PROSPECTS FOR RICE SECTOR IMPROVEMENT WITH THE SYSTEM OF RICE INTENSIFICATION, CONSIDERING EVIDENCE FROM INDIA

Norman Uphoff, Cornell International Institute for Food, Agriculture and Development; A. Satyanarayana, Acharya N. G. Ranga Agricultural University, Hyderabad, India; and T. M. Thiyagarajan, Tamil Nadu Agricultural University, Killikulam, India

ABSTRACT

While the System of Rice Intensification (SRI) has been controversial in some circles, researchers in China, India, Indonesia and other countries have been laying scientific foundations to explain its superior performance. At the same time, SRI adoption is spreading around the world as farmers find merit in the recommended practices. Recently, the Government of India endorsed SRI for Indian rice farmers 'wherever feasible' (May, 2005). This paper reviews SRI and the controversies surrounding it, presenting data from the Indian states of Andhra Pradesh and Tamil Nadu that document a 1.6-2.5 t/ha yield advantage for SRI over more input-intensive rice-growing practices, with a reduction in water requirements and in costs of production.

I. INTRODUCTION

Rice sectors around the world, including that in Indonesia, face some major challenges as this 21st century begins. At the beginning of the International Year of Rice (IYR) in 2004, the previous director-general of IRRI, Dr. Ronald P. Cantrell, noted: "The Asian rice sector is in trouble… [with] a crisis in the supply of such essential resources as land, labor and water, but – most important of all – many nations are finding it difficult to develop sustainable ways to provide decent livelihoods for rice farmers and consumers" ("Asian stability threatened by stagnating rice sector," IRRI press release, February 12, 2004). The challenges facing the sector are considered both technical and socioeconomic in nature.

In his presentation to an international rice conference held at FAO headquarters in Rome to launch the IYR, Cantrell enumerated a number of objectives that the rice sector needs to achieve if it is going to meet better the needs of both people and countries in this new century (Cantrell and Hettel, 2004):

- **Increased land productivity** -- because the productive rice land available per capita is diminishing at the same time populations continue to rise.
- **Greater water productivity** when growing irrigated rice -- because this natural resource is becoming ever-scarcer for agricultural production, with competition from other sectors.
- **Accessibility for the poor** to any new technologies -- so that the rice sector will become more effective in ***reducing poverty*** as well as in ***enhancing food security***.
- **Environmental friendliness** -- not just requiring less water, but also reducing methane emissions and agrochemical impacts on soil, water, climate and biodiversity.
- **More pest- and disease-resistance** -- so that the application of agrochemicals can be reduced to contribute to ***better human and environmental health***.
- **More tolerance of abiotic stresses** -- particularly of drought, but also of storm and other weather damage, in order to be more resilient and to ***cope with likely climate change***.

- **Higher rice quality** -- to meet consumer tastes and demand, and particularly to have rice that has ***greater nutritional value*** so as to contribute more to human health.
- And most important of all, according to Cantrell, **more profitability** of rice production – so as to assure decent livelihoods for rural households by conjoining productivity increases with ***reductions in farmers' costs of production***.

These challenges constitute an agenda for all persons working in the rice sector -- producers, researchers, extensionists, NGO workers, and policy-makers. It turns out that the methods and principles of SRI can contribute to achieving all of these objectives -- including also **higher labor productivity** and even **labor saving**, as discussed below.

II. THE SYSTEM OF RICE INTENSIFICATION (SRI)

A brief summary here should suffice since SRI has become fairly well-known around the world, in part due to the controversy over SRI claims, although it is often superficially or incorrectly understood. Evidence has been accumulating over the past half dozen years, since SRI was first validated outside of Madagascar in China and Indonesia in 1999-2000, that all of the above objectives can be met, and met cost-effectively, by changing in complementary and synergistic ways the management of plants, soil, water and nutrients from some long-standing practices. Published reports on SRI are found in Stoop et al. (2002) and Uphoff (2003), and many various reports have been posted on the SRI home page: http://ciifad.cornell.edu/sri/

SRI was developed in Madagascar 20 years ago by Fr. Henri de Laulanié, SJ, after almost two decades of working with farmers, observing, and experimenting (Laulanié, 1993). The practices recommended for initial SRI use, for farmers to evaluate and adapt to local conditions, are:

- **Transplanting of young seedlings**, grown in unflooded nurseries and carefully planted into moist but unflooded fields, preferably between 8 and 12 days of age (not more than 15 days); somewhat older seedlings may still perform satisfactorily in colder climates because phyllochron length there is longer.
- **Wider spacing** -- something to be optimized, not maximized – planting initially in a square pattern, 25x25 cm, with single seedlings per hill (although in poorer soils, 2 seedlings may give higher yield than one). Wider spacing becomes more productive as soil fertility improves with SRI practices due to increases in organic matter in the soil. SRI spacing aims to create 'the edge effect' throughout the whole paddy, for larger roots and canopies.
- **Soil aeration** – also to be optimized -- so plants have sufficient water but mostly aerobic soil conditions to sustain root growth and health and to create favorable conditions for more abundant and diverse soil biota. Using a rotating hoe is recommended to control weeds (which become more of a problem when paddies are not kept continuously flooded). This provides ***active soil aeration***, enhancing growth of both roots and beneficial soil organisms. Hand weeding or herbicides can accomplish weed control but do not aerate the soil.
- **Increased soil organic matter**, to benefit the roots and soil biota. Compost made from any decomposed biomass is beneficial. Fertilizer used with the other SRI practices will increase yield, but the best results come from composed biomass. Augmentation with manure is good. Larger root growth induced by the above practices adds organic matter through exudation.

These practices, when used together, contribute to a more productive, robust phenotype from practically all genotypes of rice so far. They change the E in the equation: ***G*** (genetic potential) ***x***

E (environment) **=** ***P*** (phenotype). The most obvious impact of SRI practices is on root growth, as root systems are larger and healthier than when grown under anaerobic conditions. Increased tillering, larger panicles and heavier grains are also evident and measurable.

What is not so obvious are the induced changes in populations of soil microflora and fauna. Simply doing the SRI practices gives no assurance of results. For desired effects, these practices need to stimulate root growth and enhance soil biotic activity (see data in Table 1). Quite possibly these changes in turn stimulate the growth of plant root systems through the production of phytohormones (Frankenberger and Arshad, 1995); however, this has not been measured yet. The kind of remarkable root growth that SRI practices can produce is shown in Figure 1.

Table 1: Microbial populations in rice rhizosphere

Microorganisms	Conventional	SRI
Total bacteria	88×10^6	105×10^6
Azospirillum	8×10^5	31×10^5
Azotobacter	39×10^3	66×10^3
Phosphobacteria	33×10^3	59×10^3

Source: Gayathry (2002), from on-station trials at TNAU.

Figure 1: Two rice plants from Cuba, both same variety (VN 2084) and same age (52 DAP), raised in the same nursery. Plant on right was transplanted from the nursery at 9 days into an SRI environment: wide spacing, aerated soil, good organic matter. Plant on left was kept in nursery until transplanting at 52 days (common age for transplanting seedlings in Cuba is 50-55 DAP). (Photo: courtesy of Dr. Rena Perez)

A. Relation to Plant Genetics: SRI is compatible with and not opposed to genetic improvement of rice varieties. All SRI yields over 15 t/ha have come from using the practices with either high-yielding or hybrid varieties. But traditional varieties also respond well to the practices, giving yields as high as 12-13 t/ha (Dissanayake, 2002). They are usually more profitable to grow with SRI given the higher price they command in the market because of consumer preferences.

SRI started gaining attention in China when Prof. Yuan Longping, known there as the 'father of hybrid rice,' began promoting its evaluation after his own trials satisfied him that the methods could enhance the record-setting yields obtained with his hybrids and conventional practices (Yuan, 2002). The success of SRI could indeed become a boon for rice breeders because it suggests that cultivar selection has for decades been based on suboptimal growing conditions, and many of the past steps in rice breeding could usefully be retraced.

SRI is compatible with genetic modification (Uphoff, 2005), even though some of its proponents see SRI as an alternative. Work being done at Cornell on transferring the trait for increased trehalose production, for example, to enhance food crop resistance to drought, cold and salinity is a very promising application of genetic modification, for example.

However, SRI shows that making improvements in rice crops' growing environment, particularly paying attention to the soil biota (Randriamiharisoa et al., 2005), should prove both productive and cost-effective. The IYR presentation made by Cantrell gave little attention to modifying the growing environment through changes in crop management, however. Rather it focused on potential benefits from making changes in rice genomes, e.g., through molecular breeding of complex traits, the transfer of C_4 maize genes to C_3 rice, and allele mining (Cantrell and Hettel, 2004).

Because some varieties respond to SRI management practices better than others (e.g., Lin et al., 2005), it is important to pay attention to varietal differences. Plant breeding in the future can benefit from the agroecological perspective that SRI introduces, considering the effect of soil organisms on plant performance and health when planning and carrying out breeding efforts.

B. On-Station Evaluations: SRI is controversial in part because its methods do not give the same results every time. This should not be surprising since rice production is a biological process, not an industrial one. What has been surprising is that often SRI methods used on experiment station plots have given results inferior to those attained with SRI methods on farmers' fields. This reverses the usual situation where farmers have difficulty replicating researchers' results.

When SRI methods have been used on the IRRI station as Los Baños in the Philippines in the wet season 2002, for example, the yield was only 3.0 t/ha (Rickman, 2003). Concurrently, average SRI yields in a wide variety of locations in the Philippines averaged about 6.4 t/ha, more than twice as much (Verzola, 2003), with yields up to 12 and 14 t/ha reported (ATI, 2002; LSU, 2005). These are very great differences. When the National Wheat Research Programme in Nepal undertook on-station and off-station evaluations of SRI methods at different spacings in 2002 main season, it got the results shown in Table 2.

Table 2: Rice yields with farmer practice vs. SRI methods at different spacing

	Low yield	High yield	Ave. yield
On-Station Results (N = 3)	(t/ha)	(t/ha)	(t/ha)
Farmer practice	5128	5135	5132
SRI @ 30x30 cm	4975	6842	5744
SRI @ 20x20 cm	5955	6577	6266
On Farmers' Fields (N = 4)			
Farmer practice	5260	6756	5919
SRI @ 30x30 cm	6319	8855	7627
SRI @ 20x20 cm	7705	9675	8821

Source: Bhatta et al. (2003), results on-station and near-station, Bhairawa, Nepal.

We have seen this pattern, i.e., similar differentials, in a number of countries. This directed our attention to the role of soil biota in SRI results, hypothesizing that the abundance and diversity of biota may have been reduced in experiment-station soils after years of monocropping (because monotonous repetition of the same root exudates tends to reduce the biodiversity of soil microbes and fauna) and after long-term and long-term application of chemical fertilizers, pesticides, herbicides, fungicides, etc. (which can have the same effect). In the IRRI trials where SRI yield was only 3 t/ha, the best yield that IRRI got from any of the other five management systems being evaluating was only 4 t/ha (Rickman, 2003). With all of IRRI's resources and expertise, this was little better than typical Philippine production of irrigated rice.

It has been reported that long-term trials at IRRI's Los Baños farm keeping input levels constant have been showing a downward trend (Cassman and Pingali, 1995). While this has recently been attributed to the effects of global warming (Peng et al., 2004), it is more plausible to suggest that this trend reflects declining soil fertility, attributable to a combination of continuously anaerobic soil conditions and heavy chemical applications that affect soil biota. Some recent work has focused on how continuous flooding of soils appears to be affecting available N (Schmidt-Rohr et al., 2004). We suspect that there has been also a deterioration in soil biotic populations at Los Baños. However, this suggestion cannot be evaluated because IRRI does not assess its soil biotic resources on-station.

C. Broader Evaluations: Because more satisfactory SRI results are being obtained on farmers' fields than on-station, there is growing acceptance and use of SRI methods. In India, after several years of evaluation, particularly in the states of Andhra Pradesh and Tamil Nadu -- with results also obtained across this large and diverse country under an evaluation managed by the Indian Council for Agricultural Research (ICAR) -- the Government of India is now recommending use of SRI (see GOI press release, May 31, 2005: http://pib.nic.in/release/release.asp?relid=9545). In this current kharif (summer) season, the state government of Andhra Pradesh, taking the lead in India, is promoting SRI on at least 100,000 ha of its major irrigation systems. Evaluations of SRI from both Andhra Pradesh and Tamil Nadu states are discussed in Section IV. below.

The Agency for Agricultural Research and Development (AARD) in Indonesia began evaluating SRI at its Sukamandi station in 1999-2000. The first (wet season) results were not so impressive, just 6.2 t/ha, but the next (dry) season result, 9.2 t/ha, raised much interest within the Agency.

After six seasons of evaluation, moving trials out of Sukamandi to eight provinces representing varied agroecosystem for rice cultivation, AARD decided to incorporate SRI methods into its new Integrated Crop and Resource Management (ICM) strategy to reverse the yield stagnation that had beset the rice sector (Gani et al., 2002).

Official extension efforts have not accelerated in Indonesia as they have, starting more recently, in India. However, the Farmer Field School program promoting integrated pest management (IPM) in the rice sector began evaluating SRI in the Ciamis area in 2001, and it has integrated SRI into rice program, so that SRI has been spreading in this major rice-producing country too. Farmer Field School alumni have had SRI yields of 7.36-12.6 t/ha (Kuswara, 2003). Before offering evidence from India in Section IV below that should satisfy any remaining doubts about SRI, we review some of the objections that have been raised about this methodology.

Endin, KSP coordinator Tirtamukti, inspecting SRI plot, 2003 (from Kuswara, 2003).

III. OBJECTIONS

A. ***SRI is 'a niche innovation'*** (Dobermann, 2004) ***and will make 'no major contribution to improving rice production generally'*** (Sheehy et al., 2004). The first conclusion was based on a narrow explanation of SRI yield advantages on acid soils that had high Fe content, taking no account of the multiple factors contributing to higher yield, nor considering the multiple benefits of SRI beyond yield increase. The second was based on a modeling exercise that can be easily discredited and three small experimental trials done in China without following an acceptable SRI protocol. Five years of SRI evaluations by dozens of rice specialists in China contradict the conclusions of both the modeling and the experiments.

In fact, SRI benefits, sometimes dramatic, have now been demonstrated in 22 countries, from Philippines to Peru, with widely varying conditions. In China, SRI methods have raised yields and factor productivity in the north (Heilungjiang), south (Guizhou and Hainan), East (Zhejiang), West (Sichuan) and center (Hunan). In the large Indian state of Andhra Pradesh, yield advantages under controlled conditions on farmers' fields in all 22 districts, from low-lying coast to upland interior showed SRI yield advantages, as discussed in the next section.

B. ***Even if offering agronomic advantages, SRI is not widely adoptable because of its labor intensity*** (Dobermann, 2004; Namara et al., 2004), ***and it is subject to significant disadoption*** (Moser and Barrett, 2003). Initially, without doubt, SRI requires more labor per hectare while the methods are being learned. Transplanting tiny young seedlings singly takes more time at first compared to shoving handfuls of large seedlings into flooded paddy soil. When the fields are not kept flooded, weed control is more of a challenge and requires more labor input.

However, it is increasingly reported that SRI methods can be *labor-neutral* on average, with more experienced farmers able to save labor (Anthofer, 2004, based on survey of 500 randomly selected farmers in Cambodia for GTZ); or even *labor-saving* (Singh and Talati, 2005, based on study of 150 SRI farmers in West Bengal, India, for IWMI; also Li et al., 2005, based on village survey where SRI use went from 7 to 398 in one season in China, for China Agricultural University). So what looked like a necessary tradeoff to get SRI's benefits – accepting greater labor-intensity – no longer appears to be an unavoidable condition for SRI adoption.

In Cambodia, farmer use of SRI has gone from 28 in 2000 to almost 17,000 in 2004, with no evident disadoption, and expected spread to 50,000 farmers in 2005. The Moser-Barrett finding of significant disadoption seems to reflect the Madagascar villages that were covered in that study, something not necessarily representative of that country (Hirsch, 2000), and not indicative of how SRI is being received by farmers in other countries.

The Moser-Barrett study found poorer farmers less able and likely to adopt SRI methods because of its initial costs in terms of labor. However, the IWMI evaluation in Sri Lanka did not find much disadoption, and indeed, it found that poorer households were less likely to give up SRI than were rich ones (Namara et al., 2004). The CAU study in Sichuan, China found poorer and richer farmers equally adopting SRI and documented a huge (57-fold) increase in one year, spurred in large part by SRI's resistance to the effects of drought (Li et al., 2005). Disadoption was not an issue in this Chinese experience and has seldom been reported elsewhere.

C. ***SRI is "voodoo science"*** (Cassman and Sinclair, 2004) ***and not even worth considering*** (Sinclair, 2004). There is nothing magical or mystical about SRI, and its merits are becoming more and more established. Dismissing it summarily, without evaluation, is a disservice to rice science as well as to the rice sector. Chinese researchers have shown that there are scientifically based foundations for SRI, documenting significant phenotypic differences that result from SRI practices (Tao et al., 2002; Wang et al., 2002; Zheng et al., 2004; Lin et al., 2005).

Fortunately, a number of scientists in India, China, Indonesia and other countries have been more receptive to the opportunities that SRI opens up than most international and U.S. scientists have been. Complementing their research findings are results obtained by farmers, universities and NGOs in more than 20 countries, showing that the combination of methods which Fr. de Laulanié assembled through careful observation and experimentation, with the benefit also of some serendipity, are in fact more productive than conventional practice. The evidence from India in the following section should satisfy readers that SRI is not 'voodoo science' and that it is indeed 'worth considering.'

IV. EVIDENCE FROM INDIA

Rice is the most important food crop in Andhra Pradesh (AP) and Tamil Nadu (TN), and indeed, the Godavari and Krishna deltas on the coast of AP constitute one of the major 'rice bowls' of India, with over 1 million ha in this area well favored with infrastructure and climate. The Cauvery delta in TN is also a major rice-growing area. In recent years, the vagaries of weather and possible climate change have affected the water supply for irrigated rice production, both in the rivers for gravity-flow irrigation and in lowering water tables for groundwater supply.

It has been the potential of SRI to reduce water requirements for rice-growing that has made the new methods most attractive to farmers and to government, even though substantial cost savings have also been possible accompanying a significant yield advantage. In AP, this has averaged almost 2.5 t/ha, even against best current practices, while in TN the gain has been about 1.6 t/ha.

SRI requires greater knowledge and skill from farmers, but South Indian farmers are known for their progressive and innovative attitudes. There has been genuine farmer enthusiasm for SRI, which has helped to motivate the extension service (rather than just relying on it to motivate farmers). Farmers have been inventing labor-saving equipment, in particular a roller-marker to speed up transplanting and modifications of the rotary weeder to work in different types of soil.

The uptake of SRI has been rather rapid in part because its dissemination to farmers is not as complicated as some would make it appear. Farmers do not need to learn much that is new; they just need to modify certain practices that they already know. It is important, to be sure, that they understand the reasoning behind the recommended changes. This not only motivates them but enables them to make appropriate adjustments to suit their field conditions.

SRI uptake started sooner in Tamil Nadu, where Tamil Nadu Agricultural University (TNAU) began working with SRI in 2000, at the initiative of Dr. T. M. Thiyagarajan, who was at the time Director of TNAU's Crop and Soil Management Center at Coimbatore. An initial focus was on the effects of using the rotary hoe (or cono-weeder), which incorporates weeds back into the soil, conserving the nutrients they contain, at the same time that it aerates the soil. By 2002, on the basis of good results demonstrated in on-station trials on TNAU, the TN state government began supporting on-farm trials, and the TN extension service picked up SRI information and began spreading it to farmers. However, we start with consideration of experience in Andhra Pradesh, where SRI spread has been more rapid and where the data available from on-farm evaluation trials are more extensive.

A. Andhra Pradesh

The second author of this paper, while Director of Extension for the state agricultural university, Acharya N. G. Ranga Agricultural University (ANGRAU), was invited by the first author to visit Sri Lanka in January 2003, together with a senior rice researcher from Warangal research station. The second author had previously served for 10 years as director of the Lam agricultural research station in the Krishna and Godavari delta areas have 1.2 million ha of rice land. Despite initial skepticism, their observations of the phenotypical changes in rice that SRI methods induced and their discussions with farmers who had made the new system work for them with yields, even in the 10-15 t/ha range, persuaded them that SRI should be given a fair trial in Andhra Pradesh.

When Satyanarayana returned to AP state, he planned evaluating the new methods in the summer *kharif* (rainy) season of 2003. Demonstrations were set up in farmers' fields across all 22 districts of the state, 50 supported by ANGRAU and 250 by the AP Dept. of Agriculture. Widespread publicity was given to create awareness through the print media, TV and radio. In addition, an educational powerpoint presentation was circulated on SRI methods. As a result, additionally several hundred farmers tried SRI by themselves that first season.

The area sown under SRI ranged from 0.1 to 1.6 t/ha, with a majority of experimenting farmers planting around 0.4 ha. The trials were laid out on all types of soils and with all kinds of irrigation sources, using 12 different rice varieties (as chosen by the farmers). In all comparison trials, the same variety was used on both plots.

Wider spacing, at least 25x25 cm, with single young seedling was adopted by almost all the participating farmers on their SRI plots. However, most did not do weeding as recommended with a 'rotating hoe.' Also, their water management was not optimum in many places, either having dry periods too long or flooding. Even so, good results came without utilizing all of the practices fully or properly. Farmers came to realize the importance of each of these during the season and learned the skills needed, though this was too late for the standing crop. The consensus of farmers at post-harvest meetings was that there are no serious barriers to SRI adoption. Most became keen on using the whole system as recommended.

That these farmers participating in the trials were more progressive than the average, and were already using best practices, is seen from their 5.31 t/ha average yield with their usual methods. In AP, the average paddy yield is 3.87 t/ha, so their paddy production was 64% above the average. With SRI methods, on the other hand, their average paddy yield were 8.25 t/ha -- still 58% higher than these farmers got with their best use of recommended practices. The yield advantage with SRI that first season was almost 3 t/ha, with a reduction of 30-50% in water requirements and with other costs also being reduced (Satyanarayana, 2004).

The performance of SRI during 2003 kharif season varied widely given the range of practices used. Also, there were considerable differences between areas within AP as seen from an analysis of the first 134 trials reported (mostly shorter-maturing varieties) (Table 3). These differences give some indication about the importance of having well-drained paddy soils for rice production. In the coastal region where soils are more difficult to keep well-aerated, there was less yield advantage from SRI methods than obtained in the interior Rayalseema region, which is thought to have ‘poor soils’ for paddy because water is less abundant and most soils are less water-retentive. Half the farmers in Rayalseema region got yields >10 t/ha, as did one-quarter of the farmers in the intermediate Telengana region. This benchmark was surpassed by only one-seventh of the farmers in AP’s coastal districts, however.

Table 3: Results of SRI trials in Andhra Pradesh State, India, Kharif 2003

	No. of trials	Yield results > 10 t/ha	Range of results (t/ha)	Yield advantage (t/ha)
Coastal region (low-lying, wetter)	84	12	3.17-14.3	1.15

Telangana region (intermediate)	40	10	4.17-16.2	2.50
Rayalseema region (higher, dryer)	10	5	7.76-15.5	4.73

It was observed generally that rice plants under SRI developed extensive root systems and a large number of robust tillers. The increased number and larger size of panicles was responsible for the higher yields. These appeared to derive from having a more favorable soil environment which we inferred was created by a proliferation of soil microorganisms, thanks to the addition of organic matter, alternate wetting and drying, and churning of the soil for aeration.

SRI fields were uniformly greener than other fields. Some farmers applied urea at the time of panicle emergence in their anxiety to ensure higher yields from the excellent canopy. However, this application often affected the crop adversely, perhaps due to an inhibition of microbial activity. There was at first luxuriant growth, but ultimately the yield was not commensurate. Farmers who were willing to try out the new SRI practices as recommended found that they could get better results by applying less water and fewer chemicals.

Given the reduction in water and other inputs as well as the increased yield, considerable farmer enthusiasm was engendered for the new methods, making it easier to expand the trials in the following seasons. Data for four seasons from trials monitored and measured by ANGRAU staff and by Department of Agriculture extension staff are reported in Table 4. These encompass the results of 1525 on-farm comparison trials, managed by farmers under the supervision of either university or government extension personnel.

We noted that there were higher yields for both SRI and standard methods in the winter (*rabi*) season, when there is more control over water than in the summer monsoon and also greater diurnal temperature variation. For all the trials together, there was an average SRI yield of 8.73 t/ha compared with 6.31 t/ha with conventional methods, a yield advantage of 2.42 t/ha, with input and cost reduction. Compare this with the average paddy yield in AP of 3.87 t/ha.

Table 4: Summary of results reported in ANGRAU and Dept. of Agriculture on-farm trials

	Kharif 2003		Rabi 2003-04	Kharif 2004	
	ANGRAU	DOA	ANGRAU	ANGRAU	DOA
No. of trials	167	476	94	194	599
SRI yield (t/ha)	8.25	7.92	9.67	7.81	7.11
Conv. yield (t/ha)	5.31	5.48	7.12	5.94	5.40
Yield advantage	2.94	2.44	2.55	1.87	1.72
Highest yield (t/ha)	16.2		17.25		16.5

Source: Compiled by A. Satyanarayana from field reports from ANGRAU and DOA staff.

With such results, it should not be surprising that there is growing farmer enthusiasm and support for SRI in Andhra Pradesh. During 2004-2005, over 15,000 farmers practiced SRI voluntarily. One richer farmer was able to get an average harvested yield of 11.15 t/ha from an SRI extent over 40 ha in the West Godavari delta. This showed that with good organization of labor and logistics, SRI can be practiced on a large scale, although its benefits are relatively greatest for smaller and poorer farmers.

In this 2005 kharif season, the state's Department of Agriculture had 25,000 demonstration plots. In addition, the state's Department of Irrigation organized a campaign to extend SRI to 100,000 ha under its major irrigation schemes. The Department's concern is to reduce water demand so that a larger area of rice can be cultivated than would otherwise be possible with AP's growing water shortages. Any and all yield gains will be to the benefit of farmers. To spread SRI farmer-to-farmer, the Department recruited 1,000 experienced SRI farmers, supported by 25 NGOs, to carry knowledge of SRI to other farmers. Any additional yield benefit will represent an added success since water-saving alone can justify SRI use in AP.

In the 2004-05 rabi season, the international conservation NGO WWF sponsored an evaluation with 200 on-farm trials in different districts of AP, making water measurements to determine how much saving, if any, can accompany yield improvements. If significant savings are properly documented, WWF's program for conservation of aquatic ecosystems will publicize SRI in other countries to reduce environmental pressures that are created by current excessive and unnecessary water withdrawals for irrigated rice.

B. Tamil Nadu

In Tamil Nadu, SRI evaluation began on-station at TNAU, the state agricultural university, in 2000; and by 2002 there was enough evidence that top officials became willing to support its wider use. In the 2004 kharif season, TNAU supervised 100 on-farm comparison trials in the Tamiraparani river basin, as reported by the third author at the World Rice Research Conference in November last year (Thiyagarajan, 2004). The results in Tamil Nadu are consistent with what has been seen in AP. Thiyagarajan has been able to do a number of detailed evaluations of plant phenotype, soil biological changes and other parameters that help to account for the improved performance of rice plants with SRI methods.

The differences in microbial populations in the rice rhizosphere between rice plants raised conventionally, with anaerobic soil conditions and chemical fertilizers, and with SRI methods, having anaerobic soil and inorganic fertilization, were reported already Table 1 above. Other findings were that higher leaf area index (LAI) was higher and root volume at panicle initiation, flowering, and grain filling stages was greater (Nisha, 2002). Resistance to lodging and leaves remaining green up to harvest were both seen. Other comparative data from the TNAU evaluation that help explain the yield advantage of SRI widely seen in AP are given in Table 5. These data are consistent with the findings of Chinese researchers referred to in section III.C.

Table 5 : Physiological comparisons between conventional rice and SRI rice (means of values recorded at active tillering, panicle initiation, flowering and grain filling stages)

Season	Wet 2001-02		Dry 2002	
Variable	Conv.	SRI	Conv.	SRI
Total chlorophyll (mg g^{-1})	2.76	3.20	2.60	3.13
Soluble protein (mg g^{-1})	8.35	12.62	10.25	11.95
Nitrate reductase (mg NO_2 g^{-1} h^{-1})	12.42	18.11	11.74	16.70

Root CEC			8.40	11.23
Root cytokinins (pmol g^{-1})			56.77	72.47

Source: Nisha (2002).

These results were with a modified, partial use of SRI. The data calculated on labor and water productivity even without full use also showed some marked differences (Table 6). These were on-station trials. The on-farm evaluations in 2004 showed a reduction in water use of 40-50%, with an 11% reduction in the costs of production (Thiyagarajan, 2005). Yield increase data and economic analysis are shown in Table 7. The average net return per hectare with SRI methods was 114% higher than when farmers used their best conventional methods. These kinds of results were also seen in the on-farm comparison trials in Godavari delta, encouraging extension staff and farmers both to support a reorientation of rice production practices in the state. For several years, organic farmers in the Godavari delta have already been using SRI (Prasad et al., 2005).

Table 6: Labor and water productivity calculated for conventional and SRI methods

Season	Wet 2001-02		Dry 2002	
Factor of production	Conv.	SRI	Conv.	SRI
Labor productivity (US$ d^{-1})	3.29	4.64	3.46	3.91
Water productivity (kg rice m^{-3})	0.4	0.62	0.44	0.72

Source: Thiyagarajan (2002).

Table 7: Yield and profitability of conventional vs. SRI methods of production, 2004 on-farm comparison trials in Tamiraparani river basin (N=100)

	Conv.	SRI
Average yield (kg ha^{-1})	5657	7227
Minimum yield	3887	4214
Maximum yield	8730	10655
Gross revenue (US$ ha^{-1})	708	933
Costs of production (US$ ha^{-1})	466	414
Net revenue (US$ ha^{-1})	242	518
B:C ratio	1.52	2.25

Source: Thiyagarajan (2005).

C. Experience in Other Indian States

Other states in the south of India have also begun taking SRI seriously. In a report on SRI in *The Times of India* (September 29, 2004), Karnataka's Minister of Agriculture K. Srinivas Gowda was quoted as saying: "In successive years, farmers reeled under drought. Crop production came down drastically, upsetting the agroeconomy. With the rainfall pattern changing rapidly, the emphasis is on low-water-consuming methods. We will take up extensive training to popularize this new method [SRI]." The Department of Agriculture reported that with SRI, yields were raised from 3.75-4.5 t/ha to 6.25 t/ha, requiring 30% less water. Similar results in the state of Kerala during the kharif season 2004 have given impetus for its system of KVKs (Farmers'

Science Centers) through which agricultural extension is carried out to take up SRI as a major program.

The prominent NGO known as PRADAN is introducing SRI in very poor communities in northern states. Its success so far has been most dramatic in Purulia district of West Bengal, where the concepts and practices of SRI have been adapted to rainfed conditions since the trial villages where PRADAN is working do not have irrigation facilities. Over three seasons, the number of SRI users went from 4 to 150, which prompted the India Program of the International Water Management Institute (IWMI) to do an evaluation, sending a special team to the area.

In the one village studied which had fairly normal rainfall, the SRI yield was 49.8% higher than conventional yield that season; in other village with drought, the increase was 11.9% higher. With SRI, straw yield was 49.1% and 54.3% higher than conventional yield in the two villages, respectively. Straw has much value to poor villagers, so this was an added advantage of SRI.

The productivity of seed, a very important consideration for very poor villagers, was 845.6 kg per kg of seed in SRI cases vs. 61.2 kg per kg of seed with conventional methods, an 13.8-fold increase in seed productivity. Labor productivity was 46.20 rupees per day with SRI and 32.20 rupees per day with conventional methods, an increase of 43.5% in labor productivity.

To everyone's surprise, the IWMI team documented a 9% reduction in the number of days of labor required per hectare with SRI methods. This freed up labor that poor households could use profitably in other activities, thereby adding their household income. The direct increase in profitability with SRI was 67%, as the net return per acre with conventional methods was 4222.96 rupees, while that with SRI was 7052.14 rupees (all data from Singh and Talati, 2005).

To the extent that SRI concepts and practices can be adapted to rainfed cultivation, this can make an even greater contribution to poverty reduction and food security than what can be attained in irrigated paddy alone. An NGO partner in the Philippines, Broader Initiatives for Negros Development (BIND), in Negros Occidental, has averaged >7 t/ha with an upland adaptation of SRI using a popular traditional variety that has drought-tolerance (Gasparillo, 2003).

V. DISCUSSION

As noted at the outset and in Section III, SRI has been controversial in some circles because the results reported initially were so divergent from what had been observed and measured with rice grown under conventional management practices, particularly with continuous flooding and chemical fertilizer, plus agrochemical sprays against pests and diseases. In recent years, however, scientific recommendations have tended to encourage the transplanting of younger seedlings (2-3 weeks instead of 3-4 weeks or more, but not 1-2 weeks as recommended with SRI) and less dense plant populations (30-50 plants per m^2 although not yet 15-25 plants as SRI recommends).

The work of scientists in a number of countries who were willing to put SRI through systematic and fair evaluations is confirming what was previously reported, even some of the 'super-yields' as seen in Table 4. These are exceptions – and most attention should focus on the difference in averages. A yield advantage of 1.5-2.5 t/ha, with reduction in water use and costs and increase in profitability, should be more than sufficient to make SRI of interest to scientists and to farmers. The very high yields reported (the exceptions or outliers) are important to indicate the potential that is still available to be capitalized upon if 'E' can be suitably managed so as to extract the full productivity from existing 'G's in the 'GxE' equation discussed at the top of page 3.

A new line of criticism of SRI has emerged (McDonald et al., 2005) which concedes that SRI methods can be beneficial for small, poor farmers, enabling them to raise their productivity at low cost. But it maintains that SRI cannot outperform current 'best management practices' (BMP), maintaining that SRI is not anything new, but rather just BMP. As seen in Section IV, when SRI has been put head-to-head with BMP in India, in the hands of farmers who were already getting the most out of currently recommended modern practices, SRI added significantly – and at lower cost – to farmers' production.

In China, the yield differential in favor of SRI has been >3 t/ha in Sichuan province, as evaluated in on-farm comparison trials in 2004 by the Crop Research Institute of the Sichuan Academy of Agricultural Sciences (Prof. Zhang Jiaguo, pers. comm.). In Tamil Nadu, one farmer has already taken up SRI for seed production on an area of >10 ha, so its use is not limited to small holdings; and in Andhra Pradesh, a large farmer in the Godavari delta used SRI methods on 40 ha, getting a harvested average yield of 11.15 t/ha and further demonstrating the possibilities for large-scale production with these methods.

The McDonald et al. article claims to have analyzed 'the empirical record,' but in fact, the data base put together is not representative of SRI experience. Its conclusion that BMP give superior yields to SRI in head-to-head comparisons is contradicted by much larger data sets from India and China. However, proponents of SRI are not so concerned with whether it can improve upon BMP, which it does, but rather with improving the production, income and security of the millions of small farmers around the world who urgent need to raise the productivity of the land, labor, capital and water that they devote to rice production, for the sake of food security and poverty reduction. The benefits for environmental (soil and water) quality are a bonus. Experimental and on-farm trials have shown that SRI can increase rice productivity with a concomitant advantage of reducing the water use in irrigated rice cultivation.

REFERENCES

ATI. 2002. System of Rice Intensification Field Day Report. Agricultural Training Institute, Department of Agriculture, University of Southern Mindanao, Cotabato, Philippines.

Bhatta, M. R., J. Tripathi, R. B. Neupane, and Scott Justice. 2003. Short notes on SRI work carried out at National Wheat Research Program (NWRP), Rupandehi, Nepal. Unpublished NWRP report.

Cassman, Ken G. and Prabhu Pingali. 1995. Intensification of irrigated rice systems: Learning from the past to meet future challenges. *GeoJournal* 35, 299-305.

Cassman, Ken G., and Thomas R. Sinclair. 2004. Agronomic UFOs? ACSSA (Agronomic, Crop and Soil Science Alert), March, Elsevier.

Cantrell, Ronald P. and Gene P. Hettel. 2004. New challenges and technological opportunities for rice-based production systems for food security and poverty alleviation in Asia and the Pacific. Paper for International Conference on Rice in Global Markets and Sustainable Production Systems, FAO, Rome, February 12-13, 2004.

Dissanayake, Salinda. 2002. A policy-maker's perspective from Sri Lanka. In: N. Uphoff, E. C. M. Fernandes, Yuan L. P., Ping J. M., S. Rafaralahy and J. Rabenandrasana, eds., *Assessments of the System of Rice Intensification (SRI): Proceedings of an international conference held in Sanya, China, April 1-4, 2002*, pp. 26-28. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY.

Dobermann, Achim. 2004 A critical assessment of the system of rice intensification (SRI). *Agricultural Systems* 79, 261-281.

Frankenberger, William T., and Mohammed Arshad. 1995. *Phytohormones in Soils: Microbial Production and Function*. Marcel Dekker, New York.

Gani, Anischan, T. S. Kadir, Arti Jatiharti, I. P. Wardhana and Irsal Las. 2002. The System of Rice Intensification in Indonesia. In: N. Uphoff, E. C. M. Fernandes, Yuan L. P., Ping J. M., S. Rafaralahy and J. Rabenandrasana, eds., *Assessments of the System of Rice Intensification (SRI): Proceedings of an international conference held in Sanya, China, April 1-4, 2002*, pp. 58-63. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY.

Garg, Ajay, J-K. Kim, T. G. Owens, A. P. Ranwala, D. C. Yang, L. V., and R. J. Wu. 2002. Trehalose accumulation in rice plants confers high tolerance levels to different abiotic stresses. *Proceedings of the National Academy of Sciences* (USA) 99, 15898-15903.

Gasparillo, Robert. 2003. Growth and yield response of traditional upland rice on different distance of planting using Azucena variety. BIND document. Broader Initiatives for Negros Development, Bacalod City, Philippines.

Gayathry, G. 2002. Studies on dynamics of soil microbes in the rice rhizosphere with water-saving irrigation and in-situ weed incorporation. M.Sc.(Ag.) thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Hirsch, Robert. 2000. La riziculture malgache revisité : Diagnostic et perspectives (1993-1999). Agence Français de Développement, Antananarivo.

Kuswara. 2003. Dasar gagasan dan praktek tanam padi metode SRI (System of Rice Intensification). Paper for Field Foundation, Jakarta.

Laulanié, Henri. 1993. Le système de riziculture intensive malgache. *Tropicultura* 11, 110-114.

Li Xiaoyun, Xu Xiuli, and Li He. 2005. A socio-economic assessment of the System of Rice Intensification (SRI): A case study of Xinsheng Village, Jianyang County, Sichuan Province. Report for College of Humanities and Development, China Agricultural University, Beijing.

Lin Xianqing, Weijun Zhou, Defeng Zhu, and Yubin Zhang. 2005. Effect of SWD irrigation on photosynthesis and grain yield of rice (*Oryza sativa* L.). *Field Crops Research*, forthcoming.

LSU. 2005. Progress report: Community-Based Watershed Support Project. Farm and Resource Management Institute (FARMI), Leyte State University, Baybay, Philippines.

McDonald, A.J., P. R. Hobbs, and S. J. Riha. 2005. Does the System of Rice Intensification outperform conventional best management? A synopsis of the empirical record. *Field Crops Research*, in press.

Moser, C. M., and C. B. Barrett. 2003. The disappointing adoption dynamics of a yield-increasing, low external-input technology: The case of SRI in Madagascar. *Agricultural Systems* 76, 1085-1100.

Namara, R. E., P. Weligamage, and R. Barker. 2004. *Prospects for Adopting System of Rice Intensification in Sri Lanka: A Socioeconomic Perspective.* IWMI Research Paper 75. International Water Management Institute, Colombo.

Nisha, P. T. 2002. Physiologiocal responses of rice hybrids CORH2 and ADTRH1 to integrated crop management techniques. M.Sc.(Ag.) thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Peng Shaobing, J. Huang, J. E. Sheehy, R. C. Laza, R. M. Visperas, X. Zhang, G. S. Centeno, G. S. Khush, and K. G. Cassman. 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences* (USA), 101, 9971-9975.a

Prasad, Shambu, Prajit K. Babu and Andrew Hall. 2005. Assessing SRI as a Process: Evidence from India. IWMI-Tata Water Policy Research Highlight No. 22. International Water Management Institute India Program, Anand.

Randriamiharisoa, Robert, Joeli Barison, and Norman Uphoff. 2005. Soil biological contributions to the System of Rice Production. In: N. Uphoff et al., eds., *Biological Approaches to Sustainable Soil Systems*. CRC Press, Boca Raton, FL, forthcoming.

Rickman, Joe F. 2003. Preliminary results: Rice production and the System of Rice Intensification. Unpublished report, IRRI, Los Baños, Philippines.

Satyanarayana, A. 2004. Rice, research and real life in the field: Letter. *Nature* 429: 803.

Schmidt-Rohr, K., J-D. Mao, and D. C. Olk. 2004. Nitrogen-bonded aromatics in soil organic matter and their implications for a yield decline in intensive cropping. *Proceedings of the National Academy of Sciences* (USA), 101, 6351-6354.

Sheehy, John E., Shaobing Peng, Achim Dobermann, P. L. Mitchell, A. Ferrer, Jiangchang Yang, Yongbu Zou, Xuhua Zhong, and Jianliang Huang. 2004. Fantastic yields in the system of rice intensification: Fact or fallacy? *Field Crops Research* 88, 1-8.

Sinclair, Thomas R. 2004. Agronomic UFOs waste valuable scientific resources. *Rice Today*, July-September, p. 43. International Rice Research Institute, Los Baños, Philippines.

Singh, S.K. and Talati, J. 2005. Impact of the System of Rice Intensification (SRI) on Rice Yields: Results of a New Sample Study in Purulia District, India. IWMI-Tata Water Policy Research Highlight No. 47. International Water Management Institute India Program, Anand.

Stoop, Willem, Norman Uphoff, and Amir Kassam. 2002. A review of agricultural research issues raised by the System of Rice Intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-poor farmers. *Agricultural Systems* 71, 249-274.

Tao Longxing, Wang Xi, and Min Shaokai. 2002. Physiological effects of SRI methods on the rice plant. In: N. Uphoff et al., eds., *Assessments of the System of Rice Intensification (SRI): Proceedings of an international conference held in Sanya, China, April 1-4, 2002*, pp. 132-136. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY.

Thiyagarajan, T. M. 2004. On-farm Evaluation of SRI in Tamiraparani Command Area, Tamil Nadu, India. Powerpoint presentation at World Rice Research Conference, Tsukuba, Japan.

Thiyagarajan, T. M., K. Senthilkumar, P. S. Bindraban, H. Hengdijk, S. Ramasamy, V. Velu, D. Durgadevi, K. Govindarajan, R. Priyadarshini, C. Sudhalakshmi, P. T. Nisha, and G. Gayathry. 2002. Crop management options for increasing water productivity in rice. *Journal of Agricultural Resource Management* 1, 169-181.

Thiyagarajan, T. M., K. Senthilkumar, R. Priyadarshini, J. Sundarsingh, A. Muthusankaranarayanan, H. Hengsdijk, and P. S. Bindraban. 2005. Evaluation of water saving irrigation and weeder use on the growth and yield of rice. In: T. M. Thiyagarajan, H. Hengsdijk, and P. S. Bindraban, eds., *Transitions in Agriculture for Enhancing Water Productivity: Proceedings of an International Symposium held in Killikulam, Tamil Nadu, India, September 23-25, 2003*, pp. 3-18. Tamil Nadu Agricultural University, Killikulam, India, and International Rice Research Institute, Los Baños, Philippines.

Uphoff, Norman. 2003. Higher yields with fewer external inputs? The System of Rice Intensification and potential contributions to agricultural sustainability. *International Journal of Agricultural Sustainability* 1, 38-50.
Uphoff, Norman. 2005. Agroecological alternatives: Capitalizing on genetic potentials. *Journal of Development Studies*, forthcoming.
Verzola, Robert. 2003. System of Rice Intensification: Practices and results in the Philippines. Paper for Philippine Society of Soil Science and Technology annual meeting, May.
Wang Shaohua, Cao Weixing, Jiang Dong, Dai Tingbo, and Zhu Yan. 2002. Physiological characteristics and high-yield techniques with SRI rice. In: N. Uphoff et al., eds., *Assessments of the System of Rice Intensification (SRI): Proceedings of an international conference held in Sanya, China, April 1-4, 2002*, pp. 116-124. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY.
Yuan Longping. 2002. A scientist's perspectives on experience with the System of Rice Intensification in China for raising the yields of super-hybrid rice. In: N. Uphoff et al., eds., *Assessments of the System of Rice Intensification (SRI): Proceedings of an international conference held in Sanya, China, April 1-4, 2002*, pp. 23-25. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY.
Zheng Jiaguo, Xianjun Lu, Xinlu Jiang, and Yonglu Tang. 2004. The system of rice intensification (SRI) for super-high yields in rice in Sichuan Basin. Poster for 4th International Crop Science Congress, September, Brisbane, Australia (http://www.cropscience.org.au/icsc2004/poster/2/3/319_zhengjg.htm)