen between SRI results in researchers' on-station evaluations and those from farmers' fields. Yields from SRI trials on IRRI's experimental plots at Los Baños were only half of what Philippine farmers were obtaining with SRI methods on their own farms (Rickman 2003). Similarly, SRI results at the Bhairahawa research station in Nepal were considerably lower than those being achieved on nearby farmers' fields (Neupane 2003). SRI is *one of the few innovations where researchers have had difficulty in replicating farmers' yields*. Usually it is the reverse; farmers find it hard to match researchers' on-station results.

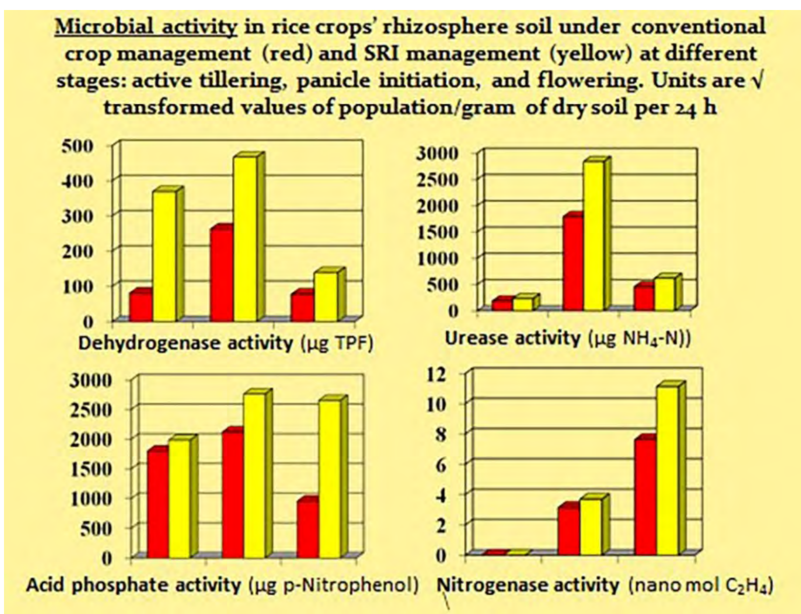
- This has not always been the case. Trials in the Philippines at the Agricultural Technology Institute (ATI) demonstration farm at Cotabato in Mindanao gave average yields of 12 tons per hectare from three varieties in 2002, and a top yield of 17 tons per hectare in 2004. Still, in general, research scientists have reported lower yields with SRI methods in their on-station trials compared with what is reported from farmers' fields.

- This has been seen in the trial results reported by Indian Council of Agricultural Research (ICAR) scientists (Kumar et al. 2014). Absolute levels are of less interest and relevance than are the *ratios* between yields with SRI and conventional practices. If the same methods of measurement are used for both sets of data, the ratios between them should be considered as valid and reliable, subject of course to normal, unavoidable errors in measurement.

No systematic research has been done on the differentials between on-station and on-farm yields, so only inferences can be suggested. On most experiment stations, the plots have been supplied with inorganic fertilizers, particularly N, over many years, and also have had heavy applications of agrochemical biocides. These will have usually had some suppressive or unbalancing effect on the soil biota, on its abundance or biodiversity, or both. Since SRI crop performance benefits from both the abundance and diversity of soil organisms, it would be surprising if SRI results were not diminished on soils so affected by chemical inputs.

This is an area where much research remains to be conducted. There is already some evidence that SRI management practices enhance the populations of beneficial microorganisms in a rhizosphere (Uphoff et al. 2009; Zhao et al. 2010; Anas et al. 2011).

- Research at the Institut Pertanian Bogor (IPB) in Indonesia has found enhancement both of the *numbers of beneficial organisms* in the soil around the roots and in the *biochemical activity* of these organisms as indicated by the levels of certain enzymes in rhizosphere soil. The patterns and magnitudes show considerable fluctuation during the crop cycle, which is not surprising if one knows the variability of soil microbiology. But when these parameters have been studied, SRI methods generally enhance both the numbers and the activity of beneficial soil organisms that could improve crop performance.



Slide from a presentation by Iswandi Anas, director of the Soil Biotechnology Laboratory at the Bogor Agricultural University (IPB), reporting on research done under his supervision. These enzymes are involved in processes of decomposing organic matter, solubilizing soil phosphates or in fixing atmospheric nitrogen (N_2). These are processes that increase nutrient availability in the soil and also nutrient uptake by plants.

A further realization is that some of the physical effects observed with SRI management (larger root systems, more tillering) and changes in some key parameters documented in controlled trials (higher levels of chlorophyll in the leaves, higher rates of photosynthesis, greater water use efficiency) as reported by Thakur et al. (2010) are the same as have been shown to be associated with the presence of certain rhizobacteria living in rice plant tissues and cells as *symbiotic endophytes*.

Endophytes are microorganisms that live around, on and in the roots of rice (and other) plants. They can also migrate upward from the roots into the plants' canopies where they live in, on and around the tillers, sheaths and leaves. Their presence in plant organs is associated with measurable effects (physiological and morphological) similar to those that are seen with SRI management (Chi et al. 2005; Thakur et al. 2010). There is also evidence that these microorganisms can *affect the expression of rice plants' genetic potential*, up-regulating and down-regulating gene expression (Chi et al. 2010).

These findings cast some new light on SRI observations and may open up very interesting avenues for research (Uphoff et al. 2013). The observed variability that results from SRI management may turn out to be traceable to much more complex explanations than presently known or suspected. In the discussion of *reasons* for SRI yield improvement below (pages 122-132), we do not go into this microbiological domain as its investigation is still in its early stages. However, persons interested in this question of variability in SRI results should keep in mind the dynamism and effects of this microbiological realm.

- Indeed, as this book was being finished, an article in *Science* reported on N-fixing bacteria that live in the leaf tissues of poplar trees. In greenhouse experiments when rice seedlings were dipped in a broth that contained these bacterial endophytes, these microorganisms subsequently inhabited the resulting plants; these grew taller, had more biomass, and produced more tillers than did untreated rice seedlings (Pennisi 2015).

Both crop and soil scientists as well as agricultural practitioners and policy-makers will surely be paying more attention to microbiology and epigenetics in the years ahead (Uphoff 2012b). I think it will be found that microbes affect the variability of crop yields more than has heretofore been imagined.

5.2 Are the super-yields reported with SRI practices credible?

In retrospect, it would probably have been better for the acceptance and progress of SRI if the 'super-yields' beyond what rice scientists have considered the 'biological maximum' had never been reported. Yields exceeding 15 tons/ha, more than researchers could get on their own experiment stations, became a 'red flag' that shifted the focus of discussion away from differences in *average* yield, which were substantial and sometimes phenomenal, to debate over *outliers*, which there will always be in normally-distributed data. Some of this distraction may have been inadvertent; but some could have been deliberate.

The very high SRI yields reported from Madagascar and India, more than 20 tons/ha, were not reported boastfully or as attainable average yields, but with as much factual foundation as possible. They were presented in terms of the productive potential that exists within the rice genome when plants are given the best growing environments above- and especially below-ground. This was at odds, however, with the prevailing conception that yield improvement depend upon creating and using *new, more improved varieties* and also purchasing *complementary agrochemical inputs* (and using more rather than less water). It is understandable why there was so much resistance to SRI's approach.

Those who worked with SRI might have been better-advised in retrospect never to have mentioned the very high yields sometimes obtained with SRI methods. But these results were reported in a spirit of truthfulness, not braggadocio, and ultimately, as more and more such results are achieved, they may help to modify prevailing thinking about how best to meet our world's food security needs.

Madagascar results

The highest SRI yield that the author can personally vouch for was 21tons per hectare, produced by Ralalason, a Malagasy farmer in Soatanana village in central Madagascar in the main season of 1999. The author became interested in knowing more about Ralalason's methods and results because he had planted single young seedlings at the very wide spacing of 50x50 cm. Bruno Andrianaivo, an IRRI-trained government rice specialist who had twice seen Ralalason's standing crop, told the author that this was the most spectacular rice field that he had ever seen in his 20 years of professional work. Previously the widest SRI spacing with good results that I knew about had been at 35x35 cm; so I travelled with Bruno to see this field and learn whatever we could about this farmer's practices.

Such a high yield has been categorically rejected by some rice scientists as biologically impossible (Sheehy et al. 2004). Yet the fact that Ralalason's paddy yield has now been exceeded in Bihar and Tamil Nadu states of India makes his earlier yield more understandable and more credible. The author thinks that something can be learned from Ralalason's experimentation and experience. It is important to underscore that 1999 was the 6th year in which Ralalason was using SRI methods. This was not, and probably could not be, a first-year achievement.

- When he started with SRI, Ralalason had only 1,300 m^2 of paddy land to cultivate, in four adjacent paddy plots. (With his earnings from SRI, he was subsequently been able to triple his paddy landholdings, but that is another matter.) Before taking up SRI methods, Ralalason's usual yield was 3 tons per hectare. In his first year with SRI management, he was able to raise this to 10 tons/ha, an increase reported by many farmers in Madagascar. By his 5th year, he had reached *17 tons,* using the recommended 25x25 cm spacing. During this time his soil's fertility was being improved each year with large applications of compost and by the exudation from his SRI plants' large root systems of carbohydrates, amino acids, phytohormones, etc. into soil around the roots.

- Ralalason was applying large amounts of compost to his paddy plots, about 5 tons of compost several times a year. This organic material was made from any and all biomass that he could acquire from his surroundings: rice straw, weeds, manures, sawdust, loppings from N-fixing trees, etc. Having only 1/8 of a hectare of paddy land, he made the decision to invest as much labor as he could into building up the fertility of the very small area he had to cultivate. At first he alternated his rice crop with an off-season crop of potatoes, but subsequently he intensified the cultivation of his small area with a four-crop annual rotation of rice-cabbage-potatoes-beans, with each crop preceded by an application of compost (at a rate of 40 tons/ha), 60-day compost before the rice and 30-day compost before the other crops.

- In his 6th season with SRI management, Ralalason decided to try much wider spacing, 50x50 cm, *planting only 4 plants per m^2*. This was consistent with the advice of Fr. Laulanié who had written about how soil fertility under SRI management should improve over time and thus give more yield with wider spacing. By reducing his plant population from 16 plants to 4 plants per m^2, Ralalason pushed his yield beyond 17 tons per hectare, up to 21 tons. This was not a sampled yield, but rather the result of weighing the total grain harvested from his four contiguous rice paddies, 2,740 kg from their 1,300 m^2, and from this calculating what would be the paddy yield per hectare.

- When the author visited Ralalason's field with Bruno, who had seen the crop twice during the 1999 growing season, the field had been harvested a few days before. Thus there was no standing crop to see, but they each took a random sampling of 10 plant stumps in the field and counted their numbers of tillers. The average number of tillers per plant (for 20 plants) was 70, with one plant that Bruno counted having as many as 140 tillers.

- Before harvesting, threshing and weighing the rice, Tefy Saina technicians had done their own analysis of components of yield. They had also calculated 70 to be the average number of tillers per plant, and the average number of grains per panicle that they counted and calculated was 270. This comes to 75,600 grains per m^2. A grain weight of 28 grams per 1,000 grains would give a 21-ton yield. The root ball that we dug up in the middle of Ralalason's field from a harvested rice plant was huge, like that on shown on page 122.

- Perhaps the yield was only 18 or 19 tons/ha; even 15 tons/ha would have been spectacular. Nobody can know the yield for certain, but what gets missed in disputing about exact numbers is that a very needy and hard-working smallholding farmer with just 1/8 of a hectare of paddy land could multiply his yields many-fold and increased his landholding area by 3x within a few years.

Ralalason of Soatanana, Madagascar, with a compost pile for enriching the soil of his 1,300 m^2 paddy holding, that produced unusual yields with careful use of SRI methods.

Bruno Andrianaivo, FOFIFA, now a professor at the University of Antananarivo, counting tillers in Ralalason's paddy field after it was harvested for the 1999 season.

Indian results

Most international attention to 'super-yields' with SRI management was sparked when a farmer in Nalanda district of the state of Bihar was reported to have achieved a world-record yield of 22.4 tons/ha with SRI methods in the 2011 kharif season, well above the previous record of 19.2 tons/ha in China (Diwakar et al. 2012; Vidal 2013). This yield was at first denied by Indian rice scientists. But when the methods used were reviewed, the yield report was accepted by the Ministry (http://www.thehindubusinessline.com/industry-and-economy/agri-biz/article3016481.ece).

The information was checked out by the director of the central government's Directorate of Rice Development and one of his senior rice scientists in Patna. They reported that the yield from Sumant Kumar's one-acre SRI plot was measured by standard estimation techniques. Trained technicians demarcated and harvested an area 10 meters x 5 meters in the middle of the field; they threshed and then weighed the grain collected from this 50 m^2 area. The dry matter weight adjusted to a 14% grain moisture content was 20.16 tons/ha (see picture on the next page). These operations were witnessed by hundreds of observers who had gathered because the paddy field was recognized locally as the most productive one that residents had ever seen.

- What was, unfortunately, *not reported* that four other farmers in the same village that season also got similar super-yields, 19 tons/ha or more. So Sumant Kumar's yield was no random occurrence. Details on these five farmers' methods of production and on the means of measurement used by the technicians have been published in Diwakar et al. (2012).

Sumant Kumar, Darveshpura village, Bihar state of India, whose record yield in the 2011 kharif season touched off considerable controversy around the world.

Sheaves of rice being carried from a 50-m² crop-cutting area in the middle of Sumant Kumar's 1-acre SRI field to be threshed and weighed at the end of 2011 kharif season.

Proponents of input-oriented 'modern' agriculture should have been pleased that these huge yields were achieved with hybrid varieties (Bayer and Syngenta) and with integrated nutrient management. The five farmers each applied modest amounts of inorganic fertilizer (40 kg/ha of urea [N], 80 kg/ha DAP, and 40 kg/ha potash) complemented by larger amounts of organic fertilization: 6 tons/ha of farmyard manure at the time of land preparation, plus poultry manure (400 kg/ha), vermicompost (100 kg/ha), and a biofertilizer application containing P-solubilizing bacteria (40 kg/ha). Both the SRI and conventional plots received a micronutrient foliar spray of monohydrated zinc sulphate (25 kg/ha).

- That season, these five farmers used *the same hybrid varieties* on their farms employing conventional cultivation methods: older seedlings, denser plant populations, flooding of the fields, and with the same mineral fertilizers but without the organic nutrients listed above. Their paddy yields on *the same soils* and with *the same climate* were 7 tons/ha. While this was a respectable yield, about 3 times higher than the usual paddy yields in the area, it was *only about one-third as high as they attained with SRI crop management methods*.

- Two years later in Tamil Nadu state, a farmer S. Sethumadhavan of Madurai was reported to have achieved an official yield level of 23.8 tons/ha with SRI crop management. This reported yield, unlike that of Sumant Kumar, was virtually ignored, however, despite national publicity (*The Hindu* 2014; *Times of India* 2014). The preceding year, a woman farmer near Tirunelveli, Ms. T. Amaralani, was given the *Krishi Karman* award, worth 100,000 rupees, by the President of India for achieving a yield of 18.1 tons/ha (*The Hindu* 2013).

There will probably still be some controversy about ‘super-yields’ for some time, with questions raised about the precision of measurement or adjustments for grain moisture. As stated above, outlier yields are not particularly important for evaluating SRI *since it is averages that are most important for people’s well-being*. By now it is quite evident, however, that from time to time farmers can ‘hit the jackpot’ with SRI methods when these mobilize the benefits of the soil biota and the plant-soil microbiome to support fuller expression of crop genetic potential, getting far-above-average yields. The previous conclusion that 15.9 tons/ha represents some kind of ‘biological maximum’ that cannot be exceeded without making further varietal improvements (Yoshida 1981) is no longer tenable.

‘Super-yields’ are not needed for households to achieve food security -- or for countries to meet their food needs. Such yields are of interest primarily because they indicate *how great is the productive potential of rice plants* when they and the soil biota are given ideal growing conditions. This experience suggests that farmers should monitor their SRI crop performance season-to-season, to assess whether and when *even-wider spacing* may give them still higher yields as SRI methods increase soil fertility. Optimum SRI spacing thus can change over time.

That rice scientists have not attained such high yields in their on-station trials does not mean that these are impossible. Soils that have been plied for years with inorganic nutrients and chemical sprays will not necessarily produce the highest yields. In one of his technical papers on SRI, Fr. Laulanié (1992) suggested that with greater tillering based on a more complete understanding of phyllochrons, paddy yields might eventually be as high as 30 tons/ha (3 kg per m^2). Let us see.

As noted in the previous section, one cannot control or reliably predict yields simply from the practices employed because a large part of SRI yield increases is related to *the activities of soil organisms in, on and around the plant for its growth and protection*. The abundance, diversity and activity of soil organisms are all affected by management practices. How the complex communities that constitute the soil biota grow and function is and will remain quite variable.

Few evaluations study and report on the *biological endowments and functioning* of soil systems. Almost all analyses and evaluations of crop-soil relations are at present done simply in terms of *soil chemistry*, with possibly some consideration of the soil’s physical properties. But biological parameters are usually ignored.

Until appropriate attention is given to the soil’s biological characteristics and performance, assertions about what yields are or are not attainable, based just on soil-chemical analyses, are questionable. Most of our knowledge about rice growing to date *derives from observations and measurements made of plants grown under sub-optimal conditions*, e.g., with plants crowded together in hypoxic soils. Better results can surely be obtained under other conditions.

6. What are the requirements for SRI?

SRI does not require farmers to make any purchases or to take out loans, although the impact of SRI methods is significantly enhanced if farmers have access to and can use an inexpensive weeding implement that aerates the soil while it controls weeds, as noted below. A mechanical weeder is the only purchase recommended for SRI. Hand weeding can be done instead or herbicides can be used if this implement is not available. Hand weeding is less effective than mechanical weeding as it does not aerate the soil and return weeds' biomass to the soil to decompose. The following can be considered as requirements.

Water Control: The main requirement for SRI success is being able to apply *small amounts of water regularly and reliably*, or to be able to *flood the field and then drain it* after a few days, with some assured water supply to re-flood the field after a few more days.

- In some places, farmers' access to water is too unreliable for them to be willing to try to cultivate with a much-reduced water supply as advised by Fr. Laulanié, i.e., with what he referred to as *'le minimum de l'eau*.'

- Farmers may be cultivating rice in a season or on topography where there is *continuous inundation* of fields from rainfall, such as in monsoon climates with poor drainage of fields. Or farmers may have low-lying fields and heavy clay soils that make it difficult or impossible to evacuate water from them so that their soil is perpetually saturated and hypoxic. Drainage is practically as important as irrigation. When the soil is anaerobic or hypoxic with only water and no air in its pore space, benefits from SRI practices will be reduced or can even be nullified.

SRI paddy field on left in Dolpa district of Nepal, about 1,700 m elevation. This soil has been allowed to dry out enough for surface cracking before the next irrigation. The SRI paddy field on the right is in Indonesia where abundant worm castings on the surface indicate that there is enough oxygen in the soil to support large populations of earthworms which enhance the soil's fertility.

The most favorable circumstance for practicing SRI is to have fields irrigated with water that is *pumped* from groundwater sources or from a river or reservoir. This circumstance gives farmers both:

- *Means* to control and limit their water, turning the pump on or off; and

- *Incentive* to do this, since they can save money on pump operations, provided that electricity or diesel supply for powering the pump is reliable.

Where water control is difficult, such as in the middle of a large irrigation system where other farmers are still practicing continuous flooding, *digging drainage channels* within the field and *making raised beds* can buffer the SRI plants from having too much water and too little air in their root zones.

While precise water control is ideal for SRI, farmers can adapt their soil, plant and water management practices to benefit from SRI methods *even under less-than-ideal water management conditions*. Water control and aerobic soil conditions are matters of degree. Farmer practice can be guided by the principle and goal of managing water to enhance root growth and health and the abundance, diversity and activity of beneficial soil organisms.

Labor: A second requirement is that the farmers have enough labor and time to be able to invest more of both while they are learning SRI methods. *Any new practice requires some investment of time and effort for learning.* Farmers who are starting SRI, especially those whose rice-growing practices have been more extensive than intensive, will find that they need more labor per hectare at first, perhaps 20-30%. On the other hand, where farmers have already been growing their rice intensively to get the most yield from their available land, SRI can be *labor-saving even in their first year*, because there are so many fewer plants to raise in the nursery, to transport and transplant, and to manage.

Mechanical weeding may require some more labor at first, but farmers report that they can usually offset this, at least in part, with their labor savings from stopping chemical spraying, which also gives considerable cost reduction. With practice, farmers can learn to do mechanical weeding more quickly and easily. One evaluation of SRI in India found that the mechanical weeder cut women's labor for weeding time by 72% (Mrunalini and Ganesh 2008).

As discussed next, more labor is required for making and applying *compost* compared to simply buying and spreading chemical fertilizer. The amount of time required for this operation depends mostly on the availability of biomass, and it is usually possible to make some large reductions in cash costs.

Farmers when starting out with SRI *should be prepared to invest more labor initially*. This can be a barrier to adoption for poor households leading a hand-to-mouth existence, not being able to afford to invest labor in SRI even if it is (and they know it is) more profitable for them to use SRI practices (Moser and Barrett 2003). For farmers in countries like India and China, labor-saving has become one of the main attractions of SRI methods. Even in Madagascar, it was found that SRI management reduced farmers' labor per hectare once they had acquired skill and confidence in it (Barrett et al. 2004).

Biomass: A third requirement is an adequate supply of biomass if farmers want to rely mostly or entirely on organic sources for soil fertility enhancement, rather than rely on synthetic fertilizer from bags. The compost that can substitute for fertilizer can be made from *any available biomass*: rice straw, weeds, loppings, manure, etc. But biomass is often in short supply, especially for farmers whose rice fields are large enough so that substantial amounts of compost are needed. They will probably not find 'fully organic' SRI feasible. But their crop will benefit from applications of as much organic matter as possible.

SRI does not require organic fertilization. But its yields are best when the soil's fertility and functioning are supported by organic inputs to the soil system. It is very desirable to have appropriate tools and implements for collecting, transporting, shredding, processing and applying decomposed biomass as compost. Many of the currently available tools and implements are of very old design, not very efficient means for managing and applying biomass in terms of the labor time and effort required.

Making SRI more broadly accessible and productive will depend very much on developing and having *better tools and implements* that can raise the productivity of the labor used in these processes; and on ways to grow or access more *ample and convenient stocks of biomass*. To date, very little research and development have gone into improving tools and biomass supply so that farmers can have efficient and reasonably attractive means for organic enhancement of their soil systems' fertility. Developing such tools sand supplies should be a priority for SRI to be utilized further.

Crop Protection: Where both rice plant biomass and grain production are increased, there is always the possibility that more or better crop protection measures will be needed to protect against pests and diseases. In general, farmers' reports and evaluations have supported the observation that with SRI crops, the incidence of and damage from pests and diseases is less. However, SRI farmers always need to be prepared to deal with pest and disease hazards.

Since SRI is not necessarily organic in its practice, chemical protection is an option and acceptable, except for those farmers who are committed for personal or economic reasons to organic production. SRI farmers in many countries use organic insecticides or pesticides, home-made from local plant and other materials, and find that these are sufficient and preferable.

The most difficult crop-protection problems encountered with SRI so far have been with *vertebrate pests*: rats often, and in particular cases, snakes (in Peru) or elephants (in Aceh, Indonesia). Some farmers have reported that rat damage is less with SRI as the wider spacing between plants discourages their coming into the field because they feel more exposed (visible) to predators.

There are also some *invertebrate pests* that need to be controlled, especially the golden apple snail in many parts of Southeast Asia. Philippine farmers have found that by controlling their water applications to inhibit the hatching of snails until about 20 days after transplanting of young SRI seedlings, it is possible to convert the snails into predators of the newly-emerging weeds rather than preying on the young rice plants (Porte et al. 2006).

In general, we recommend that farmers utilize, as much as possible, practices and strategies of *integrated pest management* (IPM). An interesting example of this was seen by the author in Tripura state of India where SRI farmers place convenient perches for owls and raptors within their SRI fields to encourage these avian predators to come to and rest in their rice paddies, for natural control of rats, mice, etc. Minimization of agrochemicals in the fields enhances bird populations that can control insects. However, one does not want to attract rice-eating birds at the end of the season. These can be a menace that requires bird-scaring methods, such as noise, drumming, scarecrows, predator perches, or stringing audiocassette tape above the fields.

Motivation and Aptitude: The most important requirement for SRI success is that farmers be willing and able to *invest the necessary labor and thought* in their rice production – expecting to get in return sufficient payoff from this investment to justify it. If farmers already know how to grow rice, then learning SRI methods can be very quick, provided that they are motivated to improve their production and are ready to make this happen. If farmers do not yet know how to grow rice, it can take years for them to acquire the skills, knowledge, habits and insights, even reflexes, for growing rice successfully.

Farming is a skilled occupation, drawing on much tacit knowledge that is not readily taught. If farmers already know how to grow rice, then explaining to them the *reasons* for making changes in past practices (pages 122-132) – as well as giving them some *personal exposure* to the new practices such as by visiting existing SRI rice fields and/or by talking with experienced SRI farmers – usually suffices to motivate and empower farmers to use the new methods without very long training or much laborious learning.

Appropriate Inputs and Implements: As with all agricultural practices, some inputs are needed, but not necessarily what are called 'modern' inputs. Because SRI methods enhance the productivity of practically any rice variety, farmers can continue using their same rice seeds as before. However, it is wise to try SRI methods with several varieties to see which respond most vigorously to its management under local conditions. If farmers can make and apply sufficient compost, even just 2 tons/ha can suffice to enhance supportive soil biological processes, chemical fertilizer need not be purchased. Agrochemical crop protection (pesticides, etc.) is usually not needed.

As noted above, the main input recommended for most SRI is a *soil-aerating mechanical hand weeder*. Such weeders can usually be manufactured locally and can be purchased for $15 to $30, or even for less with local materials. If weeders are not available or are too expensive, hand weeding or herbicides can be used to control weeds. If cost is an obstacle to purchasing a weeder, several farmers can buy one together for shared use. In the future, we anticipate that *improved and motorized weeders* will be made and become available which will greatly reduce labor time and tedium for weeding SRI fields.

Weeder built by Nong Sovann, a farmer in Kandol village in Kampong Spreu province of Cambodia. The materials cost him $3.60 -- for the large nails (that were driven into a wooden axle), the welding of iron rods, and adding a rake on the handle behind for better soil aeration. Nong estimated that this implement added at least $20 of value to the rice production from his very small field. See pages 9-10 of: http://sri.cals.cornell.edu/countries/cambodia/camphiltrpt305.pdf.

Inexpensive hand-weeding tool made and used by Govinda Dhakal in Morang district of Nepal, costing 20 cents. The first time that Govinda utilized SRI methods on his farm, the weed growth was so great that his neighbors thought he would never try SRI again. But he was determined and made this simplest of weeders out of wood and nails. This enabled him to triple his SRI area the next year to 1.5 ha. He told the author in 2006 that this tool enables him to reduce labor-time for weed control by 60% vs. manual weeding. See pages 6-9 of: http://sri.cals.cornell.edu/countries/nepal/neptrntu110206.pdf.

Popular cono-weeder design for SRI use in Sri Lanka. The float in front can be adjusted to set the depth of soil churning; designed for spacing of 25x25 cm; it could be fabricated locally for as little as $10.

A two-row SRI weeder designed and made by local engineer in Madagascar, The adjustable cross-bar accommodates planting widths between 20 and 40 cm. This never became popular because of its weight and its awkwardness in the field.

6.1 Isn’t it true that SRI requires more labor?

Initially, when farmers start to learn any new methods, it will take some time for them to use the methods quickly, confidently, and well. Handling the tiny young seedlings -- when farmers are used to handling larger, older ones -- can be worrisome; and transplanting will go slowly at first. However, once farmers get accustomed to the new methods, they can carry out the practices more quickly.

- Depending on the difficulty of controlling water, applying small amounts of water regularly can take more time than simply keeping fields always flooded. But in general, farmers find that as they become more comfortable with and more confident in SRI practices, this alternative system of rice production is at least *labor-neutral*, i.e., it does not increase labor, and more often they find that it becomes *labor-saving*, reducing their labor requirements.

- An evaluation of SRI use in **Madagascar** by Moser and Barrett (2003) first raised the issue of greater labor-intensity with SRI management. This was observed from a survey of five villages in one region. However, when a broader evaluation was done by these authors with two other colleagues, analyzing a data base of 108 farmers in four parts of the country having different lengths of SRI experience, it was found that although SRI required more labor at first, by farmers' 4th year of practicing SRI, their labor inputs per hectare were *4% less* than with usual conventional practices; and by farmers’ 5th year their labor requirements were *10% less* than with standard practice (Barrett et al. 2004).

In other countries, where farmers’ rice cultivation methods are *usually more intensive than they are in Madagascar*, the achievement of labor-saving with SRI management is usually more rapid and more significant.

- Evaluations of SRI in **Cambodia** for the German aid agency GTZ and in **Indonesia** by a Nippon Koei technical assistance team found SRI methods to be, on average, *labor-neutral* (Anthofer 2004; Sato and Uphoff 2007). While new SRI farmers required some more labor at the outset for growing an SRI crop, more-experienced SRI farmers managed with less labor, so on average in these studies there was no change in labor inputs.

- Evaluations in **China** and in **India**, on the other hand, have shown *reductions in labor requirements* with SRI, even from the first year (Li et al. 2005; Sinha and Talati 2007). Subsequent reports on SRI use in China and in India have noted that SRI is considered by farmers and by officials to be generally labor-saving there (Uphoff 2007b; *The Hindu*, January 1, 2008).

- In India, Tamil Nadu Agricultural University researchers evaluated side-by-side plots managed respectively with SRI and conventional methods on 100 farms in the Tamiraparani river basin. Their data showed labor inputs per hectare with SRI *reduced overall by 11%* (Thiyagarajan 2004).

    - Disaggregation by gender showed that with SRI, men's labor inputs per hectare *went up by almost 60%,* while the amount of labor that women put into rice production were *lowered by 25%* when SRI methods were used. Why? SRI weeding with mechanical weeders was considered to be 'men's work,' so they took over this task. Why did men accept this redistribution of labor? TNAU researchers calculated that with SRI methods, the net income per hectare was $519, whereas with usual methods, it was only $242 (Thiyagarajan 2004).

Conventional method of hand weeding in Tamil Nadu is seen on the left, and mechanical weeding with SRI methods is shown on the right.

It should be kept in mind that farmers continually find ways to *reduce their labor inputs* with SRI, such as by improving the design and operation of weeders, by replacing transplanting with direct-seeding, by finding ways to reduce their labor requirements for nursery management and transplanting, or by doing alternate wetting and drying of their paddy fields rather than the more precise but more labor-demanding routine of daily small applications of water.

The labor needs with SRI are not something fixed. Both farmers' skills and the techniques that they use with SRI are undergoing continuing change. Labor inputs in years 2 or 3 or 4 with SRI management are unlikely to be the same as in year 1. Farmers should always be told that *SRI will usually require more labor when starting out*, while they are learning the new methods. But there are reasons to expect that this increase will be transitory or transitional, not necessary and permanent. Whether SRI will save them labor or increase it will depend more upon their previous level of labor-intensity than upon the SRI methods themselves. In Madagascar, traditional rice production was basically labor-extensive, so any efforts to raise yield would, at least at first, increase labor requirements. This was not true in most of Asia, where rice production was already labor-intensive.

6.2 Can SRI practices be utilized without irrigation?

This is an important question because so much of the world's poverty is found in rural areas *where there are no irrigation facilities*. If SRI is beneficial only under irrigated conditions, it could not redress much of the poverty and the worsening income distribution in the world.

By 2005, NGOs working with farmers in the Philippines, Myanmar and India had found that with suitable adaptations, SRI principles and practices could give substantial increases in rice production under upland or rainfed conditions, even averaging 7 tons per hectare in several places. Most rice farmers with irrigation facilities would be very happy to achieve such yields.

- **Philippines**: In 2003, the NGO *Broader Initiatives for Negros Development* (BIND) in Negros Occidental Province did on-farm replicated trials with a popular local variety *Azucaena* to evaluate the results of rainfed SRI with five different spacings (and 4 replicated trials of each) on a total area of 4,000 m^2. Three or four seeds were sown in hills spaced at 15x40 cm, 20x40 cm, 25x40 cm, 30x40 cm, or 35x40 cm.

  Then, at 12-15 days after sowing, the hills were thinned to *one plant each*, leaving the most vigorous young plant and removing the others. The soil between the hills was mulched with leaves and branches of a leguminous shrub (*Gliricidia*) to conserve soil moisture, suppress weeds, and lower soil temperatures so that soil organisms would become more abundant.

  The highest yield was 7.7 tons/ha with 20x40cm spacing. The average grain yield across all 20 trials was 7.2 tons/ha, compared with usual rainfed yields in the area of 1.5 tons/ha. Organic fertilization was used: chicken manure and a seaweed foliar spray. Remarkably, virtually all of the tillers that the plants produced were fertile, giving almost 100% effective tillering (BIND 2003).

Farmers in Negros Occidental province of the Philippines clearing land for upland SRI trials; the traditional local variety Azucena *responds well to SRI management methods.*

- **Myanmar**: Starting in 2001, Metta Development Foundation, a Burmese NGO, began introducing SRI methods through farmer field schools (FFS) in the ethnic-minority Kachin and Shan states in the north (page 53). SRI practices had to be adapted to rainfed conditions because farmers in this region have no irrigation facilities. Average rainfed yields in the area are 2 tons/ha. On FFS demonstration plots, where SRI methods were used mostly as recommended, average yields (without irrigation) were over 6 tons/ha. On farmers' own fields with partial use of SRI methods, yields averaged over 4 tons/ha and have increased over time (Kabir and Uphoff 2007).

A rainfed SRI field in Kachin state of Myanmar

- **India**: In 2003, PRADAN, an NGO working in impoverished districts of eastern India, introduced SRI with 4 farmers in Purulia district of West Bengal state. When the number expanded to 150 farmers the next year, an evaluation team from the India Programme of the International Water Management Institute (IWMI) sent a research team to study that experience. It found that farmers who used all of the recommended methods, adapted for rainfed production, achieved average yields of 9 tons/ha (Sinha and Talati 2005, 2008), while one farmer even reached 15 tons/ha, according to the team leader (S.K. Sinha, personal communication).

  - SRI use kept expanding in Purulia district. A 2007 PRADAN report showed that of the 3,793 households using SRI methods there the previous season, 54% had yields in the range of 6-8 tons/ha, and 28% of yields were over 8 tons/ha. While rainfed yields in that area are usually 2-3 tons/ha, the average yield with SRI for a 5-year period was reported to be 7.4 tons/ha. PRADAN has since introduced SRI into rainfed areas of Bihar, Odisha, Jharkhand, Madhya Pradesh and Chhattisgarh, also with good results.

A tribal farmer in Odisha state of India showing an individual rainfed SRI rice plant from his field. Farmers in eastern India who learned 'rainfed SRI' concepts and methods from the NGO PRADAN were able to average 7 tons per hectare. Weed control was a big challenge. But mechanical weeders with their active soil aeration made weeding also a benefit and not just a cost.

Field experience in a number of countries has indicated that *SRI methods with appropriate adaptations can enhance food security and incomes for households in areas that have no irrigation.* Farmers need to learn not to hoard rainwater in their fields when the rains come, because ponded water will lead to degeneration of their rice plants' root systems in soil lacking oxygen. Not keeping as much standing water on the field as possible is, however, hard for perennially water-stressed farmers to accept. They need to see the difference in results.

If farmers establish their rice crop by transplanting, rather than by direct-seeding, they should also learn to start several nurseries, not just one -- in sequence about 2 weeks apart -- and then whenever the rains come, to *use only whichever nursery has seedlings of the best age* (under 15 days). At first, because rice is very scarce and precious, households are reluctant to plant 'extra' nurseries and to agree that they will 'sacrifice' all but one of them. But once they can see that a decision to grow a succession of young-seedling nurseries -- to have 'young seedlings' available when the rains arrive -- can demonstrably raise their yield, this 'waste' becomes acceptable.

6.3 Do farmers need to use new or special varieties of rice with SRI?

So far, farmers have found that SRI methods improve the performance of rice plants of *practically all varieties* -- old or new, unimproved or improved, traditional or modern, local or hybrid. But not all varieties respond equally well -- some varieties of rice are more responsive to SRI management practices than are others. By testing different varieties under local conditions, farmers can learn which varieties will be the best for him or her to plant.

Farmers should use whatever varieties of rice are the most productive and most profitable under their circumstances and for their needs. Productivity should be *evaluated in economic as well as agronomic terms*, as farmers need to be concerned with their economic 'bottom line.' They need to consider what will be the price that they will receive from buyers for their rice, and what will be their net income after deducting all their costs of production.

So far, the highest yields achieved with SRI methods have been with modern high-yielding varieties (HYVs) or with hybrids, many of which have been bred to have high capacity for producing many tillers. As noted above, the world-record paddy yields reported from Bihar state of India in 2011 were achieved with hybrid varieties and the even higher yield in Tamil Nadu two years later was with a popular ‘improved’ variety, CR1009.

At the same time, it has been found that many traditional local varieties give very good responses to SRI management: 5-10 tons per hectare, and even as high as 13 tons per hectare in Sri Lanka. Consumers who prefer the taste, texture and other qualities of 'unimproved' varieties are often willing to pay more for traditional rices, even double or more per kilogram. So a local rice yield half as high as that from a HYV can be more profitable, especially if the production costs are lower.

Some varieties respond somewhat differently under SRI management than they do with standard practices

- For example, a popular modern variety in India known as *Swarna* (MTU 7029) has been considered previously to be 'shy-tillering,' i.e., not producing many tillers per plant. However, when grown with SRI methods, it is seen to tiller prolifically, as shown on the next page.

A single SRI plant of Swarna *variety (MTU 7029). Before it was cultivated with SRI methods, this variety was thought by plant breeders and farmers to be 'shy-tillering.'*

SRI methods can make the use of *hybrid varieties* more profitable in two ways. First, these varieties usually give a very good yield response to SRI practices. But also, SRI management can raise the economic returns from planting hybrids by *reducing farmers' costs of production*, particularly because SRI reduces farmers' seed requirements by 70-90%. The high cost of purchasing hybrid seed has been one of the main barriers to farmer acceptance of hybrids.

- On the Indonesian island of Bali in the 2006 dry season, 24 farmers who used SRI methods with 'Long-ping hybrids' from China had an average yield of 13.3 tons/ha on 42 hectares, compared with a yield of 8.4 tons/ha from these hybrids when cultivated with farmers' usual methods (Sato and Uphoff 2007). This shows how SRI can make hybrid varieties more remunerative for farmers by raising their yield while lowering the costs of production.

At the same time, *traditional or heirloom varieties* when grown with SRI methods can be even more profitable than are higher-yielding varieties when SRI yield increases are combined with a higher market price and lower costs of production. Given consumer preferences, the price that hybrids and HYVs command in the market is commonly less than for indigenous varieties.

- An evaluation of 99 traditional varieties, grown under SRI management by the NGO Sambhav in Odisha state of India found that 3 of these varieties gave yields of 9 to 11 tons per hectare; 11 varieties had yields in the 8-ton range, while 15 varieties (4 of them aromatic) gave 7-ton yields; 36 varieties (5 aromatic) gave 6-ton yields, and 34 varieties (4 aromatic) gave 5-ton yields.

Indigenous varieties being conserved by the NGO Sambhav in Orissa state of India. Sambhav has over 400 accessions. Its evaluation of 99 traditional varieties with SRI management found all yielding over 5 tons/ha, and one produced 11 tons/ha.

- With SRI modifications in management, all the traditional varieties evaluated by Sambhav gave respectable yields -- over 5 tons per hectare (Sabarmatee, personal communication). Often, then, varieties that are 'unimproved' can be competitive in economic terms with HYVs, in part because they can earn premium prices if there are supportive marketing arrangements. Current marketing channels often do not reward higher quality.

Efforts are on-going in several countries to encourage the production and marketing of indigenous rice varieties, especially rice grown with organic methods, to raise farmer incomes and to conserve rice biodiversity. Such rice can find a good domestic market, but can also receive an export price premium when produced in environmentally-benign ways, particularly when reducing requirements for water. In the 2013-14 season, farmer groups working with the NGO CEDAC in Cambodia sold 10 tons of organic SRI rice in urban markets at a favorable price, while they also expanded their exports to the U.S. and Germany.

In 2005, the *SEED Initiative Award* (Supporting Entrepreneurship for Environment and Development), sponsored by IUCN, UNEP and UNDP, was given to CIIFAD together with NGO and farmer-organization partners in three countries: the *Koloharena* farmer organizations in Madagascar, assisted by the Peace Corps and a local Lions Club; CEDAC and the farmer groups that it works with in Cambodia; and Oxfam-Australia and farmer cooperatives that were taking up SRI in Sri Lanka. This collaboration to develop export, fair-trade markets for SRI-grown, organic, indigenous rice varieties has led to marketing arrangements discussed below. In June 2015, this SRI initiative was among the 10 awardees selected, out of 175 awardees recognized over the preceding decade, to be considered for ‘special recognition’ by the SEED program.

While SRI methods can be used successfully with both new and old rice varieties, they may help to conserve rice biodiversity by making those local landraces which respond well to SRI management more profitable and thus competitive economically with hybrids and high-yielding varieties (HYVs).

SRI is intended to give farmers more choices to improve their well-being and security. Those who want the highest yields will usually choose to use SRI methods with hybrids or modern varieties. SRI farmers more concerned with their 'bottom line,' on the other hand, or who rank grain quality ahead of quantity, may well prefer to plant traditional varieties.

SRI partners in several countries have been working with **Lotus Foods**, a small company in San Francisco, California that imports 'specialty' or 'heirloom' rices and distributes them throughout the U.S. with more than 3,500 marketing outlets (http://www.lotusfoods.com/index.php/more-crop-drop/).

Several product lines of organically-grown 'traditional' SRI rices have already been developed by Lotus Foods, shown on the next page, with good packaging and quality control to gain access to markets overseas and raise incomes for SRI farmers in Madagascar, Indonesia and Cambodia. SRI farmers in Indonesia and Cambodia have developed market demand for their indigenous rices, organically grown, also in Europe, Southeast Asia and Australia.

- A number of market studies and discussions are underway to increase the number of heirloom varieties produced and marketed, both domestically and internationally. Lotus Foods, SRI-Rice and partners in half a dozen countries have been assisted in the process of market development by Olivia Vent.

The rice species *Oryza sativa* has great variety and variability. We note that some of the indigenous African rice varieties (*Oryza glaberrima*) can also give good results with SRI management, as has been seen in Mali and Liberia.

'Improved' varieties usually have some superior qualities in one or a few traits, such as spikelet formation or grain weight, but not in all. For any farmer, the best variety for him or her will be one that meets multiple objectives in an optimizing way.

High-yielding varieties have been bred for highest yield in response to an abundant supply of water and synthetic fertilizer. Resistance to certain (or many) pests and diseases can be another objective of crop breeding, or resistance to drought-stress, to flooding, or to lodging. Many 'unimproved' indigenous varieties have such characteristics already, but do not respond well to applications of synthetic fertilizer, which makes them susceptible to lodging or to pest and disease attacks when the soil they grow in is supplied with inorganic NPK.

Anyone interested in growing rice with SRI methods needs to consider what will be the most appropriate genetic potential with which to begin their rice production efforts. SRI experience indicates that almost any variety that meets farmers' needs can have enhanced productivity and health when SRI practices are adapted and combined appropriately. The challenge is to elicit the variety's genetic potentials more fully and to best effect by providing the rice plants with more optimal growing environments.

Packages of organically-grown, fair-traded SRI rices from Indonesia, Cambodia and Madagascar. Each is a selected local variety that has particular qualities of taste, aroma and/or appearance that are pleasing to consumers in the U.S. and elsewhere.

6.4 Is SRI an organic system of production?

When SRI was being developed during the 1980s, Fr. Laulanié used chemical fertilizer because this was thought at the time to be the best way, and indeed often the only way, to achieve higher yields, especially given the nutrient status of Madagascar soils, generally classified as 'poor.' When the government stopped subsidizing fertilizer in the late 1980s, the farmers with whom Laulanié worked could no longer afford to purchase fertilizer. So he and they began to enhance their soils' fertility -- out of necessity, *faut de mieux* -- with compost.

- Happily, they found that compost when used in conjunction with the other SRI practices could improve rice yields even more, and certainly more cheaply, than did the application of chemical fertilizer, even when the farmers' soils were 'poor.' In soils that were very acidic, for example, adding phosphorus gave limited benefit because this became quickly bound and unavailable in such soils.

- The compost was made by farmers mostly from rice straw and any other biomass available (weeds, grass, shrubs, leaf litter, etc.), allowed to decompose for 30 to 60 days. *Little or no farmyard manure* was used by these farmers because most were too poor to own any livestock. Vegetative materials contained the necessary micronutrients for plants to synthesize enzymes and construct cells.

Chemical fertilizer used in conjunction with other SRI practices can enhance SRI yield. Replicated factorial trials in Madagascar have indicated 50% higher yields with the use of fertilizer over no use of fertilizer when the other SRI methods are used (Uphoff and Randriamiharisoa 2002). However, when compost was applied *instead of fertilizer* together the other SRI techniques, the average yield was seen to increase by another 17% (ibid.).

According to Association Tefy Saina, Laulanié did not regard the use of compost as a *requirement* for SRI, however; but only as an *accelerator* or as a *booster*. Several studies with controlled trials have found that certain *optimizing combinations* of organic and inorganic sources of nutrients can give highest yield, e.g., Lin et al. (2011). Combining sources of nutrients in what is called *integrated nutrient management* can give a yield greater than is attained with either kind of soil amendment by itself if the amounts and kinds applied are appropriate.

- There is a proviso to be considered and evaluated in this regard. The use of chemical fertilizer should not be such or so much that *the soil organisms which contribute to SRI rice plants' productivity are inhibited or adversely affected* by *the fertilizer*. Providing the soil with sufficient organic amendments essential for sustaining 'the life in the soil' is the key to SRI success.

In Indonesia, two versions of SRI were encouraged by the Nippon Koei technical assistance team: (a) *basic SRI*, in which farmers' reliance on chemical fertilizer is reduced by 50% while they increase the amount of compost added to their soils to support crop growth; and (b) *organic SRI*, in which only organic inputs are used (Sato and Uphoff 2007). In some marketing systems, the latter qualifies for a premium price in the marketplace, which makes absolute yield levels less important than profitability.

Some SRI proponents have a strong preference for 'organic SRI' for a variety of economic, environmental, health and/or ethical reasons. But SRI can be either fully organic, or only partially, or mostly organic. If no organic inputs are provided to the soil when the other SRI practices are being used, this is a very weak or minimal version of SRI. There can be some yield enhancement with just chemical fertilizer; but the full benefits of SRI management cannot be expected.

- Often, when farmers convert their cropping systems that were previously dependent on chemical fertilizer over to fully organic production methods, they have to *go through a transition period* during which their yields may be lower for a year or two as the soil system adjusts to the new nutrient regime and as the abundance and diversity of soil organisms is gradually increased. Soil systems which have become dependent on chemical fertilizer often need some time to be able to function without receiving a supply of inorganic nutrients, time to build up and revitalize their soil biota, often diminished or unbalanced by the use of synthetic fertilizers.

- It is instructive that when farmers start to use SRI methods -- in contrast to the usual experience when converting from conventional, fertilizer-dependent cropping practices to organic agriculture – there is *seldom a transition phase* during which yields decline for a while before they recover and then increase. Usually, farmers who adopt SRI practices with substantial or total reliance on organic fertilization get a satisfactory increase in yield already in their first year. This is apparently due to a 'windfall' of productivity that can be gained from converting paddy soils from anaerobic status, without air, to aerobic conditions, well-supplied with oxygen.

With petroleum prices volatile and with the prices for chemical fertilizer and other agrochemical inputs increasing, we can anticipate that there will be more and more interest in production systems that do not depend on these purchased inputs. Also, there is growing concern for the quality of soil and water resources, and for soil health and human health, which can be adversely affected by continuous agrochemical applications.

We anticipate there will be more and more demand from consumers around the world for organic food products, for food produced without agrochemical nutrient inputs or crop protection. There will also be demand from citizens to reduce the build-up of nitrates in groundwater and surface water supplies, and to stop the accumulation of toxic chemicals in their soil and water.

We expect that over time, organic versions of SRI will gain in popularity, as well as in productivity and profitability. However, the decision on whether to use organic and/or inorganic production materials is left and should be left to farmers, taking into consider consumer preferences, regulations for environmental protection, net economic returns, their own thinking and values, and any other relevant considerations.

Saepul Bahri, chairman of the Simpatik farmers' cooperative in West Java, Indonesia, with Emily Sutanto, founder and executive of PT Bloom Agro, and Stefan Fak from Lotao, standing in the cooperative's modern mill for processing organically-grown traditional rices that its 2,300 members grow and export to the U.S., Singapore, Malaysia and Germany. Simpatik coop works with Bloom Agro, an Indonesian export company that trades with Lotus Foods (http://www.lotusfoods.com/index.php/products/organic-products/organic-volcano-rice) and a German company by the name of Lotao (http://www.lotusfoods.com/index.php/products/organic-products/organic-volcano-rice/), facilitating imports of organic specialty rices from Indonesia into markets in the U.S., Europe, and several Asian countries.

7. What limitations are there for utilizing SRI methods?

Following from the preceding review of requirements for utilizing SRI knowledge, the main constraints on SRI use that need to be considered are:

Water Supply and Control: While SRI reduces water requirements, no plants can grow without water, so some *reliable supply of adequate water* is needed. At the same time there should be some reliable means of *draining off any excess water* so that the soil can remain aerobic most of the time, with a good supply of oxygen for both plant roots and soil organisms. Where insufficient water is available, SRI is not possible; and where there is no control over an abundant water supply, SRI is not recommended, especially if there are no drainage facilities and the field's supply of water is perpetually excessive.

Temperature: Plants also require warmth for their growth. If temperatures are very cold, SRI will not be feasible -- although it may be possible to practice SRI by transplanting seedlings that are older than 15 days, as these can be still 'young' in biological terms because plants lacking warmth grow more slowly.

- A Chinese 'relative' of SRI is a rice cultivation system called **3-S,** developed in the 1990s in northern China in Heilungjiong Province near Manchuria. 3-S uses seedlings 45 days old in a system that has expanded to tens of thousands of hectares with average yields of 8-9 tons/ha. Rice seedlings are started in plastic greenhouses while there is still snow on the ground (see below) and are transplanted singly with wide spacing and reduced irrigation, providing as much organic matter as possible to enhance the soil's fertility. In a cold climate like that in Heilongjiong, rice seedlings that are 45 days old may be biologically equivalent to seedlings that have been growing for just 15 days in a much warmer tropical environment.

  Two adjacent rice plots planted with the same variety are shown In the right-hand picture on the next page. The plot on the left was managed with usual production practices, while a 3-S plot is seen on the right. The difference in rice crop maturation is very visible. Standing between the plots in a blue shirt and white cap is the late Prof. Jin Xueyong of Northeast Agricultural University in Harbin, who developed 3-S on his own, without any knowledge of Fr. Laulanié's work in Madagascar. Once he learned about SRI, he recognized the 'kinship' of the two systems and hosted visits by the author to Harbin in 2003 and 2004. Through their respective management methods, both 3-S and SRI are tapping the same genetic potentials that exist in rice plants.

Labor Constraints: SRI methods will not be successful if there is not enough labor available -- or not enough patience to learn the new methods and to treat young seedlings carefully. Initially there may be some resistance from hired laborers to using the new methods because they prefer continuing familiar practices or do not like taking more care in their work if they are not compensated better (and if they see that all the benefits of their careful work are accruing to their employers). Usually within a few days, laborers report that they find the SRI methods of transplanting are easier for them physically, and weeding operations with a push-weeder are considered an improvement over stoop-weeding by hand (Mrunalini and Ganesh 2008).

Crop Pests: Root-feeding nematodes (*Meloidogyne* spp) are a pest problem that was identified as a constraint for SRI practice in northern Thailand, where this soil pest is endemic and becomes more abundant when paddy soils are not kept flooded all season long (Sooksa-nguan et al. 2009). This pest may be controllable by modifying water management schedules, to flood the fields for longer periods, or more often, than is usually recommended with SRI, but still to have enough dry stretches between periods of flooding spells to get some benefits for the rice crop from more soil aeration.

- In Southeast Asia, the **golden apple snail** (GAS) is a major pest for many rice growers. An SRI farmer in the Philippines has worked out a water management schedule that is compatible with SRI and controls the GAS. For the first 20 days after transplanting young seedlings, he keeps the paddy soil flooded just enough to keep the snails' eggs from hatching. After 20 days, the field is allowed to dry out so that the snail eggs hatch and the snails then feed upon young weeds as they emerge. Beyond 20 days the SRI plants have become tough enough that snails prefer to eat the tender new weeds rather than the farmer's rice. The farmer says that this gets the snails to do his weed control for him (Porte et al. 2006). This strategy is worth being developed because infestations of GAS can be a constraint for farmers that makes planting fewer and younger seedlings not very feasible.

- In China, one farmer has combined **duck-rearing** with SRI management to control weeds. He keeps his ducklings out of his SRI paddies until 20 days after transplanting. By this time, the ducklings prefer the emerging, tender young weeds to the older, rapidly-growing rice plants. The farmer says that ducklings thus help him with weed control, and also with control of insects and snails which become part of the ducklings' diet (Uphoff 2007b). Duck eggs and meat are an additional source of income for the farmer. This suggests some possible combination of SRI methods with the Aigamo integrated system of rice cultivation (Furuno 2002). For a video on large-scale use of ducks to carry out rice weeding in Thailand, see: www.youtube.com/watch?v=Kx3cfoPjyR4.

These examples of pest control underscore a general observation to be made about the use and spread of SRI. The dissemination of SRI should not be regarded as a matter of 'extension' -- spreading a fixed technology to any and all farmers by giving them certain instructions. Rather, SRI should be presented as a matter of *problem-solving*. Farmers should learn and understand the *principles* as well as the *practices* of SRI, so that with their knowledge of SRI principles, they can adapt their SRI practices to local conditions and opportunities.

- In America, it is sometimes said that there are two kinds of lawyers: '*can-do'* lawyers and '*can't-do' lawyers*. Whenever one needs advice or gets in trouble, we are advised to seek the assistance of the first kind of lawyer, not the second. For SRI application, there are 'can-do' and 'can't-do' agronomists.

  The former know what cannot or should not be done; but they focus on figuring out *how to achieve certain objectives given the constraints*. A can-do agronomist proposes appropriate modifications to general prescriptions, making recommendations that deal with and transcend constraints so as to achieve certain goals. Can't-do agronomists will know and cite many reasons why standard or new practices will *not* succeed, which is not of much help.

There are of course various, sometimes even many, constraints and limiting conditions to be dealt with when introducing and scaling-up SRI. There are some situations where SRI methods will not give the desired results, or will not give them at an acceptable cost, or within a reasonable amount of time.

- SRI is not proposed as 'a silver bullet' or as 'a universal solution.' Its ideas and experiences are considered to be building blocks for innovation and improvement. We want anyone who could make more productive the land and other resources that are presently available to him or her to have free and easy access to SRI knowledge, examples and information.

The principles and strategy of SRI laid out in this book have been found to have broad relevance, also applicable for other crops as seen on pages 148-153. Most constraints are more relative than absolute. Where encountered, they should become *focuses* for adaptation and innovation rather than being regarded primarily as *barriers*.

An SRI rice crop growing in Dapka village at 2650 meters above sea level in Humla district, northwestern Nepal. Dapka's elevation is so high that rice is not traditionally grown here. With assistance from the Himalayan Permaculture Centre, the farmer seen here, Hanse Buddha, tried SRI methods, using widely-spaced, 2-leaf-stage seedlings, and got quite satisfactory results.

Mahamadou Hamadou, the first SRI farmer in the Timbuktu region of Mali, looking over his SRI field on the edge of the Sahara Desert that in 2007 gave him a yield of 9 tons/ha. SRI methods can very evidently be adapted to a wide range of physical conditions.

7.1 Where would SRI methods be unlikely to succeed?

Benefits from SRI crop management have been demonstrated in a wide variety of environments, as seen from the pictures on preceding page and the following two pages. But there must be some limitations on any biological process, and certainly there will not be equal advantage gained from the new methods everywhere. To provide some context for this response, however, it will be relevant to start with a comment on the first systematic experimental evidence that was produced on the yield effects of SRI practices, respectively and collectively.

In 2000 and 2001, large-scale factorial trials were conducted in two contrasting agroecosystems in **Madagascar**. Standard research design was used with replicated trials laid out in random block design.

- Six variables (age of seedling, spacing, water management, etc.) were tested in all different combinations, first in a *tropical climate* at Morondava on the west coast of Madagascar, at sea level and on poor sandy soils; and then the trials were repeated in a *temperate climate* at Anjomakely on the country's high central plateau, located 1200 meters above sea level and with better clay and loam soils.

- Despite the large differences in agroclimatic conditions, the *patterns* of yield response to the different SRI practices -- evaluated respectively and in all different combinations -- were essentially the same under both sets of trials (N=288 and N=240).

- In the two sets of trials, although the yield levels were different (lower on poorer soils), the SRI methods were found to triple yields over usual practices. With the treatments having 6 replications, the statistical significance of the differences was very substantial. The results were reported in Randriamiharisoa and Uphoff (2002) and Uphoff and Randriamiharisoa (2002).

In **Nepal**, SRI methods have been used successfully from the plains of the southern *terai* with its sub-tropical environment several hundred meters above sea level (page 132), up to 1,700 meters (page 82), and even at 2,650 meters elevation (preceding page), where climatic conditions are similar to the mountainous areas of Afghanistan, discussed below.

In **Africa**, beneficial SRI results have been obtained under conditions ranging from the low-lying seasonally humid environment of The Gambia (Ceesay et al. 2006) to the semi-arid tropical climate of the Kenya highlands (Mati et al. 2011; Ndiiri et al. 2013) to the Timbuktu region of Mali on the edge of the Sahara desert (Styger et al. 2011).

On the left, an SRI nursery in the Timbuktu region of Mali with 8-day-old seedlings ready to be transplanted; on the right, the transplanting of young SRI seedlings.

On the left, a Malian farmer in the Timbuktu region showing the difference between 'normal' rice plants on left and an SRI plant on right. Usual paddy yields in this region are 4.5-5.5 tons/ha, while SRI yields have been between 7 and 9 tons/ha. On right, an Afghan farmer with an SRI plant on left and a more typical rice plant on right. Usual yields in Baghlan province are 5.0-5.5 tons/ha, while SRI yields there have been 7 to 10 tons/ha.

On the left, Afghan farmers transplanting 13-day seedlings at 30 x 30 cm spacing in Baghlan province at 1600 m above sea level. On the right, an Afghan farmer is looking over his SRI rice plot at 30 days after transplanting.

An SRI rice plant in Baghlan province with 133 tillers at 72 days after transplanting. The harvested yield from this field was 11.56 tons/ha.

Thus, one of the remarkable things about SRI is its versatility, although one should never assume that its methods will be successful everywhere. It is always necessary to try out SRI methods under specific circumstances to see how they will perform there. Various modifications often need to be made *in situ*.

With these prefatory comments and pictures, several contexts are noted where we would not expect SRI practices to be very successful, or even successful at all.

Cold Climate: Young seedlings are vulnerable to cold temperatures, so these can be a limiting factor. Rice plants' biological age is reckoned by their stage of development -- by the number of leaves that they have produced, rather than by the number of calendar days since sowing or germination

In colder climates, one should start with seedlings 15-25 days old since these will be more equivalent physiologically to seedlings 8-12 days old that have been growing under warmer temperatures. Reporting seedling age in terms of the number of days after sowing or transplanting is common practice, but plant age is more precisely and meaningfully assessed in terms of *leaf stage* (leaf number). For purposes of SRI practice, we consider as 'young seedlings' those seedlings that between their 2- and 3-leaf stages. Possibly ‘young seedings’ can be even older.

- A rice production system known as *3-S*, devised by the late Prof. Jin Xueyong of the Northeastern Agricultural University in Harbin, has many similarities with SRI as noted on pages 101-102: single seedlings, wide spacing, reduced water, more organic matter. By transplanting single 45-day-old seedlings, grown in greenhouse nurseries established before the snow melts, yields of 8-9 tons/ha have been attained with 3-S methods (Jin et al. 2005; http://sri.cals.cornell.edu/countries/china/cn3ssys.html). Cold temperatures will necessarily require some modifications of practice, particularly regarding seedling age.

Water Control: If a field's soils cannot be kept mostly aerobic, there will be less or maybe no benefit derived from SRI practices. Low-lying soils that are continuously waterlogged are not suitable for SRI practice because aerobic soil organisms cannot prosper in an environment that lacks oxygen. In such areas, it may be possible to install *drainage facilities* to remove excess water, however. The higher economic returns achievable with SRI methods can make investments in such infrastructure financially advantageous.

- In Indonesia, individual farmers whose rice fields are in the middle of a large-scale irrigation system command area and where irrigation flows are field-to-field will have little control over their water supply. This makes SRI management difficult as water from their neighbors’ flooded fields can move laterally into their own field. Accordingly, some farmers have devised in-field soil and water management practices that enable them to use SRI methods quite effectively: *raised beds* constructed within their fields, coupled with *drainage channels* dug around the inside edges of their fields to help them get rid of unneeded water more quickly.

- In the Indian state of Tripura, where rainfall averages 2500 mm/year, it has been found that by putting *small parallel drainage channels* across the length of SRI fields every 8 or 9 rows, the soil can be kept well-drained enough for SRI methods to be used successfully. Although this sacrifices about 10% of the field area for drainage purposes, it increases the yield on the remaining 90% of the area enough to more than compensate for the reduction in cultivated area.

An SRI paddy field in Tripura state of India 12 days after transplanting; bubbles on the soil's surface indicate earthworm and other biological activity under SRI's more aerobic soil conditions.

These examples show how adaptations and innovations can be introduced to deal with the constraint of excessive water. The numerous advantages of SRI can provide both farmers and governments with strong justification for investing in the improvement of water control structures -- gates, channels, canals, and drainage facilities. The multiple benefits also give farmers an incentive -- once they are agreed on the advantages of using SRI practices -- to form *water user associations* that can take the necessary steps to manage their water supply carefully and efficiently, to distribute water sparingly but reliably, in order to take advantage of SRI opportunities.

Soils: Soil characteristics have significant impacts on crop productivity in general. The best SRI results have been seen on soils that are slightly acidic (pH less than 6.0), but the next best yields are on moderately alkaline soils (Jagannath et al. 2013). Not surprisingly, SRI methods give least benefit on very acidic and very alkaline soils. However, even on acidic and alkaline soils, SRI is found to outperform conventional management methods (ibid.).

- Early evaluations of SRI in the Punjab state of India showed SRI methods giving a 30% lower yield on soils that were much affected by salinity, while on heavy clay ('sticky') soils, SRI yields were 70% higher. On three other categories of soils considered to be more typical, the SRI yield increases averaged 62%, as reported by Amrik Singh, ATMA-Gurdaspur.

- An evaluation of *water use efficiency* (WUE) with SRI compared to conventional crop management across different soil types (textures) found that loam, sandy loam, and sandy clay loam soils gave the highest WUE values for irrigation water. The highest *total* WUE values were found with loam and clay soils (Jagannath et al. 2013). In this meta-analysis, advantages from SRI management were seen across all soil types (ibid.).

Research in India has shown that the *application of compost* or other organic matter on saline soils can alter their pH and make them more fertile, probably in part by improving soil structure to make root growth easier (Rangarajan et al. 2002). It may be possible with applications of organic matter to make saline soils amenable to SRI production methods. Research on SRI methods used on saline soils in Mozambique showed some though not uniformly positive results (Menete et al. 2008).

Maria Zelia Menete beside some of her test plots in Mozambique where she evaluated the effects of SRI management in buffering the effects of soil salinity.

It has been argued that SRI will augment yield particularly on (and possibly only on) soils with high content of *iron* (Dobermann 2004). The conclusion that SRI benefits are limited to iron-excess soils is contradicted, however, by trials conducted in 2003 across all 22 districts of Andhra Pradesh (AP) state of India. The staff of the state's agricultural university (ANGRAU) evaluated SRI with side-by-side plots on a wide range of soil types and under diverse agroecological conditions. These trials showed SRI methods giving, on average, 2.5 tons/ha higher yields across the whole state (Satyanarayana et al. 2006). There was thus no indication that SRI is 'a niche innovation,' beneficial in only certain kinds of soils.

- Trials in all 22 districts showed yield improvements under SRI management which reduced applications of both water and fertilizer. Surprisingly, the largest average increases (4.8 tons/ha) were on the lighter, well-drained soils of the state's interior region (Rayalseema), while on the heavier, low-lying coastal soils, average increases with SRi methods were 1.8 tons/ha (ibid.). Greater increases were seen on soils that had previously been considered to be inferior for growing rice compared to AP's delta areas.

Research in Panama on the effects of soil type on SRI performance has showed that yield increases with SRI management can be greater on what are classified as 'poor' soils than on categorically 'better' soils, particularly on soils with low available phosphorus (Turmel 2011). Analysis of 70 data sets from across 15 countries showed SRI methods giving greater yield increases, in both absolute and relative terms, from soils classified as 'poor' according to FAO criteria than from soils that were classified as 'good' (Turmel et al. 2011).

Poor rural household usually must grow their crops on soils that are poorer than those that are owned and managed by richer farmers. This suggests that SRI is an unusual innovation also for its being more productive for people whose resource endowments are poor or limited.

The area around Timbuktu in central Mali on the edge of the Sahara Desert could be considered as one of the most difficult areas for achieving high rice yields, but with good and sparing use of available irrigation water and SRI methods, good results are possible, as seen on page 106 above. The Malian farmers here were attending the first SRI training program, held in the old walled city of Timbuktu and led by Erika Styger, now director of programs for SRI-Rice, standing in the back row.

7.2 Do all of the SRI methods need to be used fully and precisely?

We see over and over that using the recommended SRI practices all together, and using them with the precision and care that are recommended, will result in the most productive and robust plants. But each respective practice improves in different ways the growing environment for rice plants below-ground and/or above. The use of SRI ideas and methods *should not be considered as an all-or-nothing proposition*, as shown in an evaluation of SRI methods across 13 states of India undertaken by IWMI and TNAU researchers (Palanasami et al. 2013).

Synergy among the practices results when improving the growth and functioning of the plant roots makes for a larger, healthier canopy, while at the same time, any improvements achieved in the canopy's structure, vigor, and rate of photosynthesis benefit the roots. Plants function as a whole; but amelioration in certain parts or processes can contribute to the whole.

There are many interactions among the recommended SRI practices that should be considered. Wider spacing gives more benefit for growth of plants started from younger seedlings. Also, there is a better growth response of plants when the soil in addition to being supplied with organic matter is also actively aerated. Conversely, when young seedlings are transplanted, care must be taken so that their roots do not suffocate under a layer of standing water on the field. This is why the practices of SRI are described as constituting a 'system,' with the results of the whole being more than the sum of the parts.

Farmers who understand SRI principles and who apply SRI practices to the extent that they can will able to improve their crop's performance through the careful transplanting of single, young seedlings, reduced plant density, modified water management, more organic nutrient soil supplementation, and soil-aerating weed control. These are the main elements of SRI, each having merit. All when used together produce a superior environment for rice plant growth.

Farmers who *do not have complete water control* or whose water control is imperfect can often benefit from using some combination of the other practices, while making an effort to reduce their overuse of irrigation water. The most critical time for the crop is the first few weeks while the plants are getting their root systems established and are getting ready for accelerated their production of tillers. Avoiding over-watering them in this period is most important.

- If flooding in the early weeks cannot be avoided, then undertaking SRI becomes only marginally beneficial. The full benefits from using well all the other SRI practices will not be obtained when mostly-aerobic soil conditions cannot be maintained. Even so, farmers may be able to benefit from some experimentationto see what improvements can be made in their crop's performance despite their having less-than-perfect water control, drawing on whatever they have learned from the SRI principles.

Where *seedling mortality* is a problem, because of extreme weather conditions or because of poor water control or because of pests such as nematodes or snails, planting more than one seedling in a hill will be reasonable. Also, when the *soil is not very fertile*, a farmer can get more yield from planting two seedlings per hill rather than just one (Andrianaivo 2002).

- However, farmers' soil will often become more fertile over time as a result of their SRI crop management. As a result, farmers with poor soil should eventually become able to get higher yield by planting just one seedling per hill. This is because reducing competition between plants by having just a single, more profuse root system will facilitate the best utilization of the soil's resources.

With direct-seeding, farmers who plant a number of seeds together in a hill should remove the weaker plants once it is clear which of the emergent seedlings has gotten the best start. There is no harm in having more than one plant in a hill; only some yield is forgone when plants' root systems do not develop fully because they are inhibiting each other’s growth. Also, using 2 seedlings or 2 seeds per hill will double a farmer’s seed requirement, so single seedlings or seeds can save money.

If the seeds or young plants in a particular hill do not grow, this area will not be a complete loss because the plants around will then have more space for their tiller growth. Adjacent plants will fill in some or even all of the space that is opened up when some seedlings do not survive or some seeds do not germinate. Unless there is a lot of seedling mortality or failure to germinate, the reduction in yield in an SRI field from having, say, 5% of seeds or seedlings not survive may not be great enough to make it worthwhile for the farmer to replant or reseed.

If a *mechanical weeder* is not available, or if there is no available/affordable labor to use them, weeds can be controlled by hand weeding or by the use of herbicides. While these other means of weed control will take care of the weed problem, they will not boost yield through active soil aeration and by stimulating the growth and impact of beneficial soil organisms. Indeed, herbicides can have suppressive effects on the latter and other adverse environmental effects.

If farmers do not have enough biomass or enough available labor to make and apply *compost*, they can use chemical fertilizers instead. Providing inorganic nutrients usually has some positive effect on yield when used with the other SRI practices. However, commercial fertilizers are usually costly, so cash-constrained farmers may find this an infeasible or expensive option.

The basic SRI principle is not to *use only organic materials*, but rather it is to *add as much organic matter to the soil as possible*. The negative effects that using inorganic fertilizers can have on the soil's structure and functioning should always be considered, even if these effects are not easily or immediately apparent.

Farmers who cannot make and apply enough cormpost matter to meet fully the nutrient needs of their soil and their crop can try applying a combination of organic and inorganic materials in what is called *integrated nutrient management*. Some evaluations have indicated that this can increase yields beyond what can be achieved with organic materials alone, e.g., Lin et al. (2011). What will be an *optimum amounts and combinations* of materials will depend upon the soil's fertility status, which in turn depends to a great extent upon the abundance and diversity of beneficial organisms living in the soil.

Given the out-of-pocket cost of purchasing fertilizer, farmers need to consider whether the increment in yield that it can give is economically justified. The profitability of different means to improve one's soil fertility should be properly evaluated, not just assumed, whether in favour of *either* organic or inorganic fertilization. Currently there is little systematic information available that can inform a farmer's decision on how to choose between organic and inorganic fertilization or to estimate what will be optimizing combinations of each.

Farmers should not make a decision about whether or not to use SRI practices based upon whether they can undertake *all of the recommended practices*, e.g., whether they can maintain perfect water control or can do fully organic fertilization. SRI recommendations map out for farmers how they can achieve the *best agronomic results*. But considerations of cost and of availability of different inputs can make what is *less than the highest attainable agronomic yield* actually more advantageous in economic terms. It is said that: *The best should not be allowed to become the enemy of the good.* What is considered 'the best' sets a standard for assessing alternatives, but what will actually *be* 'the best' for a certain farmer in a given situation will depend upon a number of factors.

Most farmers can get better results than they are obtaining now by understanding *what* is being recommended for practicing SRI and at the same time, *why* these practices are recommended. With such understanding, farmers can make appropriate adjustments and innovations in their practices, considering physical opportunities and constraints as well as economic costs and benefits.

Farmers need to consider economics as well as agronomics when making decisions since they need to ensure and enhance their household's net resources. Too many agronomic recommendations do not take enough account of economics and of labor availability, factors that can dominate farmer decisions.

- An example would be deciding whether to do mechanical weeding, and if so, how much. Many farmers say that they do not have enough household labor, or enough money to hire laborers, to give their rice crop as many as four weedings, which is recommended as ideal. It is quite all right to start with a plan to do just the minimum of two weedings for weed control.

  - Farmers who want to practice *evidence-based agriculture* should choose half a dozen rows of their field for which they will do a 3rd weeding 10-12 days after the 2nd weeding. And then, they should give half of these rows a 4th weeding 10-12 days later. By the end of the season they can see for themselves whether under their soil and other conditions there was enough improvement in the tillering and grain formation from their rice plants which were given a 3rd weeding, or even a 4th weeding, to justify making the extra effort and expenditure to do additional soil-aerating mechanical weedings beyond the minimum of two.

  - In Madagascar and Nepal, we know that farmers have been able to add several tons per hectare to their paddy yield by doing 3 or 4 mechanical weedings, rather than just 2 (pager 126). How profitable it will be to do more than the minimum depends on the soil, its characteristics and dynamics, as well as on the direct costs or opportunity costs of labor. These are empirical considerations to be assessed under a farmer's own conditions.

- A similar experiment can be done with the number of plants per hill. Farmers should determine empirically whether one seedling or maybe two seedlings per hill will be best under their soil and other conditions. This can be seen by planting the field with 1 per hill in some parts and 2 per hill in other parts. Farmers should count the number of tillers per hill (from several plants, not just one) and also the number of grains per panicle in the different hills.

  - Possibly they will find that 2 plants per hill give them greater productivity, in which case that should be their SRI practice, although not necessarily forever. SRI management usually improves the soil's fertility over time, so SRI farmers should continue planting some hills with single seedlings to learn if and when this will give them more productive plants in the future.

Many present practices constrain rice plants' expression of their full genetic potentials: inhibiting tillering, degenerating roots, making plants more vulnerable to biotic and abiotic stresses. Accordingly, capitalizing on some number of SRI management practices can be beneficial even if not all of those practices can or will be followed in the way that is understood to be ideal.

This discussion underscores the idea that SRI is 'not a technology' -- but rather a set of ideas, principles and experiences that encourage farmers (and those who work with them) to '*think outside the box'* of their previous experience and training. For a farmer to say that SRI knowledge is not relevant for him or her because there is not enough water control, or not enough biomass, or not enough labor available, is to misunderstand the significance of SRI for his or her and others' agriculture.

If a household does not have enough labor power initially to cultivate all of its paddy area with SRI methods, this is not sufficient reason to dismiss SRI opportunities. Since SRI methods raise the productivity of *all* the factors of production – *seeds, water, land, labor and capital* – a household will get *more net economic benefit from using SRI methods on as much of its paddy land as it can*, not necessarily on all of the paddy land that it has.

- A farmer who cannot cultivate all of his paddy land with SRI methods because of limitations on labor availability will benefit from using the methods on part of his paddy land, leaving some of the land *fallow*, rather than cultivating all of his or her land with less-than-the-most-productive methods available. Farmers need to get the highest return per unit of their labor (per hour or per day) as well as per unit of their land (acre or hectare), and also highest returns to water.

- Land that is not cultivated with paddy rice using SRI methods can be used for growing other crops when and as labor availability permits. This will add to households' net income. SRI cropping system decisions should be made in the context of the household's total farming system. Getting higher productivity from all of one's land, labor, water, seed and capital is the key to agricultural success.

Alik Sutaryat, who left government employment to give leadership for organic SRI production in Indonesia, contrasting rice plant growth when all the recommended SRI practices are used together, 64 tillers on the SRI plant vs. 24 tillers from a hill of several plants grown with conventional cultivation methods.

7.3 Are there significant problems of disadoption of SRI?

One of the first published reports on SRI in Madagascar (Moser and Barnett 2003) reported that although SRI methods certainly raised farmers' yields substantially, there was a high rate of disadoption of SRI methods, as much as 40%, after farmers had tried them out, mostly because of a greater requirement for inputs of labor to utilize the new practices. It was concluded that even though SRI was labor-intensive, at least in the beginning, something that should favor the poor, it was not an innovation that the very poor could readily utilize and benefit from. Why?

Households that were very poor needed a continuous flow of (even meager) income to survive. Even when poor households knew and acknowledged that SRI methods could give them greater yields, it appeared that they could not afford to adopt the methods because their hand-to-mouth existence limited their ability to seek deferred returns from investing more labor in SRI practices. Farmers who could benefit from SRI were giving it up as 'too labor intensive' or for other reasons.

As seen above, the preponderance of evidence is that SRI is or can be in fact *labor-saving*, or is at least *labor-neutral* in most instances, rather than being inherently labor-intensive (pages 57-58 and 88-89). However, the question of disadoption lingers, and it is one that needs to be addressed.

There was other, concurrent evidence from **Madagascar**, from a larger data base and over a longer period of time, which indicated that disadoption was not a big problem with SRI in that country. This comes from an evaluation of a large French-funded irrigation project on the high plateau (Hirsch 2000) being implemented at the same time as the USAID project under which CIIFAD worked with Association Tefy Saina on SRI evaluation and extension in the Ranomafana area.

Farmers around Ranomafana National Park who used SRI methods attained average paddy yields of 8 tons/ha -- four times the usual yield of 2 tons/ha that they had been getting on the same fields and with the same varieties using their conventional methods. As seen in the table on the next page, the French project in central Madagascar reported results very similar to those in Ranomafana.

In the French project, SRI results were compared with those of farmer practice as well as with the *Système de Riziculture Ameliorée* (SRA), the System of Improved Rice Cultivation. SRA was comprised of the 'modern' practices recommended by government researchers: new seeds, inorganic fertilizer, dense planting in rows, and continuous flooding. As seen from the data, there is little sign of disadoption of SRI, even though it was not being promoted by any formal extension program as in Ranomafana; instead it was being spread mostly farmer-to-farmer. The following data were gathered from irrigation schemes within the project area.

Rice Yields on the High Plateau in Madagascar, 1994/95 to 1998/99, Antsirabe and Ambositra Regions Combined

AREA	Farmer Practice	System of Improved Rice Cultivation (SRA)	SRI
1994 / 95	1,875.5	4,361.9	34.5
1995 / 96	1,501.5	5,224.5	88.7
1996 / 97	1,419.0	3,296.7	226.7
1997 / 98	3,122.0	2,893.0	229.7
1998 / 99	2,768.1	2,628.0	542.8
YIELD			
1994 / 95	2.02	3.96	8.62
1995 / 96	1.96	3.41	7.89
1996 / 97	2.08	3.30	10.68
1997 / 98	2.84	3.78	8.59
1998 / 99	2.97	4.61	8.07
AVERAGE	**2.36**	**3.77**	**8.55**

Source: Data from Hirsch (2000), Annexes 13-14.

Disadoption has not been reported as a definite problem for SRI's spread elsewhere except in **Andhra Pradesh** state of India (Adusumilli and Laxmi 2009). While there are no systematic data on disadoption in the state, the most common reason given by farmers for stopping their use of SRI methods has been that the supply of electricity for pumping irrigation water is unreliable, so they prefer to keep their paddy fields as much flooded as possible.

- Lack of power for pump irrigation is a deterrent to adopting SRI and for continuing with it since water control is important for SRI. However, this is not a shortcoming of SRI itself, but rather of the infrastructure that serves rice farmers. If electricity shortages or interruptions deter farmers from using SRI methods, this reflects not on the *agronomics* of SRI, but on the *pragmatics* of using its methods under particular local conditions. These are different matters and should not be conflated or confused.

In the Indian state of **Tripura**, SRI use has increased dramatically as seen below. After several years of on-farm evaluation starting in 2002, adjusting SRI practices to local conditions, the Tripura state government decided in 2005 to support its dissemination. A rice specialist with the Department of Agriculture who gave leadership to this SRI extension effort, Baharul Majumdar, says that he has not heard of any farmers in Tripura disadopting SRI methods once these methods have been demonstrated and evaluated in the field (personal communication).

The table below shows the uptake of SRI in Tripura state. As often happens when an innovation is spread rapidly, yield improvements recorded have declined somewhat over time, attributable to the rapid expansion and to the lower quality of training and supervision as the extension effort expands. However, large increases in yield and production have been attained, mostly under rainfed conditions. With reductions in their costs of production, farmers' net incomes are increased by more than their higher production yields. The growth of area has not been increasing as rapidly in recent years, but this is partly because so many farmers are using some if not all of the SRI practices that it is hard to have an accounting of how much area is 'under SRI' cultivation methods.

SRI fields in Debipur village, Tripura state, with yellow flags denoting SRI adoption.

SRI Spread in the Indian State of Tripura, 2002-03 to 2013-14

Year	No. of farmers	Area (ha)	% of paddy area	Ave. grain yield (tons/ha)		
				Tripura	SRI	Difference
2002-03	44	8.8	.003	2.396	5.360	2.964
2003-04	88	17.6	.007	2.352	5.025	2.673
2004-05	440	176	0.07	2.383	4.690	2.307
2005-06	880	352	0.14	2.503	4.271	1.768
2006-07	73,390	14,308	6.1	2.550	4.321	1.771
2007-08	162,485	30,845	13.0	NA	NA	NA
2008-09	~250,000	39,491	17.3	NA	NA	NA
2009-10	NA	59,474	25.7	NA	NA	NA
2010-11	NA	72,815	29.3	NA	NA	NA
2011-12	NA	86,300	34.7	NA	NA	NA
2012-13	>500,000	87,978	37.2	NA	NA	NA
2013-14	>500,000	92,431	39.3	NA	NA	NA

Source: Department of Agriculture, Agartala, Tripura

In **Cambodia**, the introduction of SRI started in 2000 with 28 farmers, encouraged and supported by the NGO CEDAC. By 2012, this number had increased to over 200,000 farmers. Now it is difficult to keep track of the extent of SRI use further because many of the practices have spread beyond those farmers who are deliberately practicing SRI as a system.

- In 2007, CEDAC conducted an in-depth evaluation of SRI adoption and non-adoption in a sample of 21 villages in three districts where SRI had been available for at least five years. The survey team interviewed 348 adopters and 292 non-adopters in these villages. The study determined that 46% of the households in these villages were using SRI methods, with demonstrably good results.

- Regarding disadoption, the CEDAC survey determined that the *average number of disadopting households* -- those which had tried SRI methods and had given them up -- was only 1 per village out of 200 households (CEDAC 2008). CEDAC figures that in Cambodia where there is now extensive experience with SRI, the rate of disadoption in rice-growing areas has been negligible, less than 1% overall.

- The CEDAC evaluation identified which SRI methods have been less-adopted or which were disadopted because farmers found them difficult, such as frequent soil-aerating weeding. Only some Khmer farmers are using all of the SRI methods as recommended, which helps explain in part why the SRI yields achieved in Cambodia have been generally lower than obtained with SRI methods on farmers' fields elsewhere.

- The main reason for lower average SRI yields In Cambodia is that *over 80% of the farmers there have no irrigation facilities* and have to rely on rainfall. Regarding disadoption, the study confirmed the observations from other countries that once SRI practices have been learned and used by farmers, very few give up this approach.

In **India**, the National Consortium for SRI (NCS) commissioned a cross-state evaluation of reasons for disadoption of SRI that covered 715 farmers in six districts in Bihar, Odisha, Chhattisgarh and Jharkhand states over the period 2007-2012. These districts were some of the poorer ones in eastern India where the NGO PRADAN was introducing SRI.

- Disadoption was found to range from 2 to 11% across the six districts. When the causes for giving up SRI use were probed, almost all were involuntary, with irrigation constraints, labor limitations and personal health problems being the main reasons given. *Almost no voluntary disadoption was found*, perhaps because with the new methods, average paddy yields were doubled, from 2.83 to 5.5 tons/ha (Barah et al. 2014).

It has never been claimed or suggested that SRI practices will be suitable for every farmer. There are no agricultural innovations that will be good for every household. Some disadoption does not negate the benefits that SRI can bring to large numbers of farmers. So far there is no evidence beyond the initial study in Madagascar that the disadoption of SRI methods has been a significant problem. No innovation should be expected to be ideal for all farmers.

Iconic picture of Cambodian farmer Im Sarim holding a single SRI plant pulled up from the middle of her field in Peak Bang Oang village in Takeo province in 2006. Her harvest from this 500 m^2 field was 333 kg, amounting to a yield of 6.7 tons per hectare, almost triple her previous yield. One part of her field produced 1.1 kg of paddy from an area of 1 m^2, which is equivalent to an 11-ton yield.

When the author met Im Sarim six months after this picture was taken, on a visit to her village with Y.S. Koma, president of CEDAC, he thanked her for producing such a remarkable plant which had been seen by people in many countries around the world. Her face sagged with disappointment. When he asked why she appeared unhappy, she said with a tone more of regret than boastfulness: "If I had known how the picture was going to be used, I would have looked for my biggest rice plant to show Dr. Koma,"

8. Why change current rice-growing practices?

Why start with young seedlings? Certainly older seedlings, being larger, are easier to handle. However, once rice plants have started into their fourth phyllochron of growth (pages 154-162), generally about the 15th day after seeds have been sown in the nursery, they start losing some of their potential for tillering and for root growth. Young seedlings, less than 15 days old, when managed with the other SRI practices have more capacity for growth and greater fertility. SRI plants can have up to 100 tillers or more, compared with the 5-10 or at most 20 tillers that rice plants have when grown from seedlings which are transplanted when 3 to 4 weeks old, or even older.

Ten-day-old rice seedling on left, ready for SRI planting. On the right, the stump of an SRI rice plant grown from a single seed with 223 tillers and a very large root system, presented to the author by farmers in Panda'an, East Java, Indonesia in 2009. This rice plant, their largest that season, showed how much growth potential could be elicited by SRI management practices, potential that was not ordinarily seen in rice plants.

Why change nursery and transplanting practices? Usual transplanting practices involve removing older seedlings from a nursery that has been kept continuously flooded. This means that the seedlings have started out in a soil environment that lacks oxygen, and crowding inhibits the growth of their roots. When removing seedlings from a conventional nursery, little care is taken to protect their roots, and they often lie in the open air and sunlight for hours or even days before being transplanted into the main field, with roots that have become desiccated and traumatized.

These seedlings are pushed downward into flooded soil that has little or no oxygen. When plunged into the soil, their *root tips invert upward* so that the plant's profile is *shaped like a J*. It can take days for the root tips to reorient themselves downward so that they can resume their growth. These practices result in what is called *transplant shock,* a well-known effect that causes plants to languish for 5-10 days, or even longer. They often become yellowish for lack of nitrogen and lose growth momentum at a particularly critical time.

On the other hand, seedlings grown in a well-oxygenated nursery soil with no crowding have their performance enhanced (Mishra and Salokhe 2008). SRI seedlings are carefully removed from their garden-like nursery, with soil and seed sacs kept attached to their roots. They are transplanted quickly and gently into the main field with their roots not allowed to dry out in the sun.

These seedlings are transplanted *gently* into aerobic soil, with their roots laid in *horizontally* and *shallow* (1-2 cm), so that plant can resume its growth almost immediately. The plant's profile is shaped *more like the letter L or I than the letter J*. Avoiding or minimizing *transplant shock* gains 7 to14 days of vegetative growth for rice plants before they start flowering (anthesis). This adds significantly to their number of tillers and to their root growth.

Why use such wide spacing? Why reduce the number of plants so greatly? When rice plants are crowded together, with 3-6 plants in each hill, packed together in a clump and with little distance between hills, this reduces the room for their roots to grow, and as important, it diminishes the amount of sunlight that can reach the plants' lower leaves.

- Measurements made in 2002 by Anischan Gani at the Indonesian Rice Research Institute at Sukamandi showed that with typically close spacing of rice plants, not enough sunlight reaches the lower leaves in the canopy to support their processes of photosynthesis. This means that these leaves, instead of *contributing* to the plant's pool of energy, were *taking energy out* from the plant's energy pool in a kind of 'parasitic' way.

- Rice roots get most of their energy supply from the plant's lower leaves, needing carbohydrates from the canopy to support their metabolism (Tanaka 1958). When plants are crowded together and their processes of photosynthesis are impeded, this undermines the growth and functioning of their root systems, which in turn then compromises their ability to support the growth and functioning of the canopy, a circular dynamic.

Radiation intercepted (lumens/m²), at heading stage, of Ciherang variety at different spacings, Sukamandi, dry season, 2002

Spacing (cm)	20x20 cm	30x30 cm	40x40 cm	50x50 cm
Plant population/m^2	25.0	11.1	6.3	4.0
Radiation above canopy	235	235	243	254
Radiation within canopy	78	88	131	153
% radiation within canopy	33.2%	37.4%	53.9%	60.2%
Effective panicles/hill	18.6	21.9	35.5	44.5
% productive tillers	66.7%	72.5%	86.0%	99.6%

The radiation intercepted above and below the canopy is reported as an average for eight points measured in each plot, observed between 9:24 and10:40 am, 14 July 2002. Data provided by Anischan Gani, Sukamandi station, AARD, Indonesia.

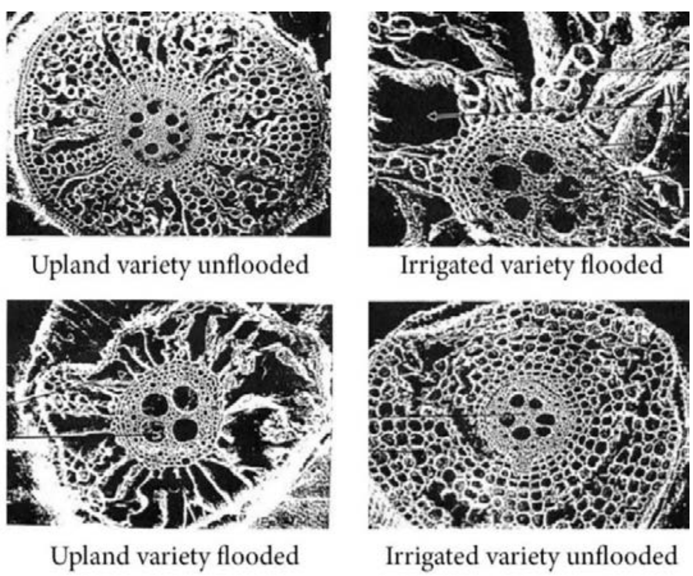
- When there are fewer plants per square meter, all of the rice plant leaves are active in photosynthesis, and their root systems are well supplied with photosynthates by the lower leaves, making the whole plant more productive. Each plant has more tillers; each of these has more grains; and the grains are themselves usually heavier. These changes in phenotype more than compensate for having fewer plants per unit area (Thakur et al. 2010).

Experimental plots for light trials at Sukamandi rice research station in Indonesia.

Why stop the flooding of rice paddy fields? Rice can survive under flooded conditions better than can most plants because of way in which the internal structure of their roots becomes *deformed* causing them to function differently. Roots' cortex is composed of cells grouped around a column of vascular tissues in the center of the root, the *stele*. The vascular tissues known as the *xylem* transport water and nutrients upward while similar tissues, the *phloem*, transport carbohydrates and other synthesized compounds downward.

When the soil lacks oxygen (becomes hypoxic), disintegration of many of the cortical cells causes *aerenchyma* (air pockets) to form in the roots (see pictures below). These permit oxygen to diffuse passively from the above-ground parts of the plant into the roots and eventually down to the root tips, which need oxygen to continue their growth. This change in roots' structure and functioning gives their root tips some but not much oxygen.

Under flooded conditions, 30 to 40% of the cortex will disintegrate, having some adverse effects on the transport of water and nutrients within the root (Kirk and Bouldin 1991). Although rice plants adapt to hypoxic (oxygen-less) conditions by creating aerenchyma within their roots, they do not necessarily perform *at their best* under such conditions. Under continuous flooding, about 75% of the rice plant's root system will degenerate by the time that the plant starts its flowering (anthesis) and begins its grain-formation and grain-filling (Kar et al. 1974).



Cross-sections of rice plant roots grown under different soil-water conditions. On left side is an upland rice variety (IRAT 13) grown under unflooded conditions (above) and under flooded conditions (below). On the right is an irrigated rice variety (IRAT 173) grown under flooded conditions (above) and unflooded conditions (below). In both varieties the cortex cells surrounding the stele (the vascular tissues in the center of the root) disintegrate under flooded conditions. However, the resulting air pockets (aerenchyma) in the irrigated variety are somewhat larger and more functional (Puard et al. 1986).

Nobody knows for sure when or why the practice of continuously flooding paddy fields began. Rice evidently evolved as an upland plant in well-drained soils. But rice was grown also already several millennia ago in low-lying fields with inundated, saturated soil probably because no other cereal crop could be grown there. Over time, rice was planted in fields that were intentionally flooded as flooding gave labor-saving weed control as other plants, including most weeds, are less able to grow under hypoxic soil conditions.

Growing rice in flooded fields requires less labor for weeding than does rice grown in upland (unirrigated) fields, where weed growth can be prolific. If weeds can be controlled by other means than flooding, however, this changes many calculations. SRI experience shows that much higher yields can come from rice plants grown in aerated soil, with small but reliable applications of water. Rice roots grow larger and deeper there and function better, instead of degenerating as they do in continuously flooded, i.e., hypoxic, soil.

Why use a mechanical hand weeder to control weeds? The answer to this question follows from the previous one. The use of rotating hoes or conoweeders to control weeds gives farmers a 'bonus' from *active soil aeration*. This enhances both plants' health and their crop yield. While weeds can be controlled or removed by hand weeding or by use of herbicides, this forgoes the benefits of soil aeration through weeding practices that promote root growth and enhance the abundance, diversity and activity of beneficial soil biota. There are many different designs now for mechanical weeders, as seen on pages 86-87 and below. Here are the results from an evaluation done in Nepal in the 2005 main season.

Effect of Active Soil Aeration

412 farmers in Morang district, Nepal, using SRI in monsoon season, 2005

SRI yield = 6.3 t/ha vs. control = 3.1 t/ha

- Data show how WEEDINGS can raise yield

No. of weedings	No. of farmers	Average yield	Range of yields
1	32	5.16	(3.6-7.6)
2	366	5.87	(3.5-11.0)
3	14	7.87	(5.85-10.4)

Bicycle-wheel weeder developed by Gopal Bhise in India (The Hindu, April 29, 2010); and a home-made weeder built by a farmer in Timor Leste from pictures of weeders.

On left, a four-row weeder designed and built by Gopal Swaminathan, a farmer in Kadiramangalam village, Tamil Nadu state of India. On right, a mass-produced weeder designed and produced KGVK Agro Ltd. This company, based in Ranchi, India, was set up by the large metal-products corporation Usha Martin Ltd. as a corporate social responsibility (CSR) initiative to support SRI by making and selling good-quality SRI equipment (http://www.kgvkagro.in/contact-us.htm).

Why use compost in preference to chemical fertilizer? The answer to this question derives from the foregoing discussion. SRI was developed by Fr. Laulanié using chemical fertilizer as the main source of supplementary soil nutrients. However, in the late 1980s when small farmers in Madagascar could no longer afford fertilizer, because the government removed its subsidy for fertilizer, he experimented with using compost, which gave even better results.

We have seen the advantages of compost confirmed in factorial trials. If less than all of the SRI practices are used together, *using a subset of them* can give higher yield with chemical fertilizer than with compost. But when all of the SRI practices are being used with compost, yields surpass those from fertilizer (Randriamiharisoa and Uphoff 2002; Uphoff and Randriamiharisoa 2002).

Compost is more than just an alternative source of nutrients, assessed in terms of the amounts of nitrogen, phosphorus and potassium that it contains. This will be less than is provided by chemical fertilizer. However, even if compost contains less macronutrients (N, P and K), it contains *a host of micronutrients* (iron, zinc, copper, molybdenum, etc.). These are important for helping plants to synthesize the enzymes that are essential for plants' metabolism.

Compost serves as a more balanced and more complete source of nutrients for soil organisms as well as for the plant itself. Moreover, compost contributes to better structure and functioning of soil systems by better supporting the soil organisms and the complex food web that operate underground in healthy and productive soil (Uphoff et al. 2006).

Soil with good structure has more *pore space*, which means that *both air and water* can be well-distributed throughout the soil's volume. This porosity enhances the soil's capacity to absorb and hold water so that rainfall does not just run off, carrying topsoil particles with it and eroding the amount and value of the soil. Soil biological activity supports the *recycling of nutrients* in the soil and the movement of nutrients from the 'unavailable' portion of the soil to become 'available' in the soil solution (Bonkowski 2004; Doebbelaere et al. 2003; Turner and Haygarth 2001; Thies and Grossman 2006).

Why is agrochemical protection against pests and diseases less necessary with SRI? For a variety of reasons, rice plants grown with SRI methods are more resistant to pests and diseases. The use of agro-chemical means of protection becomes less necessary or less cost-effective. With SRI management, farmers commonly find that there is not enough damage and loss from pests and diseases to justify expending the money and labor required for agrochemical crop protection.

One possible explanation for SRI resistance to pests is that when plants are grown in unflooded soil, they will *take up more silicon*. This would account for the fact that rice plant tillers and leaves are tougher and stronger, resisting being blown over (lodged) by strong winds and rain (pages 138-140). Chewing insects would also be deterred by encountering tougher leaves and stems. Also, drier microclimatic conditions in the canopy are less favorable for a number of insects and other organisms to reside and multiply.

A theory called *trophobiosis* proposed by a French agricultural scientist (Chaboussou 2004) is consistent with what we observe with SRI, which reduces or stops the use of chemical fertilizers as well as agrochemicals. According to Chaboussou's theory, plants' vulnerability to attacks by insects, bacteria, fungi, and even viruses is *a consequence of imbalances or deficiencies in their nutrition*. This adversely affects the plants' metabolism which would otherwise (a) convert amino acids into more complex protein molecules, and (b) metabolize simple sugars produced by photosynthesis into more complex polysaccharides. These larger molecules (amino acids and polysaccharides) are less easy for predatory insects, bacteria, fungi, even viruses to utilize.

- When *inorganic nitrogen* is abundantly provided to plants through synthetic fertilizers, they take up more N and synthesize more amino acids, the building blocks for proteins. However, with their imbalanced nutrition, the plants do not quickly and efficiently convert these amino acids into proteins. This leaves a surplus of amino acids in the plants' sap and their cells' cytoplasm. These simple molecules are attractive to insects, pathogenic bacteria and fungi, and even viruses.

- Similarly, the application of *inorganic pesticides*, particularly chlorinated ones, interferes with plants' metabolism so that the simple sugars which they create through photosynthesis do not get consolidated quickly and continuously into polysaccharides. The plants are thus producing an abundance of simple sugars in their sap and cytoplasm which offer pests and pathogens an opportunity to feed easily and to expand their populations.

'Surpluses' of amino acids and simple sugars in their sap and cytoplasm makes plant vulnerable to predation and disease. This explanation is supported by extensive research published in the peer-reviewed literature going back many decades. Note that Chaboussou was not an advocate of 'organic' practices *per se* because he proposed that any soil nutrient deficiencies which can impede or unbalance plants' metabolism should be remedied, by inorganic means if organic supplies are not available. But pragmatically his theory points toward the reduction or even elimination of most use of agrochemicals.

More research should be done on this theory of *trophobiosis*, which has been largely overlooked or ignored by research institutions, and on mechanisms for pest and disease resistance in SRI rice plants. These relationships and their explanations warrant systematic and objective evaluation. Meanwhile, the phenomenon of SRI plants having resistance to pests and diseases, although not always observed, is confirmed by many farmers from their experience and also by scientific trials and evaluations (e.g., Dung et al. 2007; Gopal et al. 2010; Karthikeyan et al. 2010).

Is transplanting necessary? Can rice crops be established by direct seeding? Although SRI was developed with and for farmers in Madagascar who were transplanting their rice crops, *SRI does not require transplanting*. The operative principle for SRI is that if a rice crop is established by transplanting, then seedling roots, which are essential to the plant's future growth, should be *treated very carefully and protected from any trauma and damage*. Since Fr. Laulanié was recommending many changes in farmers' practices for rice production, he probably concluded that making big changes in farmers' methods of crop establishment, like giving up transplanting, would make gaining acceptance of SRI even more difficult.

Some farmers who are not wedded to transplanting -- or who have labor shortages that make transplanting difficult to practice -- have adapted SRI concepts to direct-seeding methods of crop establishment, coupled with the other SRI practices. Their aim is to reduce labor requirements. They want to achieve this goal even if it means that their paddy yields may be somewhat reduced because their biggest concern is favorable economics, not just agronomics.

- One method of crop establishment developed by a Sri Lankan farmer is based on broadcasting germinated seed on a muddy, leveled field and then *thinning the resulting plants in a geometric square pattern* as with SRI. This has been evaluated by Tamil Nadu Agricultural University scientists in India (Ramasamy et al. 2006), showing favorable results, including a 40% reduction in labor requirements per hectare: no nursery, no transplanting.

  The farmer, Subasinghe Ariyaratna, uses 5 times more seed than if he were establishing his SRI crop by transplanting. Rather than establishing and transplanting an SRI nursery which would take just 5 kg of seed per hectare, he broadcasts germinated seed at a rate of 25 kg per hectare.

  When the young plants sprouting in the field are 10-12 days old, Ariyaratna weeds his field *as if* he had transplanted it with SRI seedlings at a spacing of 25x25 cm. His 'weeding' radically thins out the stand of rice, eliminating about 80% of the young plants and leaving the remaining 20% in a square grid pattern. There is usually one plant left at the intersections of the weeder transects; but there can be 2 or even 3 plants, and occasionally no plant within this intersected space. When there is no plant growing, adjacent plants themselves grow larger and fill in most of the open space.

This methodology aims to establish a sparse plant population, evenly and widely spaced. Because there is no need to construct and manage a nursery and no transplanting, SRI's labor requirements are greatly reduced. Ariyaratne says that this adaptation can give a yield of at least 7.5 tons/ha. He knows this is less yield than is attainable with a more carefully-managed SRI field; but he has competing demands for his labor time. This method of crop establishment and management gives him a profitable result with reduced expenditures on labor.

Motorized weeder developed by S. Ariyaratna, Sri Lanka

This discussion underscores the importance of flexibility and innovativeness so as to capture the benefits of SRI principles under specific local conditions. Ariyaratne had 2 hectares of rice land to cultivate, and with his two children still young, he was labor-constrained. Making tradeoffs to economize on labor requirements was a rational strategy for him.

Farmers in various countries are trying out SRI concepts with various innovations like raised beds, seedbed solarization, zero-tillage, and intercropping with potatoes, gaining momentum in Vietnam. Some examples of direct-seeding innovations were shown on page 27.

One of the most promising current versions of SRI is the direct-seeded SRI crop establishment developed in Vietnam by the Dutch development organization

SNV with funding support from the Australian aid agency (https://www.youtube.com/watch?v=51uNFQL1zMw). The various versions of direct-seeded SRI are not in conflict or in competition with 'classical' SRI. Rather, they are regarded as welcome descendants of the original SRI in as much as they can help farmers deal with labor and other constraints, and enable them to meet their economic and other goals.

Drum seeder for direct-seeding of SRI being transported to the field using a motorbike in Andhra Pradesh state of India (page 27).

Nepali farmers in the village of Devnagar who cooperated with Rajeev Rajbhandari in his introduction and evaluation of SRI in Chitwan district, trying out the solarization method (page 35) for growing healthier seedlings in an SRI rice nursery.

9. What are SRI's main economic, social and other benefits?

Environmental Benefits are discussed under FAQ 5, pages 59-66.

SRI training for Rwandan farmers under an IFAD project in that country

SRI has been sometimes dismissed or ignored on the grounds that the results being reported were 'too good to be true.' This is an uninformed and non-empirical basis for rejection, relying on *a priori* reasoning rather than on evidence. Use of SRI methods will not always produce all of the desired or reported benefits. However, the methodology offers a remarkable number of desirable outcomes that can be achieved at little or sometimes no incremental cost.

- **Increases in yield**: Grain yield per hectare is usually treated as a summary indicator of productivity. However, this measure of yield represents only *the productivity of land*, not the productivity of the other factors of production: labor (earnings per day), water (crop per drop), or returns on capital (profitability). As a rule, farmers are interested in many considerations besides or beyond agronomic yield. But yield attracts the most attention, especially when land is relatively the scarcest, most constraining factor of production.

  Increases in grain yield achieved on-farm with SRI methods usually range from about 20% to 200%, and sometimes even more, as seen in data reported below from Madagascar, India and Cambodia. The gains in output that are achieved with *reductions in one or more inputs* (labor, water, capital) are more significant for farmers than if the gains were attained through a *greater expenditure of these resources*. Also, with SRI methods, there is usually some increase in the production of *straw* (biomass). This yield increase is important for small farmers who derive benefits from being able to have and use more straw for animal fodder, thatching, and other purposes.

- **Increases in factor productivity**: *Output per unit of input* is the most important economic measure, more important than the simple agronomic measures of grain or straw yield, because *achieving more output with greater expenditure on inputs is of uncertain benefit*, whereas getting more from less is invariably advantageous, an agronomic version of Pareto optimality.

  SRI is the only innovation that we know of where the productivities of all factors of production -- land, labor, water, capital – can be raised concurrently. This has made SRI suspect in the minds of people who believe that getting 'more from less' is impossible. They invoke the economists' insistence that 'there is no free lunch,' that there must be some tradeoffs somewhere. However, this doctrine applies only to *closed systems*, in which there must be diminishing returns. It need not apply in *open systems*.

  With SRI practices, energy and nutrient inputs come from biological activity. This is 'free' provided that certain conditions for organisms' growth, health and functioning are met. This is what makes possible the broad-based SRI gains in factor productivity. *Total factor productivity* is hard to measure and to report on in a summary manner because of the difficulty of combining land, labor, water and capital even in monetary terms. But evaluations of each factor show gains in its productivity, i.e., more output per unit of input.

  For many years, it was asserted that if rice plants had *more tillers* (panicles), they would necessarily have *fewer grains per panicle* (Ying et al. 1998). To be sure, if there were diminishing returns to having greater plant growth, the profuse tillering that results from SRI management would be less desirable than if no such limitation existed. However, it turns out that the assumption that there is an inverse relationship between the number of panicles per plant and number of grains per panicle is irrelevant for SRI rice plants, whose root systems do not degenerate due to hypoxia. These plants, as open systems, capitalize better on the resources around them than can plants with degraded roots.

  With SRI management, rice plants can have *both more fertile tillers and more grains per panicle*, making rice production a *positive-sum* proposition rather than zero-sum or negative-sum. Having roots that do not senesce enables rice plants to function as open systems, rather than as closed systems (or worse, declining systems). This difference in rice plant physiology as well as morphology underlies SRI success (Thakur et al. 2010).

- **Reductions in water requirements**: Because irrigated SRI rice is grown without continuous flooding, less water is needed (25-50% less) for growing a crop that produces greater output. Water productivity can thus be doubled or tripled, or even more (Ceesay et al. 2006). Under some soil conditions, it may not be possible to make such great gains in water saving; but under other conditions, as much as two-thirds of water has been saved.

Mustapha Ceesay in SRI plot being harvested at Sapu Research Station of the National Agricultural Research Institute in The Gambia, for which served previously as director. Normal rice cultivation here uses excessive water; SRI applies it sparingly.

- **No need to rely on purchased inputs**: Farmers can use SRI methods successfully and cost-effectively: (a) without relying on chemical fertilizer, (b) without needing to purchase new seeds, and (c) not needing agrochemicals to control pests, weeds and diseases. While fertilizer can be used with positive results, farmers who have enough labor and access to biomass to make and apply compost can get quite high yields while improving their soil's fertility.

  One advantage of SRI practice that farmers reported in the GTZ evaluation of SRI in Cambodia (Anthofer 2004) was that they did not have to buy new seeds or agrochemical inputs at the start of their cropping season, when their cash resources were low, having expended most of their earnings from the previous season. Not having to purchase inputs to start the season also meant that farmers do not need to take out loans if they lacked the money to buy inputs. Getting into a cycle of indebtedness is the bane of many rural households, which then work endlessly to benefit moneylenders more than themselves.

  Some research has shown that *combinations of organic and inorganic nutrients* (integrated nutrient management) can give higher yield than using organic soil supplementation alone. What is most profitable for a given farmer will depend on the respective costs of buying fertilizer and of making compost. Rather than prescribe any particular practice or combination of inputs, farmers using SRI methods should determine which will best enable them to meet their purposes considering the costs and constraints of the different inputs and also issues such as risk factors (pages 136-137).

- **Higher returns to labor, even labor-saving**: Even when SRI methods require more labor input per hectare than conventional practice, the higher yields with SRI almost always give farmers *higher output per hour or per day of labor*, and this is what raises family income. As noted above, SRI farmers often find that once they have mastered SRI methods, they can grow their larger crop without additional labor, *or even with less labor*. If farmers can reduce labor as well as inputs of seeds, water and cost, this makes SRI very attractive.

  - **Reduced labor requirements for women**: Discussed pages 144-147.

- **Increased farmer net income and profitability**: If farmers are able to achieve a higher output with reduced cost of inputs, this raises their incomes by even more than their increase in production. A report from Cuba on SRI rice production from 26 hectares on a cooperative farm there (Socorro et al. 2008) showed a yield increase of only 15%, going from 4 tons/ha to 4.6 tons/ha, but the net income that the cooperative received from its rice production was 70% higher (747 vs. 439 pesos/ha).

  The reasons for this impact on income were: (a) seed costs were cut in half, (b) fertilizer use was reduced by 89% -- from 350 kg/ha to 37 kg/ha, (c) 40% less water was used, a significant saving because irrigation water had to be accessed by diesel pumps, and (d) the labor needed for transplanting was reduced from 16 persons to 5 persons. These economic considerations were considered by the farmers as more important to them than yield increase.

- **Reductions in economic risk**: The agronomic practices recommended for SRI -- use of very young seedlings, just one plant per hill, reduced plant population, no flooding of the field, and more reliance on organic fertilization -- *all appear to be risky*. However, two evaluations that calculated actual risks based on data from large-scale random samples have indicated otherwise.

  - An evaluation was done in Cambodia for the German development agency GTZ covering 400 SRI farmers and 100 non-SRI farmers in the same villages randomly selected in five provinces (Anthofer 2004). An economic risk assessment showed that farmers' risk of not achieving a target net income from their rice production was significantly lower with SRI practice.

    With SRI, the probability of not reaching a target net income of $US100/ha was calculated to be 17% vs. 42% when using standard methods. Rice farmers were found to be *2.5 times more likely to lose money* when they grew their rice with standard methods. The study concluded: "SRI is an economically very attractive methodology for rice cultivation with a lower economic risk compared to other cultivation practices" (Anthofer 2004).

- An evaluation of SRI in Sri Lanka was done for the International Water Management Institute (IWMI), based on 120 farmers randomly selected in two districts, half of them using SRI methods and the other half not using SRI (Namara et al. 2003, 2008). Households' economic risks were calculated when using SRI vs. conventional practice according to three alternative wage levels; labor inputs were valued (a) at zero wage, assuming use of only family labor, (b) at the prevailing agricultural wage, and (c) at the prevailing non-agricultural wage, an opportunity-cost assessment.

  In the first calculation, the probability that a household would end the season with a net economic loss was *9 times greater* using conventional practices than when using SRI methods. At the prevailing agricultural wage, this probability was *8.4 times greater*; and if labor inputs are valued at their non-agricultural opportunity cost, the probability of not having a loss from rice cultivation was *6.4 times greater*. So, although SRI cultivation methods might appear to be risky, empirical analyses have shown that they reduce rather than increase farmers' risks, partly for reasons below.

- **Climate-smart agriculture means less vulnerability to adverse weather conditions, resistance to the effects of climate change:** More evaluations need to be done on this to assess its extent and limits, but SRI rice plants are generally observed to be:

  - ***More resistant to drought and water stress***:

This picture tells the story: Two paddy fields in Sri Lanka with the same soil and climate, planted with same variety, shown 3 weeks after their irrigation water supply had been cut off because of lack of water in the reservoir. Field on left was planted and managed conventionally, with flooding until the water stopped. SRI field on right had been given limited water, so its rice developed deeper root systems, able to withstand water stress and give practically a normal crop with much less water.

- ***Less susceptible to pests and diseases*** -- discussed on pages 128-130.

- ***More resistant to storm damage and lodging***, to being knocked down by strong rain and high winds. This effect has been measured and quantified by Chapagain and Yamaji (2009). The effect is most clearly understood and appreciated visually, as seen on this page and the next one.

Test plots at Tamil Nadu Agricultural University in India after a storm passed over; the plot in foreground was conventionally cultivated, while the plot behind is SRI.

Paddy fields in the Mwea irrigation scheme in Kenya after a freak storm in November 2011; the rice on left grown with conventional cultivation practices was badly lodged; a nearby field cultivated with SRI methods, seen on right, sustained no damage.

In the Mekong Delta in Vietnam, a regular field in the foreground on left and an SRI field on the right after a storm had hit both of them (Dill et al. 2013).

A farmer in Dông Trù village, Vietnam, holding up SRI rice plant on left and conventional plant on right, in front of their respective fields, after a storm had passed over in 2005. See pages 2-7 of http://sri.cals.cornell.edu/countries/vietnam/vnntutr106.pdf

- ***Better able to recover from flooding***, provided that they have gotten their root systems established before the flooding occurs;

- ***Better able to tolerate extreme temperatures***, provided the plants' root systems have gotten well established in the soil.

While these latter benefits are important, *resistance to drought and water stress and to storm damage and lodging* will probably become some of the most significant impacts for SRI in a world that must *learn to cope with climate change*, where aberrant rainfall patterns and severe storms with strong winds and rain are likely to become more frequent and more severe. With greater variability in weather patterns and more frequent occurrence of 'extreme events,' particularly resource-limited households, often cultivating in the most vulnerable regions, will need to have crops that can withstand, as reliably as possible, the adverse effects of climatic stress (Uphoff 2011).

- **Shortened crop cycle, giving higher yields more quickly**: SRI farmers commonly report that their SRI rice crops *reach maturity 5-10 days sooner* than do crops of the same variety when grown with standard practices. When crops can be harvested sooner, farmers can reduce the amount of water needed to grow their crops, and they also reduce their crops' exposure to storms or other climatic hazards and to pest and disease damage which are often more at the end of the season. These effects should be evaluated more broadly.

- In 2007, 413 farmers in Morang district of Nepal who used SRI methods with 7 different varieties had their crops mature on average *15 days sooner* than these varieties would normally reach maturity (Uphoff 2011). Even while SRI management shortened the crop cycle by 11%, the farmers' average SRI yields were more than double those which they achieved with their usual practices, i.e., 6.3 tons per hectare compared with 3.1 tons.

Crop duration in days for rice varieties grown with SRI vs. conventional methods in Morang district, Nepal, 2007 main season (ranges denoted in parentheses)

Variety	(N)	Standard duration[1]	SRI Duration	Difference (in days)
Mansuli	48	155	136 (126-146)	19 (9-20)
Swarna	40	155	139 (126-150)	16 (5-29)
Radha 12	12	155	138 (125-144)	17 (11-30)
Bansdhar/Kanchhi	248	145	127 (117-144)	18 (11-28)
Barse 2014/2017	14	135	126 (116-125)	9 (10-19)
Hardinath 1	39	120	107 (98-112)	13 (8-22)
Sughanda	12	120	106 (98-112)	14 (8-12)
Average (total)	*413*	*140*	*125 (115-133)*	*15 (9-23)*

[1] Period of time (days) reported by rice breeders for this variety to reach maturity.
Source: Records of Morang District Agricultural Development Office, Biratnagar.

- **Higher milling outturn when SRI paddy (unmilled rice) is polished**: It was noted already that farmers and millers find that unmilled SRI paddy rice gives greater milled output, i.e., more polished rice per bushel or per bag of unmilled rice. This is attributable to (a) *less chaff* -- because SRI panicles have fewer unfilled grains, and (b) *fewer broken grains* -- because SRI grains resist breakage during milling. This means that when SRI methods are used, there is generally *a 'bonus' of about 15% more edible rice* on top of the increased amount of paddy rice harvested. So, food production is amplified with SRI.

  - Already in 2002, some grain millers in Sri Lanka were coming to SRI farmers before they had harvested their SRI crop and were offering to pay them 10% more per bushel of SRI paddy. Why? Because they knew that they could get even more than 10% more polished rice when they had milled the SRI paddy. This would give them more final product to sell as food.

  - An evaluation done at Sichuan Agricultural University in China in 2004 confirmed this. The same variety of SRI paddy rice, when milled, averaged 16% more total milled rice outturn, and 17.5% more head rice (unbroken grains) (Ma 2004; Xu et al. 2005).

Parameter	Rice grown with Conv. methods[1]	Rice grown with SRI methods[1]	Difference
Milled rice outturn (%)	41.54 – 51.46	53.58 – 54.41	+16.1%
Head milled rice (%)	38.87 – 39.99	41.81 – 50.84	+17.5%

[1]Three spacings were used for each set of trials; the data reported are ranges (Ma 2004).

- An informal survey of farmers in Tripura state of India by the author when visiting 12 villages there in October 2007 found that farmers were getting, on average, *18% more milled rice per bushel of unmilled SRI paddy,* compared to the milling outturn from their paddy rice produced with usual means, because of less chaff and less breakage of grains with SRI paddy.

Differences in root growth being shown by the author and a farmer in Kulubari village, one of the Tripura villages where farmers reported substantial increases in milling outturn from their SRI paddy. This indicated to them how SRI plants produce better quality rice, enhancing food availability by more than the amount of paddy rice they harvest. See: http://sri.cals.cornell.edu/countries/india/inntutrep1007.pdf

- **Improvements in grain quality, and possibly in nutritional value**: There are numerous reports that consumers consider the quality of rice grown with SRI methods to be higher, but we have few systematic evaluations on this.

  - The Sichuan Agricultural University evaluation noted above also measured *chalkiness* in SRI rice compared with the same variety grown by standard methods. Chalkiness is considered an undesirable quality of rice, in part because it contributes to more breakage during milling, but also because it affects eating qualities. According to Ma (2004), SRI rice had 30% fewer chalky kernels and 65% less chalkiness overall. Since there was less breakage of SRI paddy rice when it is milled, it is likely that its grains have a higher protein content since resistance to breakage during milling is known to be linked to higher protein levels in the grain (Leesawatwong et al. 2004).

Parameter	Rice grown with Conv. methods[1]	SRI methods[1]	Difference
Chalky kernels (%)	39.89 – 41.07	23.62 – 32.47	- 30%
General chalkiness (%)	6.74 – 7.17	1.02 – 4.04	- 65%

[1]Three spacings were used for each set of trials; data reported are ranges (Ma 2004).

- There is also reason to think that there could be higher concentrations of *micronutrients* in SRI grains because these are usually denser, i.e., heavier without being larger. This could contribute to less breakage during milling. Because SRI roots are larger and can reach more deeply into the soil, they would have more capacity to acquire micronutrients from the lower soil horizons. This would make the plants themselves healthier and better able to resist damage from pests and diseases because more uptake of micronutrients will give SRI plants more of the building blocks needed for synthesizing enzymes that are essential for their plant metabolism.

More systematic work should be done on this and other benefits, however. Some recent research has shown that growing rice under unflooded soil conditions enhances levels of copper, zinc, magnesium and manganese in the grain (Xu et al. 2008). Other research in India evaluating SRI rice plants in comparison with plants of the same variety conventionally grown has found significantly greater uptake of micronutrients (Fe, Zn, Mn, Cu) (Prasanna et al. 2014). This has been supported by further research (Dass et al. 2015).

- **Other health benefits**: Apart from nutritional benefits still to be assessed, it is clear that stopping the continuous flooding of paddy fields should reduce the incidence of *mosquito-borne diseases* like malaria and dengue fever and Japanese encephalitis. SRI water management has been shown to break the cycle of mosquitoes' reproduction in Kenyan irrigation schemes (Omwenga 2014).

  - According to recent research, there is *10-15 times less uptake of arsenic* by rice plants that are grown under unflooded soil conditions (Xu et al. 2008). This is currently being investigated by a five-country study coordinated by SRI-Rice, in Indonesia, Nepal, Malaysia, Philippines and Sri Lanka. There is good reason to expect that SRI management will lower arsenic levels in rice (Senanayake and Mukherji 2014).

  - *Health benefits specific for women* are discussed in Vent et al. (2015) and in the following section 9.1.

- **Integrated and diversified farming systems:** Where the productivity gains attainable with SRI permit farmers to reduce the amount of land that they devote to rice production and to diversify their farming systems, they can produce more fish, more fruits, more vegetables, legumes and small livestock on land freed up for non-staple food production. This improves not only households' *income*, but also their *nutrition* from having *more diversified diets*.

View of a intensified farm in Takeo province of Cambodia whose diversified farming system is based on SRI productivity gains. Gains in production and income as well as the low investment costs for raising household income by multiples not increments. See Lim (2007), with examples of farmer-designed integrated farming systems.

Research conducted at the Indian Council for Agricultural Research's Directorate for Water Management in Bhubaneswar has found that 'integrated SRI' which links *aquaculture* and *horticulture* with the productivity gains for rice achieved with SRI management can greatly increase the productivity of land, labor, and especially water (Thakur et al. 2015).

- This farming system under upland rainfed conditions undertook water harvesting to provide supplementary water for the rainfed rice crop and for growing also fish (Asian carp) and other crops (bananas and papaya). The economic profitability of this was quite remarkable, returning Rs. 18 per m^3 of water compared with Rs. 0.3 per m^3 under conventional rainfed rice-only management, which barely breaks even.

9.1 What are the gender implications of SRI?

Women SRI farmers at a meeting in Takeo province of Cambodia

How the introduction of SRI will affect women's situation will depend particularly on what is the prevailing gender division of labor in rice production in the local situation. Most reports have found that women's labor burden in rice production are reduced when SRI is introduced, and the work itself becomes less onerous and unhealthy. But the kind and extent of impact from changing over to SRI crop management are likely to vary and are seldom the same across all social classes.

- Rice transplanting becomes quicker once the new methods are learned because plant populations are reduced by 70-90%.

- When mechanical weeding is introduced, men often take over the task of weeding the rice fields, culturally classified as 'women's work' when done by hand. In many cultures; mechanical tasks are considered to be 'men's work.' When women continue weeding but using a mechanical weeding implement, this is usually found to make their work easier and quicker.

  - The first systematic evaluation of gender impact was done in Tamil Nadu in 2004, noted in section 6.1. This study looked at the labor and other inputs for 100 households in the Tamiraparani river basin cultivating 1-acre plots of SRI and conventional rice side-by-side. Overall, it was found that labor inputs were reduced by 11% with SRI, but there was a stark difference in labor investments according to gender. Men took over the weeding operations because when these became 'mechanical,' they were considered men's work. So men's labor inputs were increased by 60%, while the number of hours of rice work that women did per hectare declined by 25%, a significant shift (Thiyagarajan 2004).

- In Andhra Pradesh, where there is no cultural restriction on women working with mechanical equipment, women have started using weeding implements instead of doing weeding by hand. But this reduces their work burden. A study found that using weeders greatly speeded up their work. Women's time spent in weeding was reduced by 72%, while rice yields were doubled. The new technology also improved women's postures for their weeding work and alleviated muscle fatigue (Mrunalini and Ganesh 2008).

Duddeda Sugunavva, a dalit farmer in Katkur village of Andhra Pradesh state in India, using a weeder that she redesigned for women's more comfortable use.
http://harvestpublicmedia.org/blog/tackling-poverty-and-hunger-one-farmer-time
See also: Africare/Oxfam America/Worldwide Fund for Nature (2010).

- Usually women report a *reduction* in their time for doing SRI transplanting once they acquire skill and confidence in handling very young seedlings. The number of seedlings used per hectare is only 10-30% of the previous number, and the smaller seedlings are much lighter and easier to handle.

- Rice women farmers in many countries now have greater labor burdens as a result of what is being called 'the feminization of agriculture.' This occurs as men migrate to cities in search for employment, leaving women behind in the villages with more agricultural work to do.

  - When this issue was studied in Cambodia, the consensus among women interviewed was that the adoption of SRI methods had lightened their burdens of labor in rice production, and further that the higher yields with SRI reduced the pressure and stress on them of having to ensure adequate food for their households (Resurrection et al. 2008).

There are also some *health benefits* reported from the Philippines and India. This subject deserves much more study, but the reported results from SRI use so far have been favorable to enhancing the status, health and comfort of women.

- Women's Health, an NGO in the Philippines trying to minimize women's health problems in Isabela Province, reported to the author that because with SRI, transplanting and weeding are no longer done in standing, stagnant water, the incidence of women's urinary tract and vaginal infections was reduced. This is a benefit not normally spoken about, but the NGO had made an effort to evaluate this effect (Uphoff 2003).

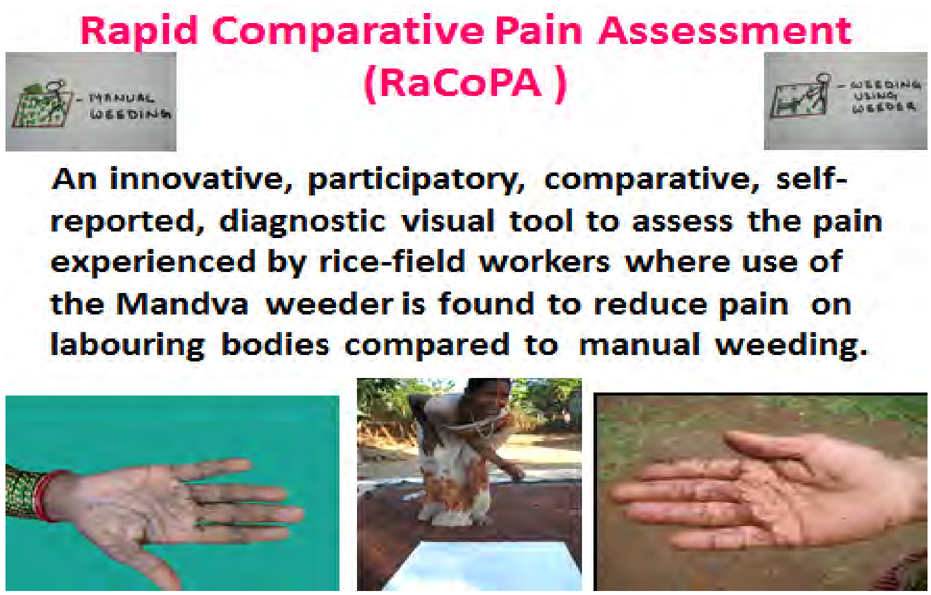
- In Odisha state of India, a study for a dissertation from Wageningen University has examined the effects of SRI practice on women's physical well-being. Detailed surveys and measurements at village level have shown agreement among women that SRI methods are less strenuous because of less discomforting postures and less total amount of work (Vent et al. 2015).

- Also, curtailing the use of pesticides and chemical fertilizers is reported to reduce skin and other ailments, not only for women, but especially for them. Women also reported an indirect benefit of more time to cook and take care of housework.

An innovative effort has been made to quantify the physical impacts of SRI adoption on women through what is called a Rapid Comparative Pain Assessment (RaCoPA). This evaluation uses participatory/rapid rural appraisal methods and a body map (shown on the next page) for villagers to identify the loci and severity of pain for both men and women when doing rice cultivation. There was wide agreement among women that adoption of SRI methods reduced their discomfort and pain (Sabarmatee 2013).

- One conclusion of the study is that an increase in the participation of men in rice-production operations means a reduction of drudgery of women, both in terms of their hours of work and of pain in their bodies. In focus groups, increases in well-being with SRI are reported by both men and women, but especially by the latter. They are now able to pay more attention to other cash crops and to do other income-generating work. They are also able to pay more attention to children and household activities, they reported.

- At the same time, some women in the focus groups reported less enjoyment from rice production as the field work is now being done more quickly, with less singing and socializing than has been traditional. This can be considered as a 'cost' for SRI introduction, although it was not enough to be a deterrent to women's using and favoring SRI practices.



Slide from presentation by Sabarmatee (2013)

Body map drawn by Odisha villagers in RaCoPA focus groups to objectify through discussion and consensus the kinds, physical locations and extent of pain and discomfort when performing different rice cultivation practices.

10. Can SRI's concepts/practices be applied to other crops?

Farmer in Bihar state of India holding two wheat plants of same age and variety, the one on the left was grown with adapted SRI methods, called the System of Wheat Intensification (SWI).

Rather than being a technology with prescribed, fixed practices, SRI is *a set of agronomic principles and methods* that together *promote greater root growth and more abundant and diverse soil biota* for rice plants Similar beneficial effects for other plants' growth and performance can be anticipated if SRI methods are suitably adapted for the production of other crops.

We have seen such extrapolations and extensions of SRI methodology particularly in India, but also in Ethiopia, Mali and Nepal. For some farmers in Bihar state of India, the acronym SRI now stands for '*System of Root Intensification*.' We are hopeful that applications of these principles can be extended elsewhere in Africa and in many other parts of the world.

Wheat: This major cereal crop, like rice, belongs to the botanical family of grasses (*gramineae* or *poaceae*), so it might be expected to be responsive to SRI practices. When the People's Science Institute (PSI), an NGO based in northern India, first tried SRI methods with two varieties of wheat in on-station trials in 2006, 28% and 40% increases in yield were recorded, plus an 18% increase in straw, which is important as cattle fodder for farmers in the region. In 2007, the yield increases for 25 farmers making comparisons were 95% with irrigated wheat and 63% without irrigation (Prasad 2008). By 2011-12, the number of farmers practicing the *System of Wheat Intensification* (SWI) was over 12,000, with yield increases of 80-100%

PRADAN and other NGOs have been expanding SWI also in the state of Bihar. (Bhalla 2010). From 415 farmers in 2008-09, the number expanded to 48,521 farmers within two years. By 2012, the area under SWI management was 183,000 hectares, with probably 400,000 farmers using the methods, with average yields of 5.1 tons/ha according to the Department of Agriculture.

In Ethiopia, on small wheat plots in Tigray province, farmers have gotten SWI yields of 9-10 tons/ha. In 2009, farmers applying SWI practices to durum wheat in Gembichu province had yields ranging from 1.25 tons/ha (the national average) to 8.5 tons.

Comparison of wheat panicles of the same variety in Gembichu woreda, Ethiopia: on left are plants grown with usual methods of cultivation (average 39 grains per panicle); and on right, SWI panicle (average 56 grains).

Farmers in Mali and Nepal have also experimented successfully with SRI methods for their wheat. So we have reason to believe that potentials for higher yield with modified management of wheat are similar to those with rice (http://sri.cals.cornell.edu/aboutsri/othercrops/wheat/index.html).

The application of SRI concepts and methods to wheat and other crops is reported in a monograph written by persons who have given leadership to this process for many crops (Abraham et al. 2014; SRI-Rice 2014). Trials at the Indian Agricultural Research Institute have given confirming evidence of SWI benefits, with advantages found to be greater in a drought year (Dhar et al. 2015).

Finger Millet: Several Indian NGOs have been working with this cereal crop which is very important for millions of poor households: in addition to PSI in the north, the Green Foundation in Karnataka state, PRAGATI in Odisha state, PRADAN in Jharkhand and other eastern Indian states. Farmers have achieved yield increases of 100-300% by adapting SRI concepts and methods to this crop: young seedlings, wide spacing, soil aeration, increased organic matter, etc. Five farmers working with the People's Science Institute in 2007 got a 33% increase in finger millet yield, and then the next year 43 farmers had a 60% increase. As so often, first-year results can be improved upon as farmers gain insight, confidence, experience, and skill.

Comparison of finger millet (ragi) plants grown with different management practices in Jharkand state of India. On the left is an improved-variety millet plant (A404) grown with farmer-adapted SRI practices; in the center is a plant of the same improved variety but grown with farmers' usual broadcasting practices; on right is a local (unimproved) variety that was similarly grown with farmers' usual methods.

In Tigray province of Ethiopia in 2003 an elderly woman farmer on her own using practices very close to SRI for her finger millet crop got a yield of 7.5 tons/ha, many times the usual yield in her region (Araya et al. 2013). Since then, adaptations of SRI ideas to finger millet in Tigray have been spreading, with yields usually of 3.5 to 4 tons/ha, instead of 1 ton/ha with broadcasting, so that this methodology is becoming standard practice in the Axum region. We are hopeful that finger millet yields can be widely enhanced with SRI methods as this is so critical a crop for so many poor people in India and Africa.

Sugar Cane: A number of SRI farmers in Andhra Pradesh and Karnataka states of India began adapting their SRI methods to sugar cane production by 2004, getting yields as high as 100 tons per hectare where before they got 30 to 60 tons. This encouraged WWF, the Worldwide Fund for Nature, together with ICRISAT, the International Crop Research Centre for the Semi-Arid Tropics, to prepare and release a manual for the application of SRI concepts to sugar cane, the *Sustainable Sugarcane Initiative* (SSI), in 2009. The methods offered 20-100% improvements in yield with 30% less water and 25% less application of fertilizer and agrochemicals.

A small company in India known as *AgSRI*, based in Hyderabad, has been established to promote SSI as well as SRI on a larger scale, focusing first on Maharashtra state: http://www.agsri.com/ssi.html. Farmer experiences with SSI are reported in Gujja et al. (2012). AgSri has begun advising on the introduction of SSI in Belize, Cuba, Kenya, and Tanzania, as well as in other states of India.

Beans and Pulses: In 2006, the People's Science Institute in northern India reported that five farmers got an average yield increase of 43% when they adapted SRI methods for *rajma*, the local name for kidney beans. With 113 farmers using these methods in 2007, learning from the first year's experience, the average yield improvement was 67%. This helped launch a number of similar adaptations as farmers working with PSI have extended their experimentation and evaluation to other crops such as *soyabeans, maize, peas, lentils,* and *sesame* in Uttarakhand and Himachal Pradesh states.

In Karnataka state, the *Agriculture-Man-Environment Foundation* (AMEF) has worked with farmers in applying SRI methods to *red gram* (pigeon pea): http://sri.cals.cornell.edu/aboutsri/othercrops/otherSCI/InKarnSCIRedGram_AME2011.pdf). A book on SRI applications to *green gram* (mung bean) has been published in Germany: http://www.amazon.com/System-Crop-Intensification-Greengram-Innovative/dp/3847372769 In Tamil Nadu state, the Department of Agriculture's *System of Pulse Intensification* (SPI) initiative for raising pulse production earned the state a national award in 2014 (Ramakrishnan and Kolappan 2014).

Tef: Typical yields of this cereal grown and eaten in Ethiopia are ~1 ton/ha, the crop being usually broadcast with little subsequent crop management. When tef is grown with adapted SRI practices, however -- with young seedlings transplanted 20x20 cm, use of organic fertilization, applying small but regular water, etc. -- its yields can be 3 to 5 tons/ha, or even higher with what iss referred to as this System of Tef Intensification (STI).

After several years of successful demonstrations, the Ethiopian government's Agricultural Transformation Agency (ATA) is now working to popularize a simple version of STI: http://sri.cals.cornell.edu/aboutsri/othercrops/teff/index.html. This is based on *direct-seeding* rather than the transplanting of young seedlings, but it uses wide and regular spacing of plants with enhanced soil organic matter and favorable new varieties. Its yield enhancement is only 70%, compared to the 100-200% or more increase with well-managed STI. But much less labor and crop management are required with what I call 'STI lite.' The ATA reports that the number of users of this simplified STI was more than 1.7 million in 2013-14, with 5 million farmers expected to use this STI in 2014-15.

Tef plants grown with SRI methods on display at a field day in Tigray province, Ethiopia

Mustard: This crop, also known as rape or rapeseed or canola, turns out to be very responsive to SRI management. Rather than usual yields of 1 ton/ha, SMI yields are around 3 tons/ha, and sometimes higher. See webpage and manual on SMI at: http://sri.cals.cornell.edu/aboutsri/othercrops/otherSCI/index.html#mustard; http://sri.cals.cornell.edu/aboutsri/othercrops/otherSCI/In_SMImustard_Pradan.pdf.

These kinds of adaptations are grouped loosely under the heading of SCI, the **System of Crop Intensification** (SRI Secretariat 2011). In Bihar state of India, this is called the *System of Root Intensification* as SCI ideas have been extended to tomatoes, eggplant, chilies, etc. Some farmers in Tamil Nadu state have developed a 'system of turmeric intensification,' another STI, applying SRI ideas to this spice crop grown from rhizomes and doubling their net income per hectare.

In Ethiopia, the application of SRI concepts and practices to a variety of rainfed crops including sorghum, maize, barley, lettuce and cabbage is referred to as *"planting with space,"* a term that seems easier to explain to farmers than a term like SRI or SCI. See discussion of this in Araya et al. (2013).

Even greater imagination has been shown by some tribal farmers in Jharkhand state of India who have extended their SRI experience and thinking beyond plant management, to increasing their collections of *lac*, an entomological product. And some farmers in Cambodia have linked their SRI experience to raising *chickens*. Better management of fewer birds they find yields households more meat and more eggs from a smaller flock. Farmers see their getting 'more from less' as a manifestation of SRI principles. These and the full range of SCI innovations are discussed in SRI-Rice (2014).

All of these management strategies aim to capitalize on biological processes and potentials that are forgone with the kind of 'industrial' thinking that currently shapes recommendations for improving agriculture. Farmers in various countries are finding productive, quick and inexpensive ways to improve their agriculture by reflecting on their SRI rice experience and extrapolating ideas from it to enhance their production and income from various other crops.

Young farmers holding a mustard plant grown from single seed with SCI methods in an ATMA demonstration plot in Manpur village, Gaya district of Bihar state in India.

11. What is the role of phyllochrons in SRI performance?

The profuse tillering of SRI plants can be better understood by considering the effects of *phyllochrons*, a little-known periodicity in rice plants' growth that regulates and determines their ultimate number of tillers and roots. When Fr. Laulanié learned practically by accident in the 1983-84 season that transplanting very young seedlings can lead to more robust and productive rice plants, this was hard to explain; it was just an empirical observation ((Laulanié 1993).

However, four years later, Laulanié learned about phyllochrons from reading a book on rice science that presented this concept (Moreau 1986). It derived from research that was done during the 1920s and 1930s by a crop scientist in Japan, T. Katayama. Unfortunately, his research findings were not published until after World War II (Katayama 1951), and they have never been translated into English, so they are not widely known outside Japan.

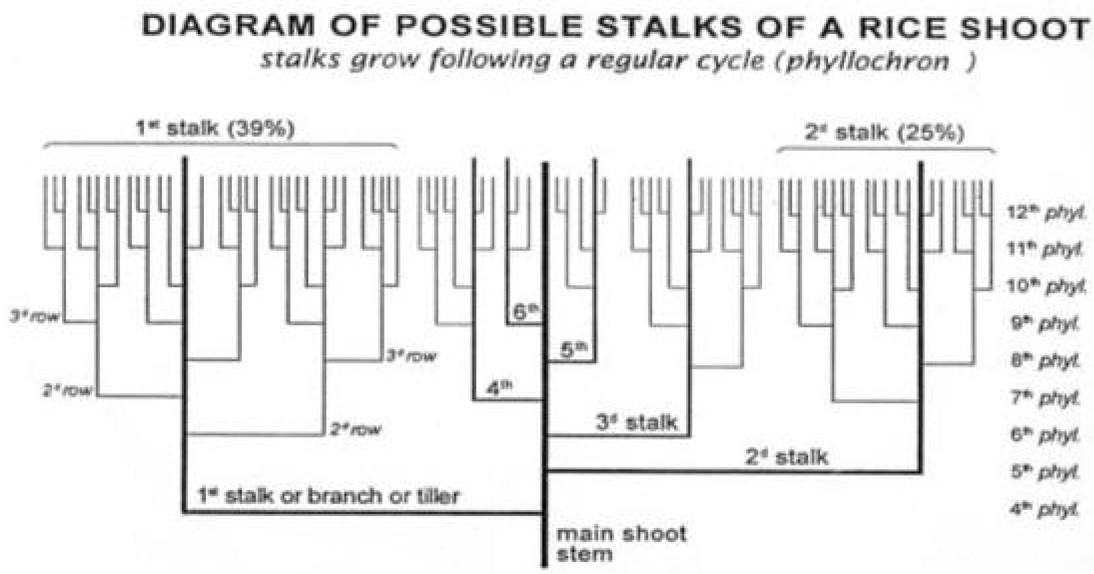
- The most detailed discussion in English of phyllochrons is Nemoto et al. (1995), summarized in Stoop et al. (2002). There is no mention of 'phyllochrons' in the Oxford dictionary of plant sciences, which has over 6,000 entries (Allaby 1998). There is a short section on phyllochrons In the English translation of the Japanese encyclopedia of rice sciences (Matsuo et al. 1993).

- From his studies of rice, wheat and barley, Katayama discovered a regularity in the way tillers (and roots) emerge from the meristematic tissue at the plant base of these cereal crops. He documented a remarkable *patterning* in the way that grass-family species (*gramineae/poaceae*) grow, described below.

Understanding phyllochrons helps explain why transplanting rice seedlings *before they are about 15 days old* can give a different and greater growth response to all the other practices of crop management than seen with seedlings that are transplanted at an older age, i.e., after the start of the 4th phyllochron. The timing and length of phyllochrons is determined by multiple factors as discussed below.

The term itself combines two Greek words *phyllo* + *chron* which respectively mean leaf + time. Phyllochron refers to *an interval of time* during which a plant leaf together with an associated root and tiller emerges from the plant's meristematic tissue which produces new cells that create plant organs. This generative tissue derived from the rice plant's seed is located at the base of the plant, at or near the soil surface, between the plant's root system and its above-ground canopy.

- Beyond the 4th phyllochron, multiple units of leaf and associated root and tiller will emerge at the same time, i.e., within a *period of time* that is designated as a phyllochron. This will become clearer from examining the following diagram.



A synchronously-emergent unit of a leaf together with a tiller and a root, referred to collectively as a *phytomer*, grows both upward and downward from the plant's meristem at the base of the visible plant. At the same time that a plant's leaves and tillers grow upward into the air, its roots grow downward into the soil. Roots emanate from the same cell-division processes as do the leaves and the tillers.

The length of a phyllochron for rice can vary considerably, from:

- *Perhaps 4 days* if the conditions for growth are ideal, i.e., if the plant is encountering no stresses that will slow or impede its growth, to:

- *8 to 10 days* if growing conditions for the plant are unfavorable because the plant is subject to many stresses (temperature, water, compacted soil, etc.).

When growing conditions are good, with favorable temperatures, enough water and sunlight, adequate availability of nutrients in the soil, lots of space all around the roots and canopy, and friable soil for root growth, a phyllochron can be 5 or 6 days in length, and the plant can complete 10, 11 or 12 phyllochron periods of growth before it (a) comes to the end of its initial phase of *vegetative growth* and (b) switches into its *reproductive phase* from panicle initiation to flowering and heading, and then (c) proceeds with grain forming and filling, ripening, and maturation, when the grains have become ready for harvesting.

- During a rice plant's *1st phyllochron* -- its first cycle of tiller and root emergence from the meristem -- its first phytomer (a functional unit of leaf/tiller/root) is produced from the seed. While the plant's first root grows downward, the first tiller with its flag leaf proceeds to grow upward. This *main tiller* is represented as the central vertical line in the diagram.

- During the *2nd and 3rd phyllochrons*, the plant does not produce any additional phytomers from the meristematic tissue at its base. This is a *time of apparent dormancy*. If growing conditions are reasonably good and the phyllochron length is 5 days, this period extends from about the 5th day to about the 15th day after germination.

- During the *4th phyllochron*, a second tiller with an associated leaf and root emerges from the base of the original main tiller. This is the *first primary tiller*, shown in the diagram as the lowest horizontal line on the left.

- During the *5th phyllochron*, another phytomer containing the *second primary tiller* emerges, bringing the total number of tillers to three. This is the lowest horizontal line on the right in the diagram.

- During the *6th phyllochron*, an acceleration of growth begins, as now *two more phytomers* are produced from the meristematic tissue in the base of the plant -- a *third primary tiller* from the base of the main tiller, and a *first secondary tiller* from the base of the first primary tiller.

- During the *7th phyllochron*, three more phytomers now emerge -- a *fourth primary tiller* along with *two more secondary tillers* from the bases of the 1st and 2nd primary tillers, respectively. This concurrent emergence of primary and secondary tillers can be seen from the diagram on the preceding page. While it takes three phyllochrons for the first primary tiller to emerge from the main tiller, thereafter tillers begin emerging from each tiller just (and always) *two phyllochrons after the parent tiller has emerged*.

- During the *8th phyllochron*, five more phytomers emerge -- one more primary tiller (the 5th), *three more secondary tillers* from the 2nd, 3rd and 4th primary tillers, and now *a first tertiary tiller* from the base of the1st secondary tiller which has branched off from the base of the 1st primary tiller. While this is complicated to describe in words, it can be easily grasped visually from the above diagram that Laulanié prepared from studying the work of Katayama.

The structure and logic of the diagram become clearer by studying the numbers shown in the table on the next page. Unfortunately, *very few rice plants presently complete a full 12 cycles of growth before they switch into reproductive mode and start to flower*, beginning to form spikelets, potential grains which if fertilized and properly nourished become grains. With ideal conditions and very short phyllochrons, more than 12 can be completed before panicle initiation when the plant switches into its reproductive phases.

Pattern of Rice Tillers' Emergence over a 12-Phyllochron Sequence

Sequence of Phyllochrons

Tillers	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Total
Main tiller	1	0	0	0	0	0	0	0	0	0	0	0	1
1st row of tillers	0	0	0	1	1	1	1	1	1	0	0	0	7
2nd row of tillers	0	0	0	0	0	1	2	3	4	5	6	5	26
3rd row of tillers	0	0	0	0	0	0	0	1	3	6	10	15	36
4th row of tillers	0	0	0	0	0	0	0	0	0	1	4	10	15
5th row of tillers	0	0	0	0	0	0	0	0	0	0	0	1	1
No, of tillers produced in each period	1	0	0	1	1	2	3	5	8	12	20	31	84
No, tillers in 3 phyllochrons	1 ($1 = 4^0$)			4 ($4 = 4^1$)			16 ($16 = 4^2$)			63 ($63 = 4^3 -1$)			
Cumulative no. of tillers	1	1	1	2	3	5	8	13	21	33	53	84	

Source: Laulanié (1993).

Sub-optimal growing conditions will slow the rate at which a rice plant grows and will extend the length of its phyllochrons, to 7, 8, 9, maybe 10 days each. This means that only 6, 7, 8 or 9 periods of growth will be completed before the plant ceases its dynamic of vegetative growth and begins its reproductive processes of panicle formation, flowering, etc. *The more phyllochrons of growth that a rice plant can complete before it starts its reproductive activities, the more tillers and potential panicles and associated roots it will have*.

Whether a rice plant can maintain *a rapid rate of growth with short phyllochrons* and thereby complete 10, 11 or even 12 phyllochron cycles before it starts its reproduction and formation of grains -- being able to produce, respectively, 33 tillers, 53 tillers, or even 84 tillers -- will depend on the conditions under which the plant is growing, i.e., on how favorable are the conditions analyzed below.

Plants that are crowded together receive less sunlight and must compete for soil nutrients. This constrains the kind of semi-exponential emergence of tillers which is shown the diagram and table above, matched by corresponding root growth. Also, when the soil is kept continuously flooded, the plant's roots will degenerate for lack of oxygen (Kar et al. 1974), so they cannot support rapid and profuse tiller growth or the subsequent production of grain.

- Readers may have noticed that the pattern of tillering indicated in the table corresponds to what is known in mathematics and biology as a *Fibonacci series*. In such a series, *the number that emerges in each period is the sum of the previous two periods*: 1+1=2, 1+2=3, 2+3=5, 3+5=8 …[1] The number of tillers

[1] This kind of a series or sequence was made well-known internationally by the plot of the 2003 best-selling book, *The Da Vinci Code,* written by Dan Brown,

produced in each period is approximately 2/3 more than emerged in the preceding period.[2] Such mathematical regularity in nature is noteworthy.

A rice plant that can complete 12 phyllochrons of growth before the end of its vegetative phase and moves into its reproductive phase, starting with panicle initiation, can have as many as 84 tillers as shown in the diagram and table above. Such a plant would have *a similarly profuse root system* because its roots emanate from the same meristem cells that go through cell division and differentiation to create tillers and leaves forming the plant's canopy above-ground.

If rice plants are transplanted during the 4th phyllochron or during even later phyllochrons, it is seen that their subsequent production of phytomers is both decelerated and diminished. Accordingly, such rice plants when they begin their reproductive phase have fewer tillers and fewer leaves, and also fewer roots.

What is described here is a mechanistic presentation of a biological process. Specific plants do not necessarily grow as mathematically as the model above indicates. For one thing, the length of their phyllochrons is not always so uniform. Also in practice, rice tillers increase according to *a modified Fibonacci series*, not a perfect one; 12 periods should hypothetically produce 89 tillers, rather than 84. This discrepancy is apparently due to physical congestion in the base of the rice plant which keeps the emergence of tillers (and roots) from the meristematic tissue from reaching its hypothetical maximum.

Transplanting rice seedlings during their 2nd or 3rd phyllochron of growth -- roughly between the 5th and 15th days -- represents a *window of opportunity* for the best management of rice plants. Their roots will be less traumatized if they are transplanted during this relatively dormant period, and these plants when they resume their growth after transplanting will produce more phytomers (units of tiller, leave and root) in an accelerated way.

We know that when transplanting occurs later than about the 15th day (the exact date is affected by the length of the phyllochrons, which is a variable length), rice plants do not experience as much growth or as rapid growth. The factors that shorten -- or lengthen – phyllochrons, discussed in Nemoto et al. (1995), are presented analytically in the table below.

[2] Laulanié (1992) reckoned that this pattern of increases in tiller number gives the following set of fractions, which have an average ratio of approximately 1.66 (1⅔): 3/2 =1.5; 5/3 =1.66; 8/5 =1.6; 12/8 =1.625; 21/12 =1.615; 33/20 =1.65, 53/31 =1.7. "These figures indicate a fairly constant rate at which new tillers are produced. Each phyllochron produces approximately two-thirds as many tillers as already exist. These ratios start somewhat lower (1.5) and become higher (1.7 and 1.75), but represent quite a narrow range." As explained below, the pure mathematics of a Fibonacci series are modified by the physical constraints of space within the base of a rice plant.

This discussion so far has been from the perspective of farmers and not that of plants, discussing plant growth in terms of *days*. Thinking in biological rather than in calendrical terms, one should talk in terms of *leaf stage*, i.e., the number of leaves that have emerged as the young plant grows from its seed. 'Young plants' according to SRI theory and practice are *seedlings in their 2-to-3 leaf stage*, having at least two leaves but not yet three leaves.

The table below presents my understanding of plant growth and management in an analytical way. The concept underlying this presentation is that the rice plants' growth proceeds according to some kind of *'biological clock.'* This runs faster or more slowly depending on *the totality of favorable and/or unfavorable growth conditions*. It is regulated operationally by the speed with which the plant's cells are growing, elongating and dividing, in turn growing, elongating and dividing.

Factors that affect the length of phyllochrons in rice growth

Growth factors	Positive influences	Negative influences
Factors that make the 'biological clock' run →	Faster	Slower
Factors that make plant phyllochrons' length →	Shorter	Longer

Climate and temperature factors

Temperature	**Warmer temperatures**	**Colder temperatures**
	Metabolism, cell growth and cell division are all faster with more warmth	Metabolism, cell growth and cell division are all slower with less warmth
Day-night variation	**Temperate climate**	**Tropical climate**
	Large day/night differentials in temperature reduce plants' night-time respiration which permits the storage of more carbohydrates	Little day/night temperature differential favors continuous night-time respiration by plants & less carbohydrate accumulation
Day length	**Longer days**	**Shorter days**
	More solar radiation stimulates more photo-synthesis in leaves	Less solar radiation gives less energy (photons) for leaves' photosynthesis

Plant management factors

Spacing	**Wide spacing**	**Narrow spacing**
	Single plants/hill and fewer plants/m^2 reduces competition among roots, enhances canopy growth	Many plants/hill and more plants/m^2 increases competition among roots, less room for canopy growth
Solar energy, which is affected by spacing	**Exposure to sunlight**	**Shading**
	More opportunity for photosynthesis, also more aeration in the canopy	Less opportunity for photo-synthesis, with reduced aeration in canopy

Water management factors

Soil moisture	**Moist conditions**	**Dryness / drought**
	Intermittent irrigation meets the plant's needs for water, while non-flooding contributes to soil aeration	Inadequate water supply creates serious stress on the growth of plants' roots and canopy evapotranspiration
Soil aeration	**Oxygen availability**	**Hypoxia (lack of oxygen)**
	Supports plant root growth and aerobic microbial communities in soil	Slows root growth and causes root degeneration; only anaerobic microbial communities live in the soil

Soil and nutrient management

Soil structure	**Permeability / friability**	**Compaction**
	Root growth is facilitated; profuse growth of soil organisms is supported by optimum O_2 and water	Root growth is constrained; growth and diversity of soil organisms is affected by soil deficient in O_2 and water
Nutrient supply	**Adequate / complete**	**Limited / unbalanced**
	Plants' demand for nutrients can be met as needed to maintain optimum metabolism	The growth of plants' roots and shoots is constrained
Soil organic matter	**Abundant**	**Scarce**
	Soil conditions support the diversity and abundance of microbial communities in the soil that in turn improve plants' nutrition and protection	Limited growth and productivity of soil microbial communities is affected by too much inorganic nutrient supply and/or too little organic-source supply

More research remains to be done on phyllochrons and on their implications for rice crop growth. There has been considerable research on phyllochrons in wheat (see, e.g., a special issue of *Crop Science*, 35:1, 1995), and on phyllochrons in forage grasses, especially in Australia. However, there has been little consideration of rice phyllochrons except by rice scientists in Japan and China, where they are well-known. In the English-reading world, phyllochrons do not figure much in plant science considerations, presumably because the original research on phyllochrons has not been translated into English.

Considerable research has been done along similar lines in terms of *degree-days*, but these are not linked to an understanding of plant physiology and morphology as closely as analysis done in terms of phyllochrons. For SRI, an understanding of phyllochrons helps to explain why the use of young seedlings has such a strong positive effect, validated empirically (Uphoff and Randriamiharisoa 2002). The rapid tillering and root growth which is possible when the full set of SRI practices are used together is not seen when older seedlings are used or when rice plants are grown under continuously flooded conditions with degenerating plant roots, which lengthens their phyllochrons. We hope that this area will become the focus of extensive research, such as that reported by Veeramani et al. (2012).

The rice plant grown in Indonesia with 223 tillers (page 122) would have been in its 15th phyllochron (cycle) of growth before ceasing its vegetative growth. Not all of these tillers would necessarily have become effective (fertile) tillers, forming panicles with grains. But the capacity of rice plants to be extraordinarily productive should not be ignored or dismissed just because most of the time, under suboptimal growing conditions, they produce fewer roots, tillers, panicles and grains than they are capable of producing under more ideal conditions, when phyllochrons are shorter and growth accelerates.

On the next page is a picture of a plant with 98 panicles taken by an SRI colleague in Nepal. It would have been in its 13th phyllochron of growth (tiller and root emergence) when it entered into its reproductive phase. In 2004 while in Sri Lanka, the author held in his hand a panicle of rice that had 930 grains, grown by a successful organic farmer (page 48), twice what most people would probably consider to be the maximum number of grains attainable in a single panicle. This panicle was Premarathne's largest that season and thus an outlier. But the average panicle size in his SRI field that year was around 400 grains.

There is thus still much to be learned about the rice plant and its productive potentials. Providing the favorable growing conditions enumerated in the above table can shorten phyllochron length and increase the number of phyllochrons of growth that they complete during their phase of vegetative growth. Improving our understanding of these dynamics that can accelerate rice plant growth should advance both rice science and practice.

This rice plant with 98 fertile tillers, grown in the Nepal terai, was able to go through more than 12 phyllochrons of growth before its panicle initiation started.

*Slide provided by Alapati Satyanarayana, at the time director of extension for the Andhra Pradesh state agricultural university in Hyderabad, India, which shows 'the phyllochron effect' with finger millet (*Eleusine coracana*). In agronomic trials at the university, two varieties of finger millet were transplanted as 10, 15 or 21-day-old seedlings. Their root growth was then compared at 60 days after transplanting.*

12. How has SRI been disseminated among and within countries?

SRI is a *civil society innovation*, not having originated through the usual channels of agricultural scientific research. This may account for some of the resistance that SRI has encountered from within the scientific community. SRI was assembled through several decades of work with farmers by Fr. Henri Laulanié, who sought simple, low-cost, accessible ways for them to increase the productivity of their land, labor, water, seeds and capital when growing irrigated rice. The insights that Laulanié gained from working with rice plants and with farmers has been extended to unirrigated rice production (pages 90-92) and to growing other crops (pages 148-153). SRI is not a typical technology to be extended in the same way that most agricultural innovations have been disseminated in recent decades.

There was initially little interest in SRI from any government agriculturalists in Madagascar or from representatives of the International Rice Research Institute (IRRI) in that country. So, responsibility for the evaluation of SRI methods and for their dissemination fell to an NGO that Fr. Laulanié and his Malagasy colleagues had established in 1990, Association Tefy Saina (http://www.tefysaina.org/). It was set up with linkages to a variety of other NGOs, church groups, and individuals.

Starting in 1994, Tefy Saina and the Cornell International Institute for Food, Agriculture and Development (CIIFAD) (http://cals.cornell.edu) started working together on the evaluation and demonstration of SRI methods. CIIFAD did not begin encouraging others to take an interest in SRI until 1997, after three years of very positive results in the area around Ranomafana National Park.

- In 1998, these partners began working with some faculty and students in the University of Antananarivo's Faculty of Agriculture (ESSA). Half a dozen students did their baccalaureate thesis research on SRI with CIIFAD support. In 1999, a small grant was received from the Rockefeller Foundation through CIIFAD for SRI evaluation in Madagascar to be done through a consortium including Tefy Saina, university researchers, and Bruno Andrianaivo, a rice specialist from the government's agricultural research organization, *FOFIFA*.

This kind of multi-sectoral collaboration of NGO, university, government and other actors became typical for how SRI has been spreading ever since.

CIIFAD in collaboration with Tefy Saina established an SRI website in 2001 to disseminate information on SRI around the world. This is now maintained by *SRI-Rice*(http://sri.cals.cornell.edu/aboutsri/aboutus/index.html) operating under the auspices of the Office of International Programs of Cornell University's College of Agriculture and Life Sciences (CALS). SRI-Rice was established with a gift from the Better U Foundation in Los Angeles, CA which provided support from 2010 to 2013.

- Two NGOs that support low-input sustainable agriculture, *LEISA* based in the Netherlands (now named AgriCultures: http://www.agriculturesnetwork.org/) and *ECHO* based in Florida (http://echonet.org/) gave early assistance to the process of dissemination by publishing articles on SRI: Rabenandrasana (1999), and Berkelaar (2001).

    - In 2013, LEISA put together a special issue on SRI with a lead edition in English (http://www.agriculturesnetwork.org/magazines/global/sri) and regional editions published in English for South Asia from Bangalore and for East Africa from Nairobi; for West Africa in French from Dakar; for Latin America in Spanish from Lima; and for China in Chinese from Kunming.

Representatives of Tefy Saina and CIIFAD and, increasingly, partners in the various countries have spoken on SRI at international and national forums and seminars such as:

- **Southeast Asian regional conference** on Sustainable Agriculture and Natural Resource management in Chiangmai, Thailand, organized by the German agricultural university in Hohenheim in 2002.

- **International Rice Congresses** held in Beijing in 2002, New Delhi in 2006, Hanoi in 2010, and Bangkok in 2014, organized by the International Rice Research Institute (IRRI).

- **Latin American regional rice meetings** convened in Cuba in 2002 and 2008, and a regional organic agriculture conference held there in 2003.

- **The 2004 International Year of Rice inaugural conference** at FAO, Rome, and the **World Rice Research Congress** at Tsukuba, Japan, organized by IRRI and the Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF).

- **International Farming Systems Association conferences** in Orlando, FL in 2004 and in Rome in 2005.

- **21st meeting of the International Rice Commission,** convened by FAO in Chiclayo, Peru in 2006.

- **13th meeting of the U.N. Commission on Sustainable Development** in New York City in 2008, and in 2009 an inter-sessional UNCSD meeting convened in Windhoek, Namibia, and a follow-up preparatory meeting in NYC.

- **8th and 10th meetings of the Paddy and Water Environment Engineering Society** (PAWEES) held in Bogor, Indonesia in 2009, and in Taipei, Taiwan in 2011.

- **ECHO agricultural annual conferences** in Ft. Myers, FL in 2010 and 2013; and **ECHO regional agricultural conferences** held in Chiangmai, Thailand in 2009, and in Ouagadougou, Burkina Faso in 2011.

- **Biovision international conferences** held at the Alexandria Library in Alexandria, Egypt, in 2010, 2012 and 2014, at the invitation of Dr. Ismail Serageldin, former vice-president of the World Bank and former chair of the Consultative Group on International Agricultural Research (CGIAR).

- **Soil and Water Conservation Society annual meetings** in St. Louis, MO in 2010, and in Washington, DC in 2011.

- **International Symposium on Abolishing Hunger**, sponsored by Agence Française de Développement at the College de France, in Paris in 2011.

- **A Global Food Security Forum**, held in Rabat, Morocco in 2012.

- **2nd Global Conference on Agricultural Research for Development** (GCARD2) convened in Punta del Este, Uruguay in 2012.

- **Club of Rome** international summit on food security organized by its Indian National Association that met in New Delhi in 2014.

- **3rd International Conference on Climate-Smart Agriculture**, convened at Agropolis in Montpellier, France in 2015.

Country by country, persons have come forward with an interest in raising the productivity and incomes for rice farmers and in making these improvements consistent with protection and enhancement of the environment.

The backgrounds of these persons who have given national leadership for SRI have been diverse. Here are examples: an agricultural technician working with an international NGO in northern **Afghanistan**; a retired agricultural economics professor in **Bangladesh**; a agronomy-PhD leader of a national NGO in **Cambodia**; a number of senior rice scientists in **China**; a progressive rice farmer in **Costa Rica**; a retired animal nutritionist in **Cuba**; a country representative of the Inter-American Center for Agricultural Cooperation (IICA) in the **Dominican Republic**; an agricultural administrator and NGO founder in **Ecuador**; an agricultural research station director in **Gambia**; the director of extension for a state agricultural university in **India**, as well as a business school professor, a retired agricultural-economics research director, and many, many NGO and university personnel; senior researchers at rice development centers in **Iraq** and in **Iran**; team leaders for a Japanese private-sector consulting firm working in **Indonesia** and in **Laos**; a young Protestant minister in **Liberia**; university professors in **Kenya,**

Indonesia, Malaysia and **Korea**; a Bangladeshi agronomist advising an NGO in northern **Myanmar** and then working for FAO in **Afghanistan**; an agricultural-extension specialist at district level in **Nepal**; a farmer/businessman/inventor/philanthropist in **Pakistan**; a Canadian agronomy PhD student doing her thesis research in **Panama**; a private agricultural consultant in **Peru**; an electrical engineer heading an environmental NGO in the **Philippines**; an Indian advisor to the Ministry of Agriculture in the **Solomon Islands** and **Fiji**; a senior civil servant, a deputy minister of agriculture, and a farmer-environmental activist in **Sri Lanka**; Indian agricultural professionals on the staff of the Asian Institute of Technology in **Thailand**; a program leader for integrated pest management in the Ministry of Agriculture and Rural Development in **Vietnam**; an NGO agricultural activist in **Zambia**, who has also helped to introduce SRI into **Cameroon**; and so it goes.

Leadership for SRI has been heterogeneous by disciplines, roles, statuses and age, but with shared interest in finding low-cost, widely accessible, eco-friendly ways to raise agricultural production, especially for food-insecure households.

- A great number of SRI colleagues have travelled to other countries to help transfer SRI knowledge: from **Sri Lanka** to India; from **India** and **Bangladesh** to Afghanistan; from **China** to North Korea; from **Madagascar** to Rwanda; from **Indonesia** to Malaysia and the Solomon Islands; from **Cambodia** to Vietnam and Myanmar; from **India** to Morocco, Kenya, Malawi, and Tanzania; and so forth.

- Colleagues in a number of countries have hosted visitors from other countries to share their SRI knowledge: **Cambodia** (Vietnam); **India** (Bangladesh); **Madagascar** (Indonesia and Sierra Leone); **China** and **Malaysia** (DPRK); and **Sri Lanka** (India and Pakistan). The author, who as a former director of CIIFAD has had more opportunities for international travel than do most persons, has made presentations on SRI to scientific, governmental and farmer audiences in >40 countries.

Leadership for the evaluation and dissemination of SRI in a country, state or district can come from any sector: from government agencies, NGOs, universities, research institutes, private firms, or farmer organizations, or just from individuals.

In each country, there usually emerges a *friendly network of like-minded persons* from these several sectors. The persons and institutions who become involved (we jokingly say they become 'infected' -- with a benign, indeed beneficial infection) contribute respectively to the advancement of SRI understanding and practice according to their different comparative advantages.

Participants' picture from a 2010 workshop on SRI organized for a delegation of rice scientists from the Democratic People's Republic of Korea (DPRK). This was hosted by the China National Rice Research Institute in Hangzhou and supported by The Asia Foundation. Zhu Defeng, a senior CNRRI rice scientist who has served as volunteer coordinator for SRI activities in China, is seated in the front row to the right of the author.

- A good example is **Kenya**, where SRI work started from three professionals, one based at the Jomo Kenyatta University of Agriculture and Technology (JKUAT), another in the World Bank office in Nairobi, and a freelance agricultural advisor (and recent Cornell graduate). The first has continued to provide national leadership for SRI dissemination. They brought together persons from various other organizations to launch an SRI campaign in Kenya: the National Irrigation Board (NIB); the NIB's Mwea Irrigation Scheme and its Mwea Irrigation Agricultural Development Centre (MIAD); the Ministries of Water and Irrigation (MWI) and of Agriculture (MoA); the African Institute for Capacity and Development (AICAD), an international NGO based at JKUAT; the Central Kenya Dry Areas Project; IMAWESA, a regional network for Improving Management of Agricultural Water in Eastern and Southern Africa, set up by ICRISAT and funded by IFAD; private consultants; the World Bank Institute (WBI) in Washington, DC; SRI-Rice in the USA; and progressive farmers from the Mwea Irrigation Scheme. This broad coalition has enabled rapid expansion of SRI in Kenya: http://sri.cals.cornell.edu/countries/kenya/index.html. Some of the initial Kenyan network participants are seen in the picture on the next page.

Once SRI has been introduced and demonstrated in a country, various NGOs, donor agencies, foundations and businesses NGOs have begun to support SRI and/or SCI extension in various ways and to various extents. It often takes several years for momentum to be gained, because there is limited financial support.

A stakeholder meeting of Kenyan collaborators from university, NGO, donor and farming communities, August 18, 2009.

Non-Governmental Organizations

- **ActionAid** in Bangladesh
- **ADRA** in Madagascar, Cambodia and Indonesia
- **American Friends Service Committee** in DPRK
- **Buddhist Global Relief** in Vietnam, Cambodia, India, Haiti and Ethiopia
- **CARITAS** in Indonesia (Aceh province), Philippines, Myanmar and Sierra Leone
- **Catholic Relief Services** in Madagascar, Sri Lanka, Cambodia, India and Philippines
- **Inter-American Institute for Agricultural Cooperation** (IICA) in Dominican Republic
- **Japanese Overseas Cooperation Volunteers** in Laos, Cambodia and Vietnam
- **LaSalette Missionaries** in Myanmar
- **Latter Day Saints (LDS) Charities** in Cambodia
- **Lutheran World Federation** in Myanmar, Nepal and India (Bihar state)
- **Mennonite Central Committee** in DPRK
- **Mercy Corps** in Nepal, Sri Lanka, India, Myanmar and Timor Leste
- **Oxfam-America** in Cambodia, Haiti and Vietnam; also introducing SRI/SCI applications for other crops, particularly tef in Ethiopia
- **Oxfam-Australia** in Laos and Sri Lanka
- **Oxfam-Great Britain** in Bangladesh and Philippines
- **Oxfam-New Zealand** in Timor Leste
- **Oxfam-Quebec** in Vietnam
- **Pro-Net 21** (Japan) in Laos
- **Rotary Club-Lille Est** (France) in Madagascar

- **SNV** (Netherlands Development Organization) in Vietnam and Nepal
- **World Vision** in Sierra Leone, Vietnam, Sri Lanka, Nepal, Ghana and Zambia
- **World Wide Fund for Nature (WWF)** in India and Madagascar

Donor Agencies
- **Agence Française de Dèveloppement (AFD)** in Madagascar
- **Asian Development Bank** in India (Chhattisgarh state), Cambodia, Laos, Thailand and Vietnam
- **Australian Aid (AusAid)** in Vietnam
- **European Union** in Cambodia, Laos, Thailand and Vietnam through Lower Mekong Basin project (AIT), Nepal through FAO project, and Timor Leste, and **European Development Fund (EDF)** in Vietnam
- **FAO** in project components in Afghanistan, Nepal, and DPRK
- **German Government (GTZ/GIZ)** in Cambodia, Timor Leste and Vietnam
- **Norwegian Government** in Afghanistan through FAO project and Tanzania
- **Swiss Development Cooperation** in Madagascar, Myanmar and India
- **U.S. Agency for International Development** in Madagascar, Mali, Haiti, Ghana and Tanzania
- **U.S. Peace Corps** in Madagascar and the West African region
- **World Bank** in India (Bihar and Tamil Nadu), Vietnam, Malawi and West Africa; also facilitation in Kenya, Malawi and Southeast Asia through distance-learning media with website and videos for SRI promotion through its
- **World Bank Institute** http://info.worldbank.org/etools/docs/library/245848/

Foundations
- **Aga Khan Foundation** in Afghanistan, India (Gujarat and Bihar states), Madagascar and Mozambique
- **Better U Foundation** in Madagascar, Mali and Haiti
- **Bill and Melinda Gates Foundation** supporting the spread of STI, the system of tef intensification, in Ethiopia
- **International Fund for Agricultural Development** (IFAD) in Madagascar, Burundi, Rwanda, Cambodia, Malawi and Vietnam
- **Medco Foundation** in Indonesia
- **Ohrstrom Foundation:** SRI-Rice Center at Cornell
- **Rockefeller Foundation** in Madagascar
- **Sir Dorabji Tata Trust** and **Sir Ratan Tata Trust** in India
- **Syngenta Development Foundation** in India (Bihar state) and Mali
- **Thai Education Foundation** in Thailand
- **The Asia Foundation,** assisting knowledge sharing for DPRK

Private Companies
- **Ambuja Cement Corporation** in India
- **Buddha Air** in Nepal
- **Garuda Airlines** in Indonesia

- **Lotus Foods** in Cambodia, Indonesia and Madagascar
- **Nippon Koei** professionals giving leadership in Indonesia and Laos
- **PT Sampoerna** in Indonesia
- **Syngenta Bangladesh Pvt. Ltd.** in Bangladesh
- **Usha Martin Pvt. Ltd.** in India

Also, that have been some private individuals who gave financial support for SRI's spread as much-appreciated, anonymous 'angels.' Jim Carrey's ***Better U Foundation*** has been the only foundation to give direct support for SRI extension around the world, through a gift made to Cornell University in 2010 to help establish the *SRI International Network and Resources Center*. SRI-Rice, among many other things, maintains the much-used international SRI website: http://sri.cals.cornell.edu, created in 2001 and managed since then by Lucy Fisher.

SRI benefactor Jim Carrey on left, with Erika Styger, director of programs for SRI-Rice, and Jean-Robert Estimé, director of the technical assistance team for USAID's WINNER project which is also introducing SRI in Haiti, during Carrey's visit to Haiti in March 2011. Jean-Robert headed the Chemonics technical assistance team for a USAID project in Madagascar, 1998-2004, that moved SRI work beyond where it was in Ranomafana.

In 2008, ***Groupement SRI Madagascar*** (G-SRI) began operating with grants and technical assistance from the Better U Foundation. G-SRI built up to 260 partners and affiliates (http://www.agriculture-biodiversite-oi.org/Espace-Pro/Nouvelles-pro/Actualites/Des-nouvelles-du-groupement-SRI-de-Madagascar), but it is now less active, lacking financial support. Both Tefy Saina and G-SRI have had support from the Rotary Club in Lille, France, thanks to its member Nicolas Duriez.

In a number of countries, farmers have emerged as effective SRI spokespersons and trainers, giving of their own time and money to promote SRI practices to dozens, even hundreds of fellow farmers. Several have even trained hundreds of fellow farmers at their own expense, such as Miyatty Jannah in Indonesia (cover), Mey Som in Cambodia (page iv), and Premarathne in Sri Lanka (page 48).

The extension of SRI has thus had extremely diverse support, notable for its voluntary nature. Cornell's support for work on SRI came initially through CIIFAD, which had generous and anonymous funding from the Atlantic Philanthropies, now known to have had financial backing from Charles Feeney. The spread of SRI would not have been gotten started without that absolutely unparalleled gift. But overall, the dissemination of SRI has gained most of its momentum from the contributions of time and money from many thousands of individuals all around the world. The spread of SRI, I like to say, has in addition to being labor-intensive has also been love-intensive.

Relative to the limited amount of institutional and financial support that this far-flung, voluntaristic SRI campaign has received, the amount of impact that it has already achieved is unprecedented. But then, SRI is itself unprecedented as an innovation. It is possible that SRI experience will open up new styles, strategies, roles and relationships for agricultural extension and development in general.

A tri-continental SRI get-together in an SRI field in Kenya in March 2012 with Bancy Mati and Jackline Ndiiri, professor and PhD student at Jomo Kenyatta University of Agriculture and Technology in Nairobi; Erika Styger, director of programs for SRI-Rice who has helped introduce SRI in Mali and Haiti; Moses Kareithi, first SRI farmer in Kenya; Joseph, an SRI extension worker; and Shuichi Sato, Nippon Koei engineer from Japan who took initiative for SRI spread in Indonesia, India and Philippines. The aromatic Basmati rice in this field, grown with a combination of SRI practices and urea deep-placement gave a yield of 8 t/ha compared to conventional yields of less than 5 t/ha.

With SRI, farmers are not considered as *adopters* or *recipients* or beneficiaries of scientific and technological advice. Rather, they are regarded and respected as *partners* and as *innovators* in the process of SRI adaptation and its further evolution. Farmers by themselves or in cooperation with NGO, government or other partners have been making substantial improvements in SRI, particularly to reduce its labor requirements (Uphoff 2007c). This stems from regarding SRI not as a technology that is finished and fixed, but instead seeing it as *a work in progress*.

Farmer meeting with author for discussing SRI (SICA) in Alonso de Rojas, Cuba

A trans-Africa consultation on SRI at the Rice Research and Training Center in Kafr el Sheikh, Egypt. Here Mustapha Ceesay (center), who started SRI trials in The Gambia in 2000 while on leave from his country's National Agricultural Research Institute to do a PhD at Cornell, is visiting an SRI plot at the Egyptian center with RRTC staff. This picture was taken by Waled el-Khoby, RRTC scientist who started SRI evaluation in Egypt in 2006 and who is now working as a chief agronomist with a company in Nigeria.

13. What has been the response of scientists and policy makers?

Usually in the 20th century, technological improvements have followed from advances that had first been made in the domain of scientific knowledge. SRI, however, like the airplane, was an invention that preceded the science that could explain it. Many scientists and technologists have had some difficulty in accepting that SRI is not like other technologies; indeed, SRI proponents have avoided using the designation 'technology' for reasons discussed above (page 37). Many persons have looked upon SRI and have evaluated it as they would a new variety or a new input, not appreciating that SRI is more mental than material, more a matter of ideas than of inputs. Since it did not fit neatly into the usual categories and terminology used for conventional scientific thinking, SRI encountered some resistance and opposition from the start.

Early on, SRI received endorsements from two of the world's most eminent rice scientists: ***Dr. M.S. Swaminanathan***, one of the leaders of the Green Revolution in India' and a former director-general of IRRI (Ministry of Water Resources 2006); and ***Prof. Yuan Long-ping***, regarded in China and around the world as 'the father of hybrid rice' (Yuan 2002)(see page 43). Still, for some time most 'mainstream' rice scientists withheld their approval, and this affected the willingness of governments and foundations to support research and development on SRI, and even to evaluate its effects, which would have been the logical and scientific thing to do.

- Indeed, it was argued that SRI should not even be investigated, because its reported gains were evidently not possible since they were said to violate ‘well-established principles’ for increasing rice production (Sinclair 2004).

It was thus left to civil society, broadly defined, to investigate and disseminate SRI practices. As noted below, a number of agricultural scientists in different countries who understood the ideas behind SRI undertook their own assessments of its ideas and practices. Once they were satisfied that SRI methods could indeed enhance crop productivity, they began cooperating with others engaged with SRI – farmers, extensionists, NGO workers, private sector agents. In country after country, policy makers have begun to respond to the new opportunities as they came to appreciate the benefits that these make available for farmers, consumers and environment, immediately, at low cost, and with little risk.

When Fr. Laulanié first introduced SRI to scientists and students at the University of Antananarivo in 1990, I am told that there was disbelief and derision. The IRRI country representative in Madagascar expressed no interest in SRI when upon first learning about SRI, I asked him about it in December 1993. The author found also little interest among agricultural science colleagues at Cornell when they were told about SRI in 1996, after two years of results were in hand.

In October 1998, the author discussed SRI with the newly-appointed Director-General of the *International Rice Research Institute* (IRRI), Ron Cantrell. The conversation was cordial, and Cantrell invited him to give a seminar on SRI at IRRI when in Manila in February 1999 for an ADB conference. But after this there was no evident interest in cooperating to evaluate the methods. Indeed, after Uphoff gave another seminar on SRI at IRRI in March 2003, several scientists working at or associated with IRRI began publishing critiques and rejections of SRI (Dobermann 2004; Sheehy et al. 2004; Sinclair 2004; Sinclair and Cassman 2004). For a brief review of this controversy, see Uphoff (2012a).

Fortunately, scientists in several national agricultural research institutions were more receptive to SRI's new ideas. Their willingness to evaluate the new methods helped to establish the scientific foundations for SRI.

- This process started in 1999 with evaluations that confirmed SRI results carried out at **Nanjing Agricultural University** in China and at the Sukamandi rice research station of Indonesia's **Agency for Agricultural Research and Development** (Wang et al. 2002; Gani et al. 2002).

- Further evaluations were done by scientists at the **China National Hybrid Rice Research and Development Center** (CNHRRDC) and the **China National Rice Research Institute** (CNRRI) (Tao et al. 2002; Zhu et al. 2002); also in Thailand (Mishra and Salokhe 2008) and India (Thakur et al. 2010).

- A project set up in 2000 by **Wageningen University** researchers with Dutch government support enabled scientists in China, India, Indonesia and Madagascar to do evaluations of SRI (Hengsdijk and Bindraban, 2001).

Already starting in 1998, top students in the Faculty of Agriculture (ESSA) at the **University of Antananarivo** in Madagascar began doing thesis research projects on different aspects of SRI, supervised by ESSA's director of research, the late Robert Randriamiharisoa. Factorial trials clearly showed the merits of SRI practices, both respectively and collectively (Randriamiharisoa and Uphoff 2002; Uphoff and Randriamiharisoa 2002).

In India, evaluations of SRI began at **Tamil Nadu Agricultural University** in 2000, and further evaluations were done by ANGRAU, the Andhra Pradesh (AP) state agricultural university starting in 2003. With support from the **World Wide Fund for Nature** (WWF) under a joint program with **ICRISAT** on food, water and environment, evaluations in AP expanded further in 2004-06. The project involved scientists from ANGRAU, ICRISAT, and the **Directorate of Rice Research** (DRR) of the Indian Council for Agricultural Research (ICAR), all based in Hyderabad.

In this period, the Indian Government's **Directorate of Rice Development** (DRD) in Patna also undertook its own evaluations and has been supportive of SRI based on its results. In 2007, the Government of India allocated $40 million to support the dissemination of SRI practices in >130 food-insecure districts across India under its **National Food Security Mission** (NFSM), with Ministry and ICAR endorsement.

The rice research programs in **Iraq** and **Iran**, at Najaf and Amol respectively, both began their own evaluations in 2005 and have demonstrated the benefits of SRI to the satisfaction of their scientists (http://sri.cals.cornell.edu/countries/iraq/; and http://sri.cals.cornell.edu/countries/iran/).

SRI initiators in the Middle East: Khidhir Hameed, senior scientist at Al-Mishkhab Rice Research Station near Najaf in Iraq, with SRI trials on station; Amiri Larijani, now director of the Haraz Extension and Technology Development Center in Iran, showing SRI plant reaching 93 tillers (72 of them fertile) vs. 25 tillers with usual methods.

There was, however, resistance to SRI trials and demonstrations encountered from rice scientists in countries such as Bangladesh, Cambodia and Sri Lanka who were influenced by the criticisms from some international rice scientists. Over time, most scientific opinion has become more favorable toward SRI, given that the national rice research systems in China, India, Indonesia and Vietnam -- where 2/3 of the world's rice is produced – have become supportive of SRI based on their own assessments of evidence.

A recent meta-analysis of published evaluations of SRI by Chinese researchers has compared what these scientists considered ‘best management practices’ (BMP) with SRI results (Wu and Uphoff 2015). Statistical analysis of more than 60 comparison trials found that even incomplete use of the recommended SRI practices gave paddy yields that were on average >10% greater than with BMP. ‘Good’ use of the methods produced >20% higher yields, while full use could give a 30% gain in productivity.

A proposal for joint evaluation of SRI was put together in 2008 by researchers from IRRI, Cornell, and Wageningen University. This would have followed agreed-upon protocols in several countries with differing agroecological conditions. It was submitted to the Bill and Melinda Gates Foundation in 2009; however, it was not ultimately funded. Instead, a grant was made to Wageningen for a review of experience with extending SRI (http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1922760). Wageningen University also received funding from the Dutch Government for a four-year evaluation of SRI experience in India, including PhD training programs for four Indian professionals, the grant concluding in 2014.

Meanwhile, more and more Master's and PhD theses have been done on SRI at universities around the world, and more and more articles have been published on SRI in peer-reviewed journals. These have established a better understanding of how and why SRI's innovative practices produce the effects reported here, e.g., Horie et al. 2005; Mishra et al. 2006; Stoop 2011. SRI represents a shift from the present paradigm of making agricultural advances based on genetic improvements and the application of external inputs, to one that increases productivity through modified management practices which in particular promote root growth and stimulate beneficial activity from the soil biota.

Paradigm shifts seldom come smoothly, even in the realm of science where evidence is supposed to determine the tenability of ideas and propositions. In the case of SRI, a shift can eventually come more quickly because the validity of its ways of thinking will not be decided just by inner and outer circles of scientists, but more decisively by the assessments and actions of millions of farmers, eventually hundreds of millions, and their governments. When they give SRI a vote of confidence by their use and continuation of its methods, dismissals in the peer-reviewed literature will carry little weight, even among most scientists.

It now appears likely that the paradigm shift will not be limited to rice production but instead will have ramifications for agricultural science and practice more generally. It could shape some better pathways to food security and prosperity in the 21st century, dealing with the many challenges such as land and water limitations, rising costs of energy, climate change, environmental degradation, and immense unmet human needs among persons with limited resources.

The earlier limited involvement of scientists in SRI's creation and development is changing, and the 'controversy' has abated as evidence and peer-reviewed journal articles keep accumulating. Before 2002 there were few published articles; by 2011-12, the number published annually was over 60; and the total number is now over 600, most of which can be accessed from the SRI-Rice website (http://sri.cals.cornell.edu/research/JournalArticles.html). For a review of this literature, see Styger (2014).

Even if established commercial interests find SRI unattractive, increasingly the political leadership in rice-growing countries is coming to appreciate the opportunities that SRI offers to raise food production, with lower costs for farmers and thus more net income from growing rice, and also with less need for irrigation water, which reduces conflicts as well as cost.

While much of the impetus for SRI spread has come from farmers, assisted by NGO, university and other professionals whose mission it is to improve agriculture and reduce poverty, there has been notable support from top political leaders in a number of countries.

President S.B. Yudhoyono of Indonesia speaking to an SRI harvest festival in Cianjur, West Java, in 2007, praising SRI before audience of 1,300 (https://www.youtube.com/watch?v=LzlXwrGHr6Y).

Gamini Batuwitage, at the time Senior Assistant Secretary of Agriculture, talking with the then Deputy Minister of Agriculture, Salinda Dissanayake on right, who was one of the first farmers in Sri Lanka to use SRI methods, discussing different weeder designs and their effectiveness.

Former President of Madagascar Marc Ravalomanana assisting in the harvesting of an SRI demonstration plot at his presidential residence at Iavoloha outside Antananarivo.

Former Cambodian Minister of Agriculture Chan Sarun, on left, talking with the author and Y.S. Koma, president of CEDAC, at the 4th National Farmers Convention in Phnom Penh, where a presentation on SRI made to 400+ farmers was introduced by the Minister. The Minister incorporated SRI into his country's 2006-10 National Agricultural Development Plan as one of its four main pillars.

In center, Ms. Jyoti Devi, an SRI farmer/activist elected to the Bihar State Legislative Assembly, holding a large SWI plant with her husband during a village visit in 2011, standing with the farmer who grew the plant (in orange sari) and the author looking on. Ms. Devi won election to the Assembly with by 23,000 votes based in large part on her success in promoting SRI in her district (The Times of India 2010).

14. What do you see as future directions for SRI?

It is both a strength and a weakness of SRI that it is not a fixed or a single thing. SRI continues to evolve, change and expand as more experience is gained and as more and different persons engage with its ideas and effects. We refer to SRI as a *methodology* rather than as a technology (page 37), and Fr. Laulanié purposefully chose to call it a *system*.

While SRI has biological/biophysical bases and manifestations, it is at the same time a social/socioeconomic reality. It is referred to by some as a *movement*, encompassing hundreds and now thousands of persons from many disciplines and from dozens of countries. This aggregation of like-minded people complements, activates, and learns from the agronomic factors and relationships that are manifested in SRI in material ways.

Probably the most summary way to think about SRI is as a *phenomenon*. There is certainly something real and existing that is referred to by the acronym *SRI*, even as it morphs into terms like the System of Root Innovation, or the System of Crop Intensification. (It is pure coincidence that *Sri* in Sanskrit-based languages is an honorific word used for deities and noble persons.) Nobody can say what SRI will look like or refer to 10 years from now, but some reasonable conjecture is possible.

Broader Agroecological Development: SRI is related to a broad set of management systems that can be grouped generally under the term of *agroecology.* This includes agroforestry, integrated pest management, and particularly, *conservation agriculture* (CA).

- CA is gaining acceptance in most countries around the world, with over 125 million hectares now under such cultivation. CA is a progressive evolution of what started decades ago as *no-till agriculture*, now linked with maintaining *permanent ground cover* (mulch, cover crops, etc.) and optimizing *crop rotations*, moving away from monocropping and from the repetitive disruption of soil systems (Kassam et al. 2009).

- SRI was developed without making any changes in land preparation methods, trying not to require too much change in farmer practices at one time. But farmers in several countries have begun experimenting with SRI on *permanent raised beds*, e.g., Lu et al. (2013). In Pakistan, SRI, CA and organic agriculture have been merged to save both water and labor with *mechanization* (page 57). Because this system produces more output with less input, it is referred to as 'paradoxical agriculture' (Sharif 2011).

- There are substantial benefits from *not* continually ploughing up the topsoil: cost saving but also the enhancement of soil fertility and soil biodiversity. SRI practitioners are learning how to tap these benefits, letting soil organisms such as earthworms carry out the active soil aeration (pictures on pages 82 and 109) that has been otherwise accomplished by the use of mechanical hand weeders. Achieving better soil porosity and functioning by biological rather than mechanical processes is fully consistent with SRI thinking.

Broader Applications within Agriculture and Horticulture: We are already observing the extension of SRI concepts and methods to a wide range of *other crops* (pages 148-153), and not just for cereal crops or *gramineae* family species. So far we have not seen SRI principles successfully applied to fruits, but they can raise the productivity of various vegetables as well as pulses, oilseeds and legumes (Behera et al. 2013). The application of SRI to better sugarcane production (SSI) is now proceeding in India and has been started in Cuba (www.agsri.com). So, what began from inductive work devoted to irrigated rice is now spreading throughout agriculture and horticulture.

- One extension includes **aquaculture** along with horticulture and rainfed SRI. This has been evaluated over two years (one a drought year) at the ICAR Directorate of Water Technology center in Bhubaneswar, India. Adapted SRI methods raised the paddy yield by 52% over usual rainfed production. But more important, researchers found that by taking about one-quarter of a 350-m^2 area out of rice-growing -- installing a catchment pond on 10% of the area (35 m^2) and planting bananas and papayas on another 45 m^2 of land around the pond and the field -- the higher costs of this more intensive management were repaid with 10x more income generated per hectare, and with a huge increase in the productivity of (scarce) water. Fortuitously, it was found that the economic productivity of water was even higher in the drought year than in the more normal rainfall year (Thakur et al. 2015).

- This kind of productive, profitable **farming-systems intensification** has been encouraged and documented by CEDAC in Cambodia, capitalizing upon the productivity gains in rice production achieved with SRI. Smallholders with just 0.66 hectare of cultivated area, by getting much higher paddy yields with SRI methods, were able to reduce their area planted to rice by almost half. On the area taken out of monocrop paddy, they then constructed a pond and canals (15% of total area) and began growing a variety of upland crops, fruits and vegetables, plus small livestock. With an investment of ~$300 for constructing the pond and other simple infrastructure, farmers were able to raise their net household incomes from $200 a year to $600 (Lim 2007). In the future, we need to *utilize SRI ideas and practices within whole farming systems*, not just for rice crop improvement.

Linkages with Soil Biology: With the spread of SRI to more crops, we are seeing closer links forming between agricultural science and **microbiology** generally. We have been learning how *symbiotic endophytes* -- microorganisms that mostly reside in the soil but that can enter and live in plant tissues and cells in mutualistic relationships above-ground – are able to contribute to plants' growth and health (Chi et al. 2005; Uphoff et al. 2013).

- Agriculture has become heavily dependent for its increases in output upon direct inputs of synthetic fertilizers and agrochemicals. SRI does not promote 'organic' agriculture as such, as this is often conceptualized simply as 'anti-chemical.' Rather, SRI experience justifies a strategy for agricultural production that is *pro-biological* -- being 'organic' pragmatically rather than doctrinally. One of SRI's effects over time will be, I think, to *re-biologize agriculture*, making it less chemical-dependent and more a matter of nurturing than of engineering, investing more effort to elicit potentials than to create them.

New Emphasis in Genetic Analysis: SRI does not make further improvements in crop genetic potentials unnecessary. The great production increases that are possible by better exploiting existing potentials do not mean that no further improvements in genetic potential should be attempted. Rather, SRI experience shows how important it is to advance knowledge and practice with regard to *the expression of genetic potentials*, not just continuing trying to increase those potentials. Such increases are beneficial only to the extent that they can and will be *expressed*.

- The emerging scientific field of ***epigenetics*** should be getting much more attention among agronomists and plant breeders than it presently receives. Too much research is fixated on genes per se. A kind of 'double-helix determinism' is still rather widely accepted. But SRI plant phenotypes show how huge can be the effect of making alterations in plants' growth environments, both above- and below-ground. This can have greater impacts on crops' yield and health than the effects that are achieved through plant breeding alone.

- There is still much that needs to be researched and better understood about how to manage plants' environments so as to *get desired results expressed in more productive and robust crop phenotypes* (Uphoff et al. 2015). There needs to be much work done on understanding better the genome in all of its manifestations. This needs, however, to encompass more than molecular biology. Ecology and microbiology, and the combination of microbial ecology, will be part of a new supra-discipline.

Liberian farmer Edward Sohn showing respective plants of the same variety from the conventional and SRI rice fields on his farm in Grand Gedee county. The SRI plant on right is 3 days older, but this cannot explain the huge difference in plant growth.

- Recall that in Darveshpura village in Bihar state of India in the 2011 kharif season, five SRI farmers matched or exceeded the previous world record for paddy yield of 19 tons/ha using new hybrid varieties (pages 79-80). When these farmers used the same hybrid varieties on their farms with the same soil and climatic conditions but using conventional management methods (older seedlings, close spacing, flooding of paddies, etc.), their yields were ~7 tons/ha (Diwakar et al. 2012). While this was 3x higher than average paddy yields in the state, it is *only about one-third* of what these hybrid rice varieties could produce with better and different crop management which changed the plants' growing conditions.

- SRI offers plant breeders and physiologists a great opportunity to advance the science of epigenetics by studying what happens, when, where, and why, in the expression of rice plants' genetic potentials when their growing environments are modified. Chi et al. (2010) have shown that symbiotic endophytes (soil rhizobia) when they migrate from the soil up through the roots and stems to live in rice plants' leaves and sheaths can affect the up-regulation and down-regulation of specific genes which produce proteins that, e.g., increase photosynthesis and protect against pathogens. This is really important new knowledge, paralleling what is being learned about human growth and health from study of the human microbiome.

Institutional and Policy Reorientations: One of the most important impacts from the introduction and spread of SRI may well turn out to be *changes in the way that agricultural research and development are conducted.* In most of the 20th century, agricultural R&D followed what has been characterized as a *linear model* of organization (Merrill-Sands and Kaimowitz 1992). Agricultural progress was thought to derive primarily from agricultural research in formal institutions. These produced new knowledge to improve crop productivity that was passed on to extension agents, and through them to farmers as end-users. While feedback loops were provided for in theory, in practice these were weak or absent. 'Technology transfer' was idealized and was usually unidirectional.

- In recent decades, support has grown for what is called *farmer-centered research and extension* and for *participatory technology development*. This recognizes weaknesses in the established one-way systems that were set up to achieve the 'transfer of technology.' But except for the farmer field school (FFS) movement developed under FAO auspices to extend integrated pest management (IPM) knowledge and practice, there has been little real change in the thinking that guides agricultural R&D, and in the way that research and extension institutions currently operate.

- The SRI experience originated from civil society rather than from research centers, and it advanced in the initial years without support from formal institutions for research and extension, except in Sichuan and Zhejiang provinces of China; Tripura and Tamil Nadu states of India; and Vietnam. There are many examples of how farmers have themselves made many improvements in the initial SRI recommendations, with labor-saving practices, new implements, extrapolations to other crops, etc. (Uphoff 2007c).

- In countries where farmers have become *operational partners* with NGOs and state extension services in improving and disseminating SRI, it is unlikely that the formal R&D institutions will ever be quite the same again, because of the *confidence* built up among farmers in their own capabilities and because of the *respect* engendered among more-educated professionals for what farmers can contribute to their own and to others' development.

Broader Changes: SRI experience is providing a foundation for *creating more participatory and more egalitarian modes of agricultural R&D* for the future, appropriate for the 21st century. This is expected to be more democratic than in the preceding century, not least because farming communities around the world are now more educated and better informed than their predecessors.

- It is appropriate that the name which Fr. Laulaniè and his Malagasy friends gave to the NGO which they established in 1990 was *Association Tefy Saina*.

We note that the words *Tefy Saina* refer to human development (*formation de l'homme*) rather than to rice production.

- SRI proponents have agreed with this philosophical orientation, appreciating that *the human factor* is ultimately the most important for further and more beneficial development in our world. Providing more abundant, healthier and cheaper food for people can be expected to make a significant contribution to expanding human capabilities and empowerment. Thus, it is a good focus for immediate and sustained efforts. But ultimately, there need to be advances made in people's mentality, in their values, and in their modes of cooperation as constraints and injustices need to be dealt with in many realms, not just in agriculture. We anticipate SRI experience increasingly expanded across much of the agricultural sector can broad contributions to human confidence, imagination, and solidarity.

These qualities are needed to put humankind in a better position to deal with the many other serious problems that need to be tackled for us to survive through this current century -- beyond hunger and poverty, which SRI can redress. The odds of success given climate change, failing states, growing inequality, and other dire trends are not very good. But the bundle of ideas, friendships and aspirations that have been aggregated through the dynamics, impacts and opportunities of SRI can, we hope, improve the odds of successful change. It is appropriate that responses to questions about SRI thus conclude with reference to some philosophical themes and historical issues rather than just as an agronomic discourse.

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SRI technologies range from the very simple to the complexly mechanical. Here Indian farmers in Dypasandra village, Karnataka state, show use of a plastic seed germination tray for raising rice seedlings (198 in a tray) that are easily transportable to the field. Because SRI greatly reduces the number of plants per m^2, this tray developed for transplanting horticultural crops can be used also for rice production. These trays, costing less than 50 cents, are reusable. They save considerable labor time and effort and protect the seedlings' roots from trauma during transport and transplantation.

In Guanacaste province of Costa Rica where agricultural labor is relatively scarce and costly, Oscar Montero adapted a Japanese mechanical transplanter (Yanmar A400) to transplant single young seedlings widely spaced, making his version of SRI highly mechanized. The above field being combine-harvested gave a yield of 8 tons/ ha without use of chemical fertilizers, almost double his previous yield of 4.2 tons/ha.

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143: Lim (2007).
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182: *Robert Bimba, CHAP, Monrovia, Liberia
202: Norman Uphoff; *Oscar Montero, Guanacaste, Costa Rica
205: *Erika Styger, SRI-Rice
206: *Robert Bimba, CHAP, Monrovia, Liberia; Manuel Sanchez, IICA, Santo Domingo, Dominican Republic
211: *Mike Mack, Syngenta, Basel, Switzerland; *Iswandi Anas, IPB, Indonesia
212: Julius Fieshi, COOPBOD, Ndop, Cameroon; Arayaphong and Bessonova (2014)

*Young farmers in Haiti making a marker (*rayonneur*) out of wood to be able to mark their fields for transplanting SRI seedings at 25 x 25 cm spacing.*

SRI panicles from first-year demonstration plots in Liberia managed by CHAP, Community of Hope Agriculture Project, the local NGO that has given leadership for introducing SRI into its country. These panicles were displayed at a national launch of SRI which CHAP organized in May 2014 and which was presided over by President Ellen Sirleaf Johnson. CHAP's SRI promotion was carried on during the Ebola virus epidemic in 2014 alongside its EV awareness campaign (also see the picture on page 182).

Dominican farmer Fabio Diasa counting the number of tillers (66) on one of his SRI (SICA) rice plants. His yield from a 0.44 ha trial plot was 10.4 tons/ha. This and other trials were encouraged by IICA's representative in the Dominican Republic, Manuel Sanchez.

Indexes

Countries referred to

Persons referred to

Organizations referred to

SRI work has had cooperation from some organizations that might not have been anticipated. The Syngenta Development Foundation has supported SRI trials and demonstrations in India and Mali, and Syngenta Bangladesh Co. Ltd. was a founding member of the SRI national network in Bangladesh. Here Mike Mack, CEO of Syngenta, stands with a weeder beside an on-station SRI demonstration plot in Chennai, India.

The Indonesia military has invited the Indonesian Association for SRI, to give hands-on training on SRI to some of its high-level officers. Here officers, even a general, try their hands at transplanting under supervision of a farmer, on right, while the coordinator of Ina-SRI, Iswandi Anas (in red shirt) who had given them lectures on SRI, looks on.

Brunhilda Faminyi who lives in Ndop in the northern Cameroon, standing in her SRI field which gave three times more yield, 6.1 tons/ha, than from her neighbor's field where the same variety was grown with conventional methods in 2014. A student in the lower VIth form, Brunhilda tried SRI methods as soon as she learned about them, transplanting single 13-day-old seedlings with wider spacing. With her labor and input costs reduced, her net income from this field was calculated to be more than tripled (Fieshi 2015).

Supisra Arayaphong oversees her SRI plot on the left, and on the right is a picture of her plot using alternate wetting and drying (AWD) two months earlier. Supisra is a member of the Thai Weekend Farmer Network, which has over 5,000 members who live in cities. These urban residents are resuming part-time agriculture for the sake of their and others' health and to have better environmental quality. Supisra has now given up a good job in Bangkok to take up full-time farming based on SRI methods, which are preferred by Network members for their productivity and environmental merits. Supisra's blog on her SRI experience (Arayaphong and Bessonova 2014) was given an award by the SE Asia office of the CGIAR Research Network on Climate Change, Agriculture & Food Security.

THE SYSTEM OF RICE INTENSIFICATION (SRI)
Responses to Frequently Asked Questions

SRI is an unprecedented agricultural innovation, enabling farmers to achieve greater output – yield per hectare, per liter of water, per kilogram of seed, per day of labor, per monetary expenditure – while using less water than with conventional irrigated rice production, relying less on agrochemical inputs including fertilizer, and not needing to change varieties. 'Producing more from less' sounds like agricultural alchemy, but farmers in over 50 countries have seen that this is possible by modifying the management of their plants, soil, water and nutrients.

Additionally, SRI-grown rice crops are more resistant to pest and disease losses and to the drought, storm and other weather stresses that will become more common and severe with climate change. The advantages of SRI ideas and methods seen for rice are now being extended also to other crops, like wheat, millet, sugarcane, mustard, tef, and legumes. These improvements derive from growing larger, healthier root systems and from promoting the life in the soil.

While these impacts are unprecedented, so is the way in which SRI knowledge and practice has been disseminated around the world. SRI derives from the work of a French priest-agronomist living in Madagascar rather than from formal research, and it has been mostly a civil-society innovation spread particularly through NGOs, although colleagues from government agencies, universities and the private sector have joined in this effort that can benefit farmers, consumers and the environment.

Norman Uphoff, a professor of government and international agriculture at Cornell University since 1970, served as director for 15 years of the Cornell International Institute for Food, Agriculture and Development. Having been the most central participant in what has become a worldwide SRI movement, in this book he draws on a wealth of farmer experience and research results from all over the world,, providing first summary answers and then amplified responses to the most frequently asked questions about SRI. He examines its potentials for reducing hunger, poverty and insecurity in ways that are efficient, sustainable, equitable, environmentally-benign, and resistant to the hazards of climate change. It sounds too good to be true, but it is in fact true.