THE SYSTEM OF RICE INTENSIFICATION (SRI):
CAPITALIZING ON EXISTING YIELD POTENTIALS BY CHANGING MANAGEMENT PRACTICES TO INCREASE RICE PRODUCTIVITY WITH FEWER INPUTS AND MOR PROFITABILITY

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The System of Rice Intensification (SRI) is beginning to gain acceptance and spread around the rice-growing world. Five years ago, SRI was known and practiced only in Madagascar, the country were it was developed about 20 years ago by Fr. Henri de Laulanié (Laulanié, 1993). Today, its benefits have been demonstrated in at least 21 countries. This World Rice Research Conference panel reviews experience with SRI in Bangladesh, China, Cuba, India, Indonesia, and Philippines. This set of countries includes the three with the largest annual rice production, and together they produce and consume over 2/3 of the world's rice, 68.8% according to IRRI data (www. irri.org/science/ricestat).

I. WHAT IS SRI? Put most succinctly, the System of Rice Intensification is a set of principles and associated methods for getting more productive ***phenotypes*** from any existing ***genotype*** (i.e., variety) of rice, modern or traditional, improved or local, hybrid or landrace. This is accomplished with SRI (a) by inducing greater ***root growth***, and (b) by nurturing more abundant and diverse populations of ***soil biota***. These include microbes -- bacteria, fungi and actinomycetes -- and all kinds and sizes of fauna in the soil food web -- protozoa, nematodes, earthworms, etc. (Wardle, 2002). Root growth and soil biota are promoted by managing rice plants, soil, water and nutrients differently.

For centuries, even millennia:

- We have been ***flooding*** rice plants, thereby constraining root function so that as many as three-quarters of the roots have degenerated by the start of the plants' reproductive period (Kar et al., 1974);
- We have ***crowded*** plants together, putting 3-6 in a hill, and spacing hills close together, thereby inhibiting the potential growth of the plants' canopy and their root systems;
- Now we are applying various ***fertilizers*** and ***agrochemicals*** that have impacts on the populations of soil biota that provide many services to plants: N fixation, P solubilization, protection against diseases and abiotic stresses (Tan et al., 2002; Doebbelaere et al., 2003)

SRI methods restore for rice plants above-ground and below-ground environments that are more favorable for the plants' growth.

II. AN APPARENT PARADIGM SHIFT: The Green Revolution was very successful in raising rice and other grain production in the latter third of the 20th century. The conceptual framework and strategy of the Green Revolution had strong scientific foundations and produced much-needed results. However, this does not mean that it is the only or ultimate methodology for improving agricultural production. Its paradigm consisted of two complementary strategies:

- ***Making changes in the genetic potential*** of plants (or animals), in particular to make them more responsive to certain inputs; and then
- ***Increasing the use of external inputs*** -- more water, more fertilizer, more use of insecticides and other biocides.

These efforts achieved demonstrably greater production in many countries around the world; however they achieved this success at higher, and now growing, costs.

Of particular concern for economic and environmental reasons is the dependence on inorganic N for achieving greater output. In China, over-application of such fertilizers has become a serious problem as farmers have responded to diminishing returns to N fertilizer application by applying larger and larger amounts. Forty years ago, the addition of 1 kg of N fertilizer could produce 15-20 kg of additional rice; this ratio is now only about 1:5 (Peng et al., 2004). Groundwater supplies are reaching toxic nitrate levels in many parts of China, even 300 ppm in areas where annual application fertilizer application rates have exceeded 500 kg ha^{-1} (Shaobing Peng, personal communication, citing work of Jerry Hatfield, USDA). The U.S. Environmental Protection Agency considers 50 ppm of nitrate to be the minimum acceptable level in drinking water supplies, and even 10 ppm can cause serious health problems for newborns. The use and overuse of N fertilizer needs to be curtailed in much of China but also in many other areas.

Given the declining marginal productivity of N fertilizer, it has been estimated that to achieve the 60% increase in rice production that the world needs by 2030, there will need to be a ***tripling*** of N fertilizer application (Cassman et al., 1998). This can be hardly acceptable either economically or environmentally. Few producers will be able to afford such an increase in cost of production. There will be large environmental impacts in terms of energy requirements for producing so much additional fertilizer. Moreover, there would be adverse impacts on soil and water quality, as well as an increase in greenhouse gas emissions from rice paddies if continuously flooded. Such a scenario makes it essential to consider mobilizing more of the N that plants need through biological processes that would be cheaper and ecologically more benign.

At the same time, the Green Revolution has been a 'thirsty' technology, requiring substantial increases in water for irrigation. In some of the most intensively cropped areas in China and India, where groundwater is used for irrigation, water tables have been falling at an alarming rate, sometimes 1 m yr^{-1} or more. Finding ways to reduce the agricultural (and particularly rice) demand for irrigation water will be crucial for the sustainability of production in the future. Developing better plant root systems is a biological strategy to address water scarcity a less-costly alternative to relying on engineering solutions to increase supply or control its distribution better, e.g., through microirrigation.

SRI relies on neither of the two strategies of the Green Revolution for its remarkable increases in production. It does not require the use of new varieties, although we find that some varieties respond better than do others to SRI management practices. The highest SRI yields, all those over 15 t ha^{-1}, have come from hybrids or high-yielding varieties (HYVs). However, since some traditional varieties have given yields in the 6-10 t ha^{-1} range, and their grain commands a higher market price, these can in fact be more profitable for farmers.

Because SRI rice paddies are not kept constantly inundated, maintaining at least intermittent soil aeration, the methods achieve higher yields with less water, 20-50% less. Also, SRI does not require mineral fertilizer since although this will increase yield with SRI practices, the highest SRI yields are obtained with compost, i.e., any decomposed biomass. Further, agrochemicals are less used because SRI rice plants are enough healthier and resistant to pests and diseases that farmers do not find the use of biocides to be economic. All this means that SRI operates along very different lines from the Green Revolution.

The results of SRI methods shown in Table 1 below, reproduced from the 2003-2004 Annual Report of the M. S. Swaminathan Research Foundation, are typical of what is usually seen:

> Due to poor monsoon only two farmers could be identified to carry out the demonstration. The necessary technical details were given to the farmers, and the trial was carried out through close monitoring and guidance, using the paddy variety called ADT 36. Farmers from the Vannampatti village as well as rice-growing farmers in other regions were taken to the field during the different phases of crop growth. Finally farmers evaluated the SRI paddy in comparison with conventional cultivation. The results are given in [the] Table [below]. The Table shows that in both the fields the SRI method was found superior to the conventional cultivation method. An increased yield of more than 35-50 percent [actually, 85-140%] was noticed, along with decrease in seed rate as well as field duration.[1] The nursery management, as well as related cost, was also very low compared to farmers' practice. This system has gained momentum among the farmers, and nearly 45 farmers [in this village] have shown interest in trying out this new method in their own fields in the coming season (MSSRF, 2004: 80-81).

While labor requirements shown for the three main operations were 38% higher with SRI, the returns to labor (kg day^{-1}) were 73% greater. These figures are for the first season of SRI practice; usually SRI labor diminishes as farmers gain familiarity and skill with the methods.

Table 1. Comparison of SRI and conventional methods of paddy cultivation

Parameters	SRI farmer I	SRI farmer II	Conv. practice
Total tiller number	26	45	18
Productive tillers	24	38	13
No. of grains/plant	230	275	220
Yield (kg/ha)	7,500	9,750	4,056
Labor requirement			
Planting		40	25
Weeding		30	25
Harvesting		20	20
Seed rate (kg/ha)	5	6	30

Source: MSSRF (2004: 80)

[1] It has been claimed, in criticism of SRI yield reports, that SRI rice takes longer to mature (*Nature*, March 25, 2004). However, the observation here is consistent with many other observations in Cambodia, India, Nepal and elsewhere that SRI rice matures more quickly, 5- 10 days, even up to 20 days sooner, than conventionally grown rice.

The two main components of the SRI paradigm, not depending on either genetic improvement or external inputs, are:

- Promotion of large and healthy ***root systems***, by keeping soil aerated and well composted, with wide spacing between plants (and use of young seedlings being recommended); and
- Increasing the abundance and diversity of ***soil organisms*** that provide the plants with nutrient access in return for getting their own nutrition via root exudation; they also provide various protective and other services to the plants.

SRI does not replace the Green Revolution but offers some alternative methods to raise crop production, particularly for farmers who have difficulty affording the inputs that Green Revolution technology requires, or who face water shortages, or who want to avoid risks such as lodging, desiccation or cold damage that adverse climates can cause. The larger, deeper root systems induced by SRI practices offer protection against the latter.

III. SCIENTIFIC SUPPORT FOR SRI: The rejection of SRI by some scientists thus far has been mostly on *a priori* grounds, rather than putting SRI methods to the empirical test that should be the basis for resolving scientific disputes. Leading scientific institutions in China, India and Indonesia, the three largest rice-producing countries, have concluded after several years of evaluation that SRI methods do indeed offer substantial and multiple benefits, as seen from the papers being presented on this panel.

My powerpoint presentation for the WRRC panel provides pictures of rice plants that make clear even without numbers that SRI methods produce remarkable changes in rice plant phenotypes. It also reports data from research that measured and documented these phenotypical differences, from scientists at the China National Rice Research Institute (Tao et al., 2002; Tao, 2004; Zheng et al., 2004), the Sichuan Academy of Agricultural Sciences (Zheng et al., 2003), and Nanjing Agricultural University (Wang et al., 2002).

Figure 1 on the next page from Tao (2004) summarizes what can be seen from these data. It tracks the relative changes in the dry weight of different plant organs (stem, sheath, leaf and panicle), as well as senescence of leaf and sheath, as rice plants move through their different stages of growth when cultivated under SRI or standard (control, CK) conditions.

Table 2 and Figure 2 give data from Barison (2002) on the differences in root growth (root length density, measured in cm cm^{-3}) and in the relation between grain yield and nutrient uptake (shown for N, though similar relations were measured for P and K). The analysis compares rice plants grown under SRI or conventional conditions on farms in Madagascar where farmers were using both methods (N=108) so that the influence of inter-farmer and inter-farm differences could be minimized. The data were analyzed using the QUEFTS model as explained in the thesis. For reasons still to be examined, SRI plants achieved roughly twice the grain production from given uptakes of N (same for P and K). The phenotypical differences in SRI plants are apparently induced by a combination of internal, physiological factors and external rhizosphere influences.

Recent USDA research (Kumar et al., 2004) has shown how gene expression of DNA in leaf cells, specifically for senescence and disease resistance, can be affected by changes in the management of plants as well as the soil, water and nutrients that they utilize. The main observable difference between the plants grown under more 'natural' conditions (i.e., vegetative mulch and reduced N fertilizer applications) and those grown under more chemically contrived conditions (plastic mulch and higher N fertilizer application) was reported to be in the size and color of plant roots.

Figure 1. Relative and absolute comparisons of SRI and control (CK) plants of same variety in terms of dry weight of different plant organs at different stages of plant growth (Tao, 2004)

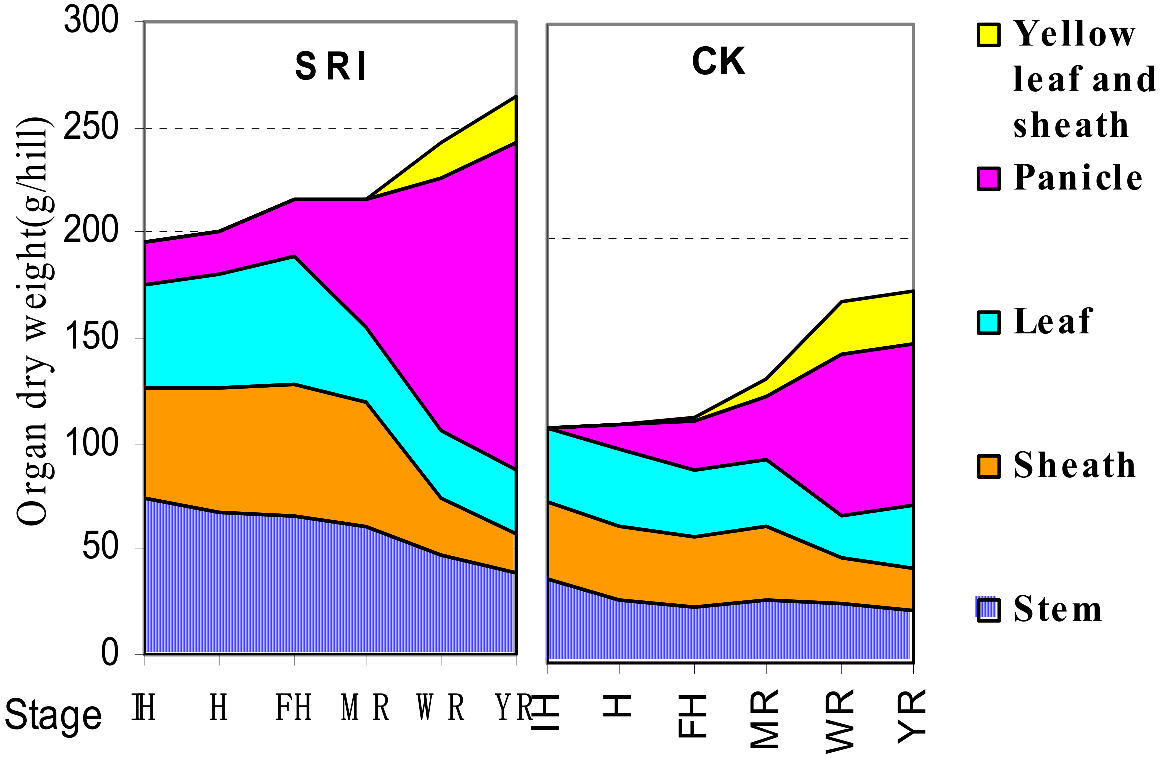
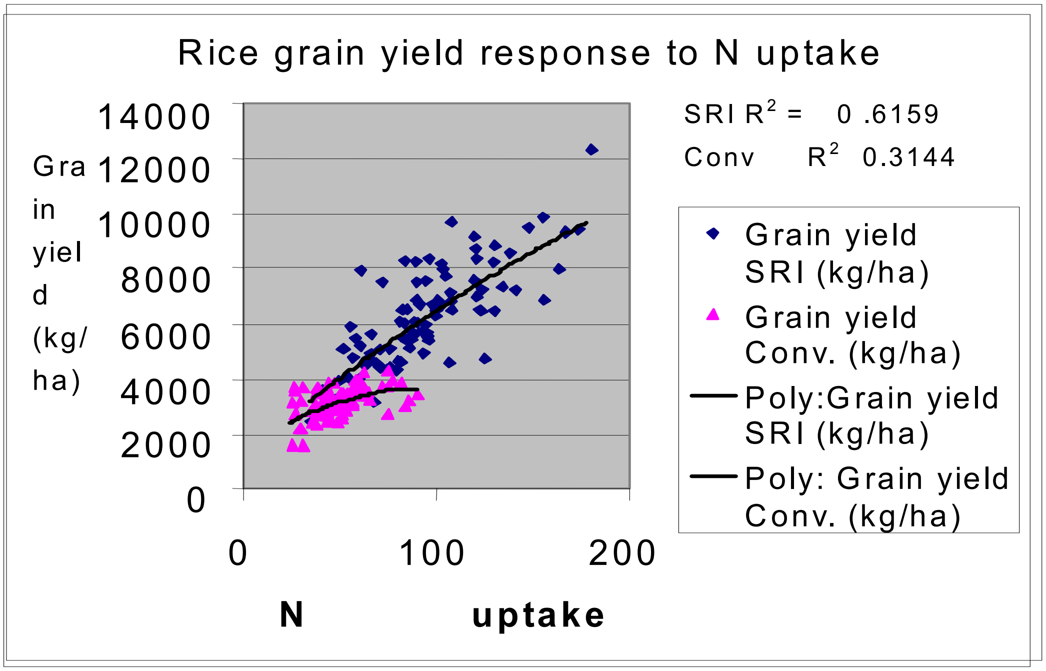


Table 2. Root length density (cm cm^{-3}) under SRI, SRA and farmer practices. Measurements from replicated on-station trials, Beforona, Madagascar (Barison, 2002)

Treatments	Soil layers (cm)					
	0-5	5-10	10-20	20-30	30-40	40-50
SRI with compost	3.65	0.75	0.61	0.33	0.30	0.23
SRI without compost	3.33	0.71	0.57	0.32	0.25	0.20
SRA with NPK and urea	3.73	0.99	0.65	0.34	0.18	0.09
SRA without fertilization	3.24	0.85	0.55	0.31	0.15	0.07
Farmer practice	4.11	1.28	1.19	0.36	0.13	0.06

Note: SRA = *Système de riziculture ameliorée* (system of improved rice cultivation), which is the modern set of practices developed and recommended by government researchers.

Figure 2. Linear regression relationship between N uptake and grain yield for SRI and conventional methods, using QUEFTS modeling methodology (Barison, 2002)



Note: For this analysis, rice plants were sampled and analyzed from SRI and conventional fields on 108 farms in Madagascar where farmers were using both methods

These and other data sets demonstrating that SRI plants have very different characteristics, structurally, physiologically and functionally, from the same varieties grown under standard irrigated rice cultivation conditions, do not give us explanations for the sources of the differences. There is, however, visual and measured evidence of differences in root size (large vs. small) and health (inferred from the color of roots, light vs. dark, indicating little or much necrosis) which points to the importance of this crucially important organ, which has been given relatively little attention in rice science as indeed in most crop research.[2]

Evidence on the contribution of soil organisms to improved rice plant performance with SRI methods is harder to come by and is just beginning to be gathered and assessed. The analysis by Randriamiharisoa (2002) of changes in *Azospirillum* populations living in rice roots associated with SRI practices compared to conventional practices in replicated trials showed a dramatic correlation, as reported in Uphoff (2003).

- Conventional methods used on clay soil plots without any nutrient amendments produced 1.8 t ha^{-1} compared to 6.1 t ha^{-1} with SRI methods and no amendments. In the respective sets of plants sampled, the counts of *Azospirillum* in root tissues were 65 x 10^3 vs. 11 x 10^5.

[2] Only about 5% of the most complete encyclopedia of rice science (Matsui et al., 1998) is devoted to roots. In the most widely cited text on rice (DeDatta, 1981), there is not a single entry on roots in 16 pages of index; there is a sub-entry on rhizosphere that refers to a sentence which says that there is a rhizosphere around rice plant roots. Root growth has even been regarded by some scientists as a negative factor because it putatively lowers the Harvest Index (the portion of the total biomass going into the edible portion). In fact, calculations of HI seldom include root weight.

- On plots where NPK fertilizer was used with SRI methods, the yield went up to 9.0 t ha^{-1}, a 50% increase. However, the *Azospirillum* count came down by 60%, to 45 x 10^4, which indicated that the plant was relying more on *inorganic* N sources for this increase.
- Where compost was used with SRI methods, the yield went even higher, to 10.5 t ha^{-1}, and the *Azospirillum* count of 14 x 10^5.

More work needs to be done to determine whether this remarkable correlation represents a direct causal connection: a more than five-times increase in yield is associated with a 21-fold increase in the endophytic population of this N-fixing bacteria. The research did not assume that the yield effect could or should be attribute entirely or solely to *Azospirillum*. Rather, this organism was regarded as indicative of changes in microbiological activity in the soil and plant more generally in response to alternative management practices.

The recurrence of much larger root growth with SRI methods, associated with aerated soil and greater root exudation, suggests that this root growth may be being stimulated and supported by the production of phytohormones by aerobic bacteria and fungi. These have been known for decades to produce auxins, cytokinins and other plant growth-promoting compounds in the rhizosphere (Frankenberger and Arshad, 1995). This is another hypothesis to be tested.

There are still other possible explanations for SRI performance, for example:

- Research on the effect of rice plants taking up N in a combination of nitrate and ammonium forms, which is possible when rice paddy soils are not kept flooded all the time, vs. taking up the same amount of N as ammonium, which is the case continuous inundation, has shown to increase yield by 40-60% (Kronzucker et al., 1999).
- In the realm of soil microbiology, protozoa are known to contribute significantly to the biological cycling of nitrogen, producing as much as 20-40% of the N that plants take up (Bonkowski, 2004). We have no studies yet on the role of protozoa and non-parasitic nematodes in enhancing soil N availability when SRI methods are used. However, we know that these methods induce larger canopies and root systems, which would produce more root exudation. This would in turn support larger populations of bacteria living on the roots, and these bacteria would support larger populations of protozoa that 'graze' on the bacteria and excrete 'excess' N in the root zone, because protozoa have a lower C:N ratio than the bacteria that they are ingesting. This would increase the supply of N readily available for plant uptake.

SRI raises more questions than it answers so far, which should be received as good news by researchers because SRI creates a larger and very interesting research agenda. How the benefits are achieved should be studied and evaluated so that SRI methods can be improved upon, since they have been derived inductively, from observation and by trial and error. Not having been guided by theory, SRI should be amenable to further development. Also, possibly SRI will encounter some problems or limitations in the future, which researchers could identify and develop counter-measures for. Further, the basic mechanisms involved in SRI -- enhancement of root growth and soil biological communities -- might improve the performance of other crops if adequately understood.

IV. SRI EVALUATIONS: Even while national rice research programs in China, India, Indonesia and other countries have welcomed this opportunity, there has been a mixed and sometimes hostile reception of SRI in some scientific circles. At the same time that a number of national rice programs have been demonstrating the merits of SRI, a series of published articles have attacked SRI this past year.

- SRI has been characterized as a “niche innovation," suitable and beneficial only for a narrow range of agronomic conditions (Dobermann, 2004).
- This conclusion has been broadened to state that SRI "has no major role in improving rice production generally" (Sheehy et al., 2004).
- SRI has been described as "voodoo science” by Cassman and Sinclair (2004), suggesting that SRI has no basis in fact and is a distraction from more serious and productive research.
- "Discussion of SRI is unfortunate because it implies SRI merits serious consideration. SRI does not deserve such consideration" (Sinclair, 2004).

These critiques have not been based on any systematic, empirical evaluation of SRI methods under field conditions, however. Paradoxically, the results obtained from SRI methods on farmers' fields have often been better than those achieved on research stations. This reverses the usual situation where farmers have some difficulty in replicating researchers' results. This reversal is what first suggested that we should look more closely at differences in soil biology, given that the more intensive and sustained on-station use of chemical fertilizers and biocides could have affected soils' ability to respond to SRI management of plants, soil, water and (organic) nutrients.

There is only fragmentary evidence supporting this proposition, but it is consistent with what has been documented in the scientific literature about plant-soil-biotic interactions. If this explanation is not sufficient (it certainly is at least partially correct), other explanations will need to be found for the large phenotypical changes that have been seen and measured by scientists and that have been observed by and are benefiting farmers in many countries.

The most impressive SRI yields, those over 15 t/ha, have been challenged (by Dobermann, 2004, for example) as being beyond some biological maximum. This focus has, unfortunately, deflected attention from the very substantial average yield increases of 30-100% achieved now in numerous countries -- with a reduction in inputs and in farmers' costs of production, thereby raising income and profitability. As can be seen in the papers by Zhu and Satyanarayana, the high yields reported originally from Madagascar are now being replicated in China and India.

In general, yield while simple and summary as a criterion for evaluation is *not* the best criterion to consider when evaluating alternative crop production systems. ***Factor productivity*** is more significant: kg of rice produced per day of labor, per cubic meter of water, and per rupee, RMB, rupiah, thaka, peso, etc. By such measures, SRI excels even more than in terms of yield because given its input-reducing paradigm, when yield is higher, then factor productivity increases even more, to the benefit of farmers and the country.

There have recently been several independent evaluations of SRI completed that should satisfy skeptics that the data reported by Tefy Saina, CIIFAD and their NGO, university and other partners in different countries have been valid. These evaluations were done in countries not covered by this panel, so their 'bottom-line' findings are summarized below:

Cambodia**:** GTZ commissioned an evaluation of SRI here in April 2004. The team constructed random samples of 400 SRI farmers and 100 non-SRI farmers in 5 provinces and surveyed them, supplementing this information with group discussion (Anthofer et al., 2004). Findings included:

- ***Yield:*** Even with incomplete use of SRI practices, the SRI farmers averaged a 41% increase, "achieved over a wide range of different agroecological environments, individual management practices, and varieties." The differential held up across all 5 provinces and over all 4 years for which data were obtained.[3]
- ***Net returns per hectare:*** Given the lower costs of production, farmers' income went up by 74%, again even with less than full use of SRI methods.
- ***Labor requirements:*** An analysis of labor inputs found SRI to be 'labor-neutral,' 305 hrs ha^{-1} for SRI production vs. 302 hrs ha^{-1} for conventional methods. Farmers preferred the former because the reduction of 10 hrs ha^{-1} for SRI transplanting (given the much smaller number of plants involved) eased household labor requirements at a time of peak labor demand. The increased need for weeding with SRI came at times when labor was more slack.
- ***Other findings:*** The report documented reductions in fertilizer and agrochemical use and increases in the application of compost. Women's labor requirements were eased by the reduction in time needed for transplanting, so a favorable gender effect was noted. 17% of the farmers interviewed had already converted their whole rice area to SRI cultivation.

The conclusion was that "Despite many open questions still to be investigated by researchers, *SRI has proven to be a worthwhile practice to be promoted and should be included in any rice intensification program.* Although some constraints may limit its use on larger proportions within a farm and certain farming households might not be able or willing to apply it, its potential should not be missed" (p. 45, emphasis in original). There has been little if any disadoption of SRI in Cambodia as the number of users, starting with 28 in 2000, has expanded to at least 20,000 in 2004, and possibly again as many not associated with any NGO or donor program.

Sri Lanka**:** A research team for the International Water Management Institute (IWMI) undertook an evaluation of SRI in this country at the end of 2002, surveying 60 SRI farmers and 60 non-SRI farmers chosen at random in 2 districts (Namara et al., 2004). As in the Cambodia evaluation, the 'SRI farmers' were not yet using all of the recommended practices. Of the non-users, 75% said they intended to practice SRI in the future, and they reported that 69% of farmers in their village had a favorable opinion of SRI (only 9% had an unfavorable attitude).

- ***Yield:*** These were 42-56% higher than for non-SRI farmers, even when not using SRI fully.
- ***Net returns per hectare:*** These were almost double those for SRI farmers compared with the income of farmers not using SRI methods.
- ***Labor productivity*** (kg/day): 50-62% higher, depending on the season, dry or wet.

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[3] The report states: "It is often claimed that SRI is a promising technology [only] for poor farming environments, while at locations with better resource endowments, other technological options are superior over SRI (Dobermann, 2004). Results of the adaptability analysis conducted separately for each province demonstrate the opposite." Regressions of 'with SRI yield' on 'before SRI yield' ($R^2 = 0.9758$ and 0.9554, significant at the .001 level) showed yields with SRI methods going up proportionally to yield before SRI, which means that SRI performed better in all environments, but did better where underlying endowments were better, contrary to the claim of Dobermann.

- ***Water productivity*** (kg/water application): about 90% higher with SRI cultivation methods.
- ***Risk:*** SRI has been characterized as riskier for various reasons. However, the IWMI analysis found that SRI farmers had net economic losses in only about 2% of their seasons, while conventional farmers, with lower yields and higher costs, had net losses in about 16% of theirs. The GTZ evaluation in Cambodia also found that SRI is considerably less risky for farmers in both agronomic and financial terms.
- ***Other findings:*** One of the early contributions to the literature on SRI raised a concern that its *adoption* may be easier for richer farmers (and harder for poorer ones), given cash liquidity constraints affecting the latter, and also that there may be significant *disadoption* of SRI (Moser and Barrett, 2003). The IWMI evaluation found, however, that poorer and richer farmers were *both* more likely to adopt SRI than were middle-range farmers, and further, that once they start with SRI, poorer farmers are *less* likely to disadopt.

The papers prepared for this panel give additional data on the spread and results of SRI in other rice-growing countries.

V. NEGATIVE ASPECTS OF SRI: Any innovation must have some adverse characteristics. These, however, have been surprisingly few, and several are receding now that experience is being gained with the methods.

A. Labor Requirements: The initial constraint for adoption has been SRI's greater labor intensity when starting to use the methods. There is an initial period when farmers are learning to use them when labor requirements can be 25-50% more hectare^{-1}. A study of 108 farmers who were using both SRI and conventional rice-growing methods in Madagascar found that the median increase in labor required with SRI was about one-third. However, by the 4th year, SRI required 4% less labor ha^{-1} and by the 5th year, 10% less (Barrett et al., 2004). This reflects socio-economic circumstances in that country and is not necessarily the norm elsewhere.

The GTZ evaluation of SRI in Cambodia, as seen above, found SRI to be, overall, *labor-neutral*. Beyond this, there are reports from China that farmers there are making SRI into a *labor-saving* methodology. They use herbicides rather than do hand weeding to reduce labor requirements, and they have learned to make their crop establishment much quicker with SRI. The most detailed information we have is from a study of SRI adoption in Xinsheng village of Sichuan province (Li et al., 2004). There, SRI use went from 7 farmers in 2003 to 398 farmers in 2004, with average size of SRI plot going from .07 mu in 2003 to .99 mu in 2004. Xinsheng farmers identified labor-saving as the main advantage of SRI, both in survey questionnaires and in focus groups.[4] So, SRI is not necessarily labor-intensive. When farmers can reduce labor inputs as well as water (a 43.2% reduction in water used mu^{-1} was calculated in the Xinsheng study) and seeds and other input costs, at the same time getting higher yields, SRI becomes very attractive.

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[4] The popularity and rapid uptake of SRI was surely influenced by the fact that 2003 was a drought year in Xinsheng village. Average yield with standard methods was 6.0 t ha^{-1} in 2002. These methods produced only 4.5 t ha^{-1} in 2003, whereas SRI methods gave 6.6 t ha^{-1}, 10% more than the previous year's 'normal' yield and 47% more than standard methods under drought conditions. In 2004, the SRI yield was 7.6 t ha^{-1} while standard methods produced 5.6 t ha^{-1}. The SRI yield was obtained with less labor and also less water. The agency that was introducing SRI was also promoting purchase of more expensive new-variety seed and more use of chemical fertilizer and sprays. So costs of production did not decline as much as they could have, and farmers' net income/mu went up only 52.7% at constant prices between 2002 with conventional practices and 2004 using SRI methods.

B. Water Control: This is the most objective and serious limitation on SRI that we have seen so far. To get best results with its methods, farmers should have enough water control that they can apply small amounts on a regular basis and be assured of having a reliable water supply for this at least through the first month, until the root systems are well established. Where farmers are constrained by field-to-field (cascade) systems of irrigation and have no independent control, or are confronted with unavoidable flooding as in many rice areas during the monsoon season, SRI may not be suitable, or the yields will be less than otherwise obtainable.

Water control can be obtained in many places where it is absent through investment in physical infrastructure or through farmer organization and cooperation. SRI creates incentives for the latter, and can assure a good economic return for the former. So lack of water control in many cases need not remain a constraint on SRI adoption. It is also possible to get improved yield even without water control, as seen in a report from Cambodia.[5] Probably the best situation for SRI adoption is where rice is irrigated with groundwater, because this gives farmers control over their water supply and also creates incentives (financial rewards) for reducing water application.

C. Farmer Training: This requirement can be regarded as a constraint and a cost, since farmers must be able and willing as well as educated to use the new practices. Fr. de Laulanié, however, regarded SRI as a methodology for human resource development, not as a technology to be 'transferred.' He advocated involving farmers in experimentation with the new methods, adapting the practices to suit their local conditions, so that farmer knowledge and confidence would be built up through the experience of using SRI. Thus, most persons working with SRI have seen this process of farmer education as a benefit, not just as a cost. SRI can be promoted in a top-down manner, but we prefer that it be disseminated in ways that are participatory and that build up human capabilities for decision-making and management.

We have been encouraged by -- and SRI has benefited from -- the enthusiasm and innovation of many farmers once they have become acquainted with the new methodology. In the powerpoint presentation, a number of pictures are shown of farmer inventions for saving labor with SRI:

- A roller-marker for imprinting a geometric grid pattern on the surface of paddies, which speed up transplanting operations,
- A 'triangular' planting pattern that increases plant population m^{-2} by 50% while maintaining the wide spacing that creates 'the edge effect' for the whole area (Yuan, 2002),
- Mechanical seeders devised for direct-seeding of germinated seed that makes transplanting unnecessary,
- Widening or motorizing weeders that reduce the time for this labor-demanding process, and
- A hybrid 'seeding-weeding' process that reduces labor requirements considerably.[6]

[5] Farmers in a village where ADRA, an international NGO, was working were encouraged to try SRI. Because they are so poor and insecure, getting only 1 t ha^{-1} average rice yield and having no water control, ADRA had to assure the 100 farmers willing to try SRI that it would compensate them for any losses incurred. When the SRI crop was harvested, the average yield was 2.5 t ha^{-1}, and not a single farmer asked for any compensation. The other 400 farmers in the village said that they would try SRI in the next season (Roland Bunch, email communication, May 17, 2003).

[6] This modification of initial SRI techniques by farmers in India and Sri Lanka may prove to be one of the most popular innovations. It broadcasts either pregerminated seeds or young seedlings on muddy but not flooded paddies. With pregerminated seed, the seeding rate is about 25 kg ha^{-1} rather than the 5-10 kg ha^{-1} rate used with original SRI.

Many more innovations will surely be made in the years ahead. The point is that farmers are not treated as recipients of a new technology but as partners in the development and application of new ideas for improving rice production.

SRI is actually very simple to learn for anyone who already knows how to grow irrigated rice. Any farmer who has experience with rice and is motivated to try something new can master SRI practices simply from an explanation of the reasons for making the changes and with a demonstration of the techniques. Simple diagrams or a video are sufficient to disseminate the methods if they are well explained. Farmer-to-farmer dissemination is the most effective, and cost-effective, way to spread SRI.

D. Disadoption: There has been concern that SRI is too difficult for farmers to continue even if they take it up and that a high level of technical support is necessary (Moser and Barrett, 2003). However, this problem appears to be fairly localized for the Madagascar villages studied. A report prepared for the French development agency in 2000 on its small-scale irrigation project in the central highlands of Madagascar, which would include some of the communities included in the Moser-Barrett study, found rapid spread of SRI even without significant technical support for farmers, as seen in Table 3. The yield levels reported by Hirsch (2000) are quite similar to those that we recorded around Ranomafana National Park to the east of this highland area during the same five-year period. Interestingly, the massive disadoption appears to have been for SRA, the government-promoted system of modern rice production relying on fertilizer and other inputs.

Table 3. Rice yields around Antsirabe and Ambositra on high plateau in Madagascar, 1994/95-1998/99 (Hirsch, 2000: Annexes 13-14)

Cropping season	**Peasant practice**	**SRA**	**SRI**
Area (ha)			
1994/95	1875.5	4361.9	34.5
1995/96	1501.5	5224.5	88.7
1996/97	1419.0	3296.7	226.7
1997/98	3122.0	2893.8	229.7
1998/99	2768.1	2628.0	542.8
Yield (t ha^{-1})			
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 yield	**2.36**	**3.77**	**8.55**

Then 10-15 days later, when the plants are established, they are radically thinned by doing a weeding with a rotating hoe as would be done normally with a transplanted crop. This makes perpendicular passes all across the field, figuring a plant spacing of about 25 x 25 cm. All but the plants growing at the intersections of the weeding passes are eliminated. This establishes an SRI crop without having to construct a nursery and without transplanting work.

The papers prepared for this panel provide new information on the expansion and/or contraction of SRI use in half a dozen countries where it is being introduced. They will give evidence on whether disadoption is likely to be a constraint with SRI.

E. Pest Problems: When the growing environment of rice is changed, one can expect that this may alter and unbalance ecological dynamics so that new pest problems can arise. This seems to have been the case in Thailand and possibly Laos, where at the first international conference on SRI, the SRI results reported from the two countries were mixed and on average lower than those reported from other countries (Uphoff et al., 2002). Trials in Thailand in several cases given lower yield with SRI methods, and Laos results were only in part encouraging. A half dozen SRI trials sponsored by different organization cooperating with the IRRI/Laos program in 2002 also gave mixed results, half showing positive results (and some up to 6-7 t ha^{-1}, double the usual yield) and half showing SRI yields lower than controls (Goeppert, 2003). Subsequent research on SRI soil dynamics in Thailand has identified that *nematodes* can be a problem with SRI production when the soil is not kept flooded as these soil mesofauna can increase under more aerobic soil conditions (Janice Thies, personal communication). There could be similar soil ecology in Laos that would account for the poorer SRI results in some case; the better results could be in soils where nematodes are not (yet) a problem.

Interestingly, this effect has not been seen in neighboring Cambodia or Myanmar, where SRI methods usually double rice yields or more. If nematode damage does indeed account for poor SRI performance in parts of Southeast Asia, and elsewhere, there should be ways that different water management, with short periods of soil saturation to create hypoxic conditions, could control this pest. Similarly, the golden apple snail (*kuhol*) which is a problem for irrigated rice production in some parts of Indonesia and Philippines could cause difficulties with SRI if not controlled. For this pest too, changes in the water regime and other management practices can probably deal with this constraint.[7]

In any case, SRI methods are not presented as being necessarily successful in every location or for every farmer. It is in the nature of biological practice that there will be variations and also limitations. However, SRI has been relatively free of constraints and problems, but we need always to be alert to negative effects if and as they appear.

VI. REPORTED ADVANTAGES BEYOND YIELD: OPPORTUNITIES FOR RESEARCH

As noted above, it is important when evaluating any production system to look beyond yield, the simplest and most evident benefit but one that can be of little value if achieved at high cost, possibly at even higher cost than the value of the incremental yield.

A. Factor Productivity: This is the criterion that economists favor for evaluation because it is increases in the returns not just to land, but also to labor, to capital, and to water that make farmers and nations richer and more secure. SRI is a unique innovation in that the productivity of four factors of production -- land, labor, capital and water -- can be increased at the same time, not requiring tradeoffs. The papers for this panel document this advantage, but further research on this to document and assess, and possibly disconfirm this generalization would be welcome.

[7] See <http://www.openacademy.ph/elearning/goldenkuhol/index.html>

B. Cost Reductions and Increased Profitability: One of the problems that quickly emerged with the Green Revolution strategy was input cost and 'dependence.' There are times and places where the use of inorganic fertilizer is productive and well-justified, and where chemical means of crop protection are necessary or cost-effective. But the increased yields with SRI methods, using fewer inputs, suggests that there be more of a burden of proof on assumptions that external inputs are necessary or will usually be more productive and profitable. SRI is showing that in many cases, farmers' incomes can be increased by using less rather than more external inputs.

Given the cost-price squeeze that many rice farmers find themselves in around the world, and given the likelihood that fossil-fuel-based agricultural inputs are likely to become more expensive in the future, it seems advisable to consider whatever options there may be to high-input modes of production. Even if there is no absolute shortage of petroleum in the next few decades, its relative availability and cost, driven by the interactions of supply and demand, are likely to become less favorable for the agricultural sector. Knowing more about the cost and profitability relationships in SRI would help to determine how much investment individuals and governments should make (can justify) in moving to SRI methods.

C. Lower Capital Requirements and Accessibility for the Poor: The fact that SRI can give higher yields with lower investment of capital makes it attractive and beneficial for poorer households. One of the benefits identified in the GTZ Cambodia evaluation was that SRI farmers could make fewer cash outlays at the start of the planting season, when their cash reserves were lowest, and they got pushed into onerous and often debilitating debt to pay for chemical inputs (Anthofer et al., 2004). There was concern that SRI would not be accessible to the poor based on the study in Madagascar by Moser and Barrett (2003), but this does not seem to be general problem in other countries and may reflect particularly institutional imperfections in that country. The IWMI evaluation found that poorer and richer households were both more likely to try out SRI than were middle-income farmers (Namara et al., 2004), and poorer ones were more likely to stick with SRI methods, being better able to accommodate labor-intensity that could richer ones. Because this is an important concern, however, more evaluations should be done of this issue.

D. Food Security: SRI should help to enhance the food security of households that are currently not producing enough to meet their subsistence needs, a large share of the rural poor. The 2003 evaluation by Moser and Barrett suggested that the poor might not benefit much from SRI, but that conclusion is we think not generalizable. Those authors accepted that SRI methods definitely could increase rice productivity. It was the cash-liquidity needs of the poor that kept them from benefiting from SRI, and these reflected a situation of institutional imperfections (where the poor lack of access to reasonably-priced credit). This problem could be overcome with institutional reform. It is hoped that with SRI increasing rice productivity substantially, the price of rice can be lowered while still maintaining favorable incomes for rice producers. This would have the desirable effect of benefiting the ***urban poor*** as well, many of whom depend heavily on rice as their main staple food. Assessing the extent of income effects will require systematic economic surveys and analysis, however. So we can only speak of potential for SRI in this regard, not yet of significant impact.

E. Resistance to Biotic Stresses: We have mentioned that SRI plants are reported by farmers in country after country to be more resistant to losses from pests and diseases. Few data are available on this, however. Here are some items in our SRI files:

- A study by IPM farmer field school groups in Ciamis, Indonesia of the ratio of beneficial-to-pest insects in SRI fields vs. conventional fields found the ratio to be more favorable in the former, which could account in part for the higher SRI yields (Asikin and Koeswara, 2001).
- In Tian Tai county, Zhejiang province of China, local agricultural experts estimated that the incidence of sheath blight, the major disease affecting the rice crop there, was 70% lower in SRI fields in 2004 compared to conventional fields (Dr. Zhu Defeng, CNRRI, personal communication).
- An evaluation of the experience of 120 Cambodian farmers who had used SRI methods for three years found that they had been able to reduce their application of chemical protection from 35 kg ha^{-1} to 7 kg ha^{-1} while doubling their yields, from 1.34 t ha^{-1} to 2.75 t ha^{-1}. The use of chemical fertilizer fell as well, from 116 kg ha^{-1} to 67 kg ha^{-1}, with compost use going from 942 to 2,100 kg. Total costs of production fell by over half (Tech, 2004).

There are many unsolicited reports from farmers in various countries that they do not find it cost-effective to spray their SRI crop to control pests and diseases. However, this information is not systematic or conclusive evidence. SRI responses to biotic stresses is an area where further research would be very beneficial, especially to understand the mechanisms involved.

F. Resistance to Abiotic Stresses: So far, no systematic evaluation has been done on this, but farmer reports are frequent that SRI fields are able to withstand the adverse effects of drought, of rain and wind that cause other rice fields to lodge, and of cold spells. All these can be attributed to having larger and stronger root systems.

- Telugu language newspapers in December, 2003, reported that SRI fields were not affected by a typhoon that struck coastal areas of Andhra Pradesh, India.
- A cold snap in February, 2004, in the interior of Andhra Pradesh did not affect SRI fields which caused other rice fields to become discolored and less thriving.
- In Sri Lanka, where there have been rain failures during the yala season the last several years, SRI farmers have come to regard the new methods as able to 'drought-proof' their crop.

However, in the absence of scientific evaluations, these reports are only suggestive of an area where research should be undertaken.

G. Environmental Benefits: Where SRI reduces farmer's applications of synthetic fertilizers and crop-protection biocides, there should be beneficial effects on soil and water quality and health. No evaluations of this have been done, however. Reductions of 25-50% in on-farm water use could become substantial for the agricultural sector and for hydraulic systems if aggregated, but so far, SRI has not been adopted on wide or complete enough scales to be able to assess what are the net benefits in economic or ecological terms from reduced irrigation offtakes. As freshwater supplies become scarcer in this century, the value of reductions will surely increase so that evaluations of potential and actual gains should be undertaken soon.

A further possible benefit from SRI is probably reduction in methane emissions which come from continuously flooded rice paddies. These are a significant source of methane, perhaps 10% of total production, adding to the greenhouse gas (GHG) effect. Possibly offsetting this benefit could be the production and accumulation of nitrous oxide, an even more powerful GHG even if in smaller amounts, which could be stimulated by SRI practice. However, if SRI fields are not being heavily fertilized with inorganic N, this effect should be minimal. Still, the net impacts should evaluated carefully and systematically. We think that SRI can make a net contribution to the reduction of global warming, but this remains to be ascertained. Present practices of continuously irrigated rice production are surely likely to have an adverse impact on our climate if continued well into the 21st century (Conway, 2000).

H. Biodiversity Conservation: There is growing concern that the widespread introduction and adoption of 'improved' varieties and hybrids is narrowing the genetic pool for rice as a crop. In country after country, traditional cultivars and landraces of rice are being lost, crowded out by new varieties that are favored by the extension service and merchants even if the rice-consuming public continues to favor the old ones for their flavor, texture and other qualities. These 'wild' varieties represent a valuable genetic resource for the future improvement of rice varieties in the future.

As noted above, practically all rice varieties, old and new, respond favorably to SRI management practices. Farmers are finding that they can get yields of 6-10 t ha^{-1} and sometimes even more with 'traditional' varieties. With higher yield, these are more profitable to produce than are new varieties that give 50-100% more yield because consumers are willing to pay 2-3 times more kg^{-1} for rice that has better cooking, eating and keeping qualities, e.g., rice that is less 'chalky.' CIIFAD is working with NGOs and farmer associations in Cambodia, Madagascar and Sri Lanka and the SEED Initiative (Supporting Entrepreneurship for Environment and Development), sponsored by UNEP and other international organizations and donor agencies, to develop local and export markets for indigenous varieties organically grown.[8] Expansion of this initiative has been discussed with SRI partners in China, India, Myanmar and Philippines, so SRI could create incentives for preservation of valued local varieties of rice that are presently being lost.

G. Grain Quality: One of the anticipated benefits reported for SRI is an improvement in grain quality when rice is grown with SRI methods. This may be due to the effect of larger, deeper root systems that access a greater variety as well as volume of nutrients, particularly micronutrients than can conventional rice root systems that remain shallow and die back under hypoxic conditions. Farmers have commented for some years on what they consider SRI's more desirable eating qualities. Some preliminary evidence on this is reported in the Philippine paper. Table 4 gives some measurement showing chalkiness to be less in SRI-grown rice. This could justify a higher price for SRI rice once its merits are better documented and more widely known.

More important economically is the higher outturn of milled rice from SRI paddy (rough rice). Millers in Sri Lanka and India have been willing to pay 10% more per bushel of SRI rice. Since rice millers are not known for their altruism, this has been informal evidence of higher outturn of SRI paddy when milled, going from a volume measure to a measurement by weight.

[8] The Paraboowa Environmental Farmers' Association based in Lunuwila, Sri Lanka has already exported 17 t of 'wild ecorice' to Italy, indigenous varieties grown organically with SRI methods, for a doubled price. The Kolo Harena farmers' association in Madagascar has begun to make connections with the Slow Food Movement in Europe to export organic SRI rice to its SFM stores there. CEDAC in Cambodia is working with farmers there to trademark, produce and sell organic SRI rice in local markets, in anticipation of eventual export opportunities for quality rice.

Because SRI paddy has fewer unfilled grains, it has less chaff, and it is usually more resistant to shattering, thus having fewer broken grains, giving a milling outturn about 15% higher. The Cuban cooperative CPA Camilo Cienfuegos, which has been the pioneer for introducing SRI in that country, has calculated that its milling outturn rate goes up from 60% with normal paddy to 68-71% with SRI paddy, a 13-18% increase in milled rice which is over and above their increase in paddy production, which has gone from 4.6 t ha^{-1} to 8.9 t ha^{-1} (José Luis Martínez, personal communication). An evaluation of SRI rice quality presented to the 10th All-China Conference on Theory and Practice for High-Quality, High-Yielding Rice, held in Haerbin, August 2004, has provided some quantitative measures of grain quality improvement with SRI methods (Table 4).

Table 4. Measured differences in grain quality with SRI and conventional methods

Characteristic	SRI (3 spacings)	Conventional (2 spacings)	Ave. difference
Chalky kernels (%)	23.62 - 32.47	39.89 - 41.07	- 30.7%
General chalkiness (%)	1.02 - 4.04	6.74 - 7.17	- 65.7%
Milled rice outturn (%)	53.58 - 54.51	41.54 - 51.46	+ 16.1%
Head milled rice (%)	41.81 - 50.84	38.87 - 39.99	+ 17.5%

Source: Data from paper (in Chinese) presented to conference by Prof. Ma Jun, Sichuan Agricultural University.

Certainly more evaluation should be done on different dimensions of grain quality before any firm conclusion is drawn about SRI advantages in this domain. The effects may vary by variety, and according to factors such as soil quality (biologically as well as physically and chemically). We suspect that the ***nutritional quality*** of SRI rice may be greater as well, given the larger root system that has more access to micronutrients in the soil. In Andhra Pradesh, grain weight has been found to increase 10-15% with SRI methods without the grains themselves becoming larger. (This is paid attention to because larger grains are considered to be of lower quality, being less 'fine.') Having denser grains could account for a reduction in shattering during milling. It could also reflect more dense packing of grain cells with nutrients. However, this remains to be evaluated. There should be research done on whether there is a nutritional gain with SRI methods. This would make rice a more valuable crop in a world that is increasingly nutrition-conscious.

VII. SUMMARY

This paper has reviewed issues and experience associated with the System of Rice Intensification (SRI). It has not gone in any detail into SRI results as this will be addressed by the other papers on the panel, with new and more extensive data from the 2004 growing season than we have had previously. It has not dwelt on SRI methods as these have been written up often elsewhere, and are anyway being further evolved by farmers and researchers working with the system.

SRI is not a fixed technology but rather a set of insights and principles originating over the 34 years that Fr. de Laulanié worked with rice and with farmers in Madagascar to devise a system of production that would not be dependent on external inputs but would rather capitalize on existing and available potentials in the rice plant itself. In his only published article on SRI (1993), he said that he regarded the rice plant as his teacher (*mon mâitre*), and that he tried to discover what growing conditions would best satisfy its needs.

Such empiricism is in the best traditions of science, being driven by empirical observation and by a desire to explain patterns and anomalies and to produce useful knowledge. SRI is still a work in progress, as Fr. de Laulanié, who passed away in 1995, would want it to be regarded. It has been largely propelled by the interest, needs and efforts of farmers and of persons who have worked with them to improve the productivity and security of rural households. Having come this far, it is desirable that the rice scientific community engage with the SRI experience to see how it might be further improved, how it might be kept from any future failings, and how its lessons might be extrapolated to other crops.

Already in India, the Green Foundation in Karnataka state has begun using SRI concepts with finger millet (ragi), doubling its yield without using purchased inputs (Green Foundation, 2004). An NGO partner in the Philippines has adapted SRI ideas and practices to upland rice production, getting an average yield over 7 t ha^{-1} with a traditional variety (*Azucena*) and only organic fertilization (Gasparillo et al., 2002). So SRI could contribute both to raising rice production and to improving the agricultural sector more broadly. But this is an empirical question. It remains to be seen how many of these benefits will be achieved with what spread and for how long. Skepticism is appropriate and will be helpful for us to get the most benefit from SRI insights and ideas so long as it is something that is optimized rather than maximized.

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