RAISING FACTOR PRODUCTIVITY IN IRRIGATED RICE PRODUCTION: OPPORTUNITIES WITH THE SYSTEM OF RICE INTENSIFICATION

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ABSTRACT

The System of Rice Intensification (SRI) developed in Madagascar has been controversial in some agronomic circles in part because there have been no large-scale, long-term evaluations of the impact of the methods recommended. This paper reports on 9 cropping seasons (2002-2006) of on-farm comparative evaluations across 3 provinces in Eastern Indonesia conducted under the supervision of a Nippon Koei technical assistance team. It summarizes the results of 12,133 comparison trials covering 9,429 hectares. Average yield increase was 78% (3.3 t/ha) with a 40% reduction in water use and 50% in fertilizer applications, with 20% lower costs of production. The controversy will not be resolved by any single evaluation, but these results support the previous reports that SRI practices in combination can achieve significantly higher output with a reduction in inputs, enhancing simultaneously the productivity of the land, labor, water and capital used in irrigated rice production.

1. Introduction

All countries can benefit by using less of their land, labor, water and capital to meet their populations' basic food needs. This can permit them to redeploy freed-up resources to other, higher-value, and more-nutritious agricultural production. Any lowering of prices for staple foods that results from productivity gains will benefit consumers and especially the poor, both urban and rural. At the same time, even with lower commodity prices, producers can improve their net incomes because higher productivity reduces their costs of production. At macro level, improvements in agricultural sector productivity permit more of a nation's resources to go into its investments in other sectors, which produce widely distributed benefits.

A growing concern is that many countries are coming under pressure from declining water availability for agricultural cropping, and from increases in the number and severity of 'extreme events' associated with climate change (Rosenzweig et al., 2001). How crop production can be made more compatible with greater variability in rainfall and temperature – droughts, flooding, heat spells, cold snaps, unseasonal extremes – is thus becoming an urgent issue. Efforts to raise productivity and reduce poverty concurrently now need to proceed with more attention to environmental and natural resource considerations than in the preceding century.

2. Background: Origin, Controversy, Limitations, and Proposed Explanations

The System of Rice Intensification (SRI) developed 25 years ago in Madagascar by Laulanié (1993) has been reported to address all of these concerns (Stoop et al., 2002). However, it has been dismissed by critics, sometimes vehemently (e.g., Dobermann, 2004; Sheehy et al., 2004: Sinclair and Cassman, 2004; see Surridge, 2004). SRI diverges from the Green Revolution paradigm which obtained higher cereal yields (a) by improving crops' genetic potentials, making them more responsive to external inputs, and (b) by increasing external inputs – water, chemical fertilizer, and protective agrochemicals. SRI requires neither of these

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changes. Instead it elicits more productive phenotypes from any existing rice genotypes by changing the management of plants, soil, water and nutrients, altering age-old practices and reducing dependence on external inputs (Uphoff, 2003). The specific practices that constitute SRI are described below.

A compilation of results from 11 evaluations conducted in 8 countries by a combination of universities, international agricultural research centers, NGOs, government agencies, private sector organizations, and donors,[2] shows SRI methods, even when used incompletely or only partially, giving the following results compared with farmers' practices:

52% average yield increase in tons ha^{-1} (range: 21 - 105%)
44% average reduction in water use (range: 24 - 60%)
25% average reduction in costs of production ha^{-1} (range: 2.2 - 56%)
128% average increase in net income ha^{-1} (range: 59 - 412%) (Uphoff, 2007).

In addition to raising the productivity of land, i.e., yield, SRI raises also the productivity of water (crop per drop, see Satyanarayana et al., 2007) and of capital (profitability, reducing costs at the same time that output is increased; see section 5 below). In addition, SRI methods raise labor productivity (output per day of work, e.g. Namara et al., 2004). During the initial learning phase, SRI requires more labor, and this labor-intensity has been reported as a barrier to the adoption of SRI (Moser and Barrett, 2003). However, once farmers have acquired skill and confidence in the methods, evaluations now show that SRI can becoming labor-saving (see section 5).

Besides needing more labor initially, other requirements or limitations for SRI include:

- ***Good water control*** so that small amounts of water can be applied regularly and reliably. This will give the best results. However, where water management cannot be fully controlled, positive results can still be obtained from using the other SRI practices.
- ***Availability of biomass*** for organic fertilization of SRI fields. Where manure supply is limited or sufficient compost cannot be made and applied, however, substantial yield improvements can be made using chemical fertilizer with the other practices.
- ***Motivation and skill*** **–** because the 'intensification' in SRI refers to greater reliance on farmers' knowledge and management effort rather than to use of more purchased inputs.
- ***More crop protection measures*** may be needed for plants which have larger canopies and panicles, although most farmers report that SRI *reduces* their incidence of pests and diseases.

From an SRI perspective, rice plants are regarded as organisms with their own capabilities and strategies for growth in association with diverse populations of soil organisms. Both plants and soil biota are nurtured together in synergistic and symbiotic relationships. This contrasts with the Green Revolution paradigm which considers plants like biological machines, to be designed and redesigned for others' purposes rather than their own, being 'fueled' by external resources rather than mobilizing endogenous processes and potentials in

[2] The evaluations were done by universities in China and India, by international centers (IWMI in India and Sri Lanka; IRRI in Bangladesh), NGOs in Bangladesh and Cambodia, government agencies in Bangladesh, Nepal and Vietnam, private sector organizations (Nippon Koei in Indonesia, and Syngenta in Bangladesh), and a donor organization (GTZ in Cambodia). Details are given in Uphoff (2006).

soil systems (Uphoff et al., 2006). Green Revolution theory and practice have ignored soil biota and attribute plants' performance to their genetic design plus exogenous inputs, seeking results that are fully predictable and assured in an industrialized version of agriculture.

SRI performance is quite variable because it results from dynamic and interactive biological processes more than from fixed genetic potentials and 'modern' inputs. That its best results, yields >15 t/ha, are not always attained does not make these any less real or instructive. One should, of course, never confuse outliers with typical results. But as seen from the data reported below, SRI *averages* surpass more input-dependent results by a large margin and offer productivity improvements for all factors of production, not just land.

This article cannot go into the reasons for such results in any detail. In brief, these productivity gains are accomplished, first, by inducing larger root systems on rice plants that are not crowded together and whose roots do not suffocate in flooded (hypoxic) soil (Kar et al., 1974). Second, aerobic soil conditions with plentiful soil organic matter enhance not only root health and performance, but also the abundance, diversity and activity of soil organisms which provide both nutrients and protective services to plants (e.g., Dobbelaere et al., 2003; Bonkowski, 2004; Randriamiharisoa et al., 2006). SRI mobilizes symbiotic processes both in and between plants and soil systems that capitalize upon potentials have developed over 400 million years of co-evolution (Margulis and Sagan, 1997; see Feng et al., 2005; Dazzo and Yanni, 2006).

Some agronomists have withheld judgement on SRI, waiting for long-term, large-scale evaluations of SRI to be published in the peer-reviewed literature. The challenge to SRI by McDonald et al. (2006) was inconclusive, being methodologically flawed and based on an unrepresentative selection of short-term trials, few of them following defensible protocols (Uphoff et al., 2007). Most of the results they considered were from small experiment-station trials, where SRI methods have a history of giving poorer results than on farmers' fields (Rickman, 2003; Neupane, 2003). Also, all Madagascar results were arbitrarily excluded from the evaluation. So that dismissal of SRI was premature.

There is now a long-term, extensive evaluation of SRI results from northern Myanmar which covers a large set of farmers (N=612) over a four-year period which has gone through standard peer review for publication (Kabir and Uphoff, 2007). That paper documents more than doubled yield on farmers' fields with incomplete use of SRI, and more than tripled yield when practices were used as recommended. However, that study evaluates 'rainfed SRI,' whereas most interest has focused on SRI under irrigated conditions, those that most affect world food supply and for which SRI was originally developed. This review presents an extensive evaluation of irrigated SRI results, from monitored on-farm comparison trials (N=12,133), done over 9 cropping seasons, across three provinces of Indonesia, and covering a large total area (9,429 ha). Detailed records were maintained on the practices used and resulting yields, so this provides an extensive empirical basis for assessing the productivity of SRI methods.

3. SRI Results in Indonesia

The System of Rice Intensification methods has been introduced and evaluated in three provinces of Eastern Indonesia since 2002 under the auspices of the Decentralized Irrigation System Improvement Project (DISIMP), executed by the Directorate-General of Water Resources of the Ministry of Public Works (PU).[3] This project implementation was supported

[3] This is the fourth in a series of projects managed by PU/DGWR and funded by the Japan Bank for International Cooperation (JIBC). This development assistance started with three Small-Scale Irrigation Management Projects (SSIMP-I to SSIMP-III, 1990 to 2003), so DISIMP (2003-08) is known also as SSIMP-IV.

by a technical assistance team from the Japanese consulting firm Nippon Koei. SRI was of interest because it supports the project's objectives of (a) raising income levels of farmers for poverty alleviation, and (b) enabling farmers toward sustainable O&M of irrigation systems and efficient water management. Since SRI was first introduced, its use has expanded steadily as seen below. Results and lessons learned can now be reported from the use of SRI methods during nine cropping seasons, from 2002 up to 2006.

The basic concepts and practices that constitute SRI start with transplanting very young seedlings (7-14 days old) singly and in hills with wide spacing (25 cm x 25 cm or even more), applying irrigation water intermittently with no continuous flooding. Weed control, more needed when there is no flooding, is done with a rotary hoe that aerates the soil at the same time that it eliminates weeds. Reliance on external inputs (water, chemical fertilizer, agrochemicals) is reduced, which surprisingly but explainably contributes to higher paddy yields.

- Aerobic soils support better root growth and functioning, as well as larger populations of beneficial soil biota.
- With larger root systems and increased soil biological activity, more N, P and other nutrients, especially micronutrients, become available, making inorganic fertilization less necessary.
- As SRI plants are more resistant to losses from pests or diseases, chemical protection is less necessary or uneconomic, possibly explainable in terms of trophobiosis (Chaboussou, 2004).

SRI is not necessarily an organic system of production in that chemical fertilizer and agrochemicals can be used beneficially with the other practices (young seedlings, wide spacing, intermittent water applications, active soil aeration). But there is a version of SRI that is called 'organic SRI' which takes the logic of SRI to a higher level. This alternative requires more sophisticated farming practices and involves the use of organic fertilization and of organic pesticides when needed, instead of relying on inorganic or synthetic agricultural inputs. This organic alternative can give similar and sometimes better yield increases, but it requires more effort and better management, as discussed in section 7. The compensation is that by reducing cash expenditures, it can improve farmers' net income at the same time that it enhances sustainable soil fertility and results in more varied and healthy rice field ecosystems. This contributes to human and environmental health.

3.1 SRI History in Indonesia

The first evaluations of SRI were carried out in 1999 dry season by the Agency for Agricultural Research and Development (AARD) at its rice research center in Sukamandi, West Java. Researchers reported initial SRI paddy yields of 6.2 t/ha compared with a control yield of 4.1 t/ha; in the subsequent wet season, the average SRI yield in Sukamandi trials was 8.2 t/ha, with one plot reaching 9.3 t/ha. Such results confirmed reports from Madagascar and led AARD researchers to expand SRI evaluations to eight provinces and to incorporate most SRI practices into their recommendations for integrated crop management (ICM) (Gani et al., 2002).

The first on-farm evaluations in West Java began in the 2001 in Ciamis district through a farmer field school there as part of the national integrated pest management (IPM) program (http://ciifad.cornell.edu/sri/countries/indonesia/indocmis01.pdf). Under the leadership of agronomist Alik Sutaryat, the area planted under SRI in West Java has expanded steadily. By the 2006 season, the SRI area reached at least 749 ha (3,200 farmers), with average SRI paddy yields of 7.85 t/ha vs. 6.24 t/ha for non-SRI methods. In the following 2006-07 season, with support from a government initiative to empower farmers in Tasikmalaya and Sukabumi districts, the SRI area almost doubled, to 1,484 ha. All of the 5,720 farmers involved are practicing 'organic SRI,' i.e., using organic fertilizers and organic pesticides with no chemical use. Their products receive a premium price in the market, about 60%, given that Indonesian consumers are becoming apprehensive about the cumulative effects of agrochemical use on staple food crops.

In 2007, SRI trainers and farmers established an NGO known as AOSC to disseminate organic SRI, and thereby to create a better rural environment and support a better life for Indonesian villagers. AOSC has established a training center at Nagrak, Sukabumi, 2 hours east of Jakarta, and the Ministry of Agriculture's Directorate of Land Management has started a program for the training of trainers (TOT) on organic SRI that is utilizing AOSC's experience and expertise. This program, focused in 39 districts in 14 provinces, is the first support given to SRI extension from the Ministry of Agriculture.

The first SRI use outside of Java was in West Timor, where the NGO ADRA introduced the methods in 2002. Seven farmers averaged 11.7 t/ha compared with their yields that season of 4.4 t/ha with regular methods (http://ciifad.cornell.edu/sri/countries/indonesia/indoagpkrst.pdf). This increase was so remarkable that few persons outside West Timor took it seriously, even though SRI use there expanded to 200 farmers the next season. ADRA produced a training video based on this experience and introduced SRI work also in Lampung district, Sumatra.

About this same time, DISIMP consultants began working with the Ministry of Public Works (PU) and its Directorate-General of Water Resources to evaluate and promote SRI in eastern Indonesia as discussed in the next section. By 2006, PU was prepared to allocate 6 billion rupiah to support SRI training and modifications in its irrigation system design and management to make SRI more practical for farmers.

3.2 SRI under DISIMP

In July 2002, information on SRI from CIIFAD first reached DISIMP consultants. Although the team leader could not at that time believe the claims made for SRI, he requested the team's agronomists working in West Nusa Tenggara and South Sulawesi to evaluate the methodology. First field tests commenced in October 2002 at three project sites.[4] After SRI effects were confirmed during subsequent trials in 2003 and 2004, the team leader formulated a strategy to promote SRI for reducing water requirements and increasing farmer incomes.

Given the location of a multi-disciplinary DISIMP consultant team in each province, SRI dissemination could proceed smoothly. Core groups for SRI extension under DISIMP were formed by the team's agronomists and SRI facilitators under the management of the consultant team leader, regional team leaders, and provincial team leaders. Good cooperation with local government officials such as agricultural officers and extension officers was realized. Recently, dissemination of SRI by farmer themselves (farmer-to-farmer spread) has started in other locations, including Bali province, outside of the DISIMP irrigation schemes.

3.3 Expansion of SRI Area

After the first stage for SRI evaluation (5 seasons), SRI entered into an extension stage under DISIMP with rapid expansion, as seen below. By 2006, the cumulative area on which SRI

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[4] Tiu Kulit dam irrigation scheme (SSIMP-I) in Sumbawa island, West Nusa Tenggara province; and Awo weir irrigation scheme and Salomekko dam irrigation scheme (SSIMP-II), both in South Sulawesi province.

methods had been practiced reached 9,429 ha (12,133 farmers). Expansion would have been considerably greater except for some unforeseen events that occurred in the 2006 dry season.[5] If these problems had not arisen, the SRI areas for that season would have been much greater than recorded in Table 1.

Table 1: Progress of SRI Practice in DISIMP, 2002-2006

	Cropping season	Number of farmers	SRI harvested area (ha)	Average paddy yield *		
				SRI (t/ha)	Non-SRI (t/ha)	Increase (%)
Trial Stage	2002	1	0.10	5.58	4.31	29.5%
	2002/2003	12	3.40	7.39	4.76	55.2%
	2003	1	0.16	8.39	4.67	79.7%
	2003/2004	8	5.62	7.77	4.18	85.8%
	2004	21	12.16	7.23	4.06	77.8%
Extension Stage	2004/2005	522	387.37	7.90	4.09	92.9%
	2005	1,336	1,016.70	6.85	3.89	75.9%
	2005/2006	5,258	4,245.46	7.98	4.63	72.4%
	2006	4,974**	3,758.13	7.39	4.04	82.8%
	Total	12,133	9,429.10	7.61	4.27	78.0%

** Dry unhusked rice (@14% moisture content – all yields reported have been adjusted to this standard.*
*** Because of disruptions in water supply (fn 5), SRI use was less than expected based on previous results.*

Although SRI areas have extended rapidly under DISIMP, the rate of progress of extension varied among schemes. Table 2 shows DISIMP schemes that have made with good progress on SRI area extension. Once the benefits of SRI practices have been made evident to farmers in an irrigation scheme, it can spread very rapidly farmer-to-farmer with project support.

Table 2: Extension of SRI Areas under DISIMP by Cropping Season, 2004-2006

Province	Scheme	SRI area by cropping season (ha)				
		2004	2004/05	2005	2005/06	2006
West Nusa Tenggara	Moyo Kanan	-	-	41.8	160.0	645.0
West Nusa Tenggara	Bau Bulan Kanan	0.2	11.4	10.2	28.0	73.0
West Nusa Tenggara	Jurang Sate Lower	-	-	33.8	68.8	90.0
South Sulawesi	Kelara Karalloe	2.0	217.9	NA	2,249	277.0
South Sulawesi	Sadang	5.0	77.8	164.9	314.6	344.1
Central Sulawesi	Karaopa	-	37.0	500.0	800.0	1,306.0
Gorontalo	Bulia	-	1.3	13.3	41.6	67.0

In general, DISIMP schemes where good progress has been made with SRI extension have: (a) good irrigation systems with reliable water sources, (b) effective WUAs, and (c) active farmer leaders. Furthermore, in such schemes, local government officials are usually quite willing to promote SRI by cooperating with the technical consultants. These conditions greatly facilitate the smooth expansion of SRI.

3.4 Paddy Yields Using SRI Practices

Average paddy yield with SRI cultivation for the entire extent of trials (9,429 ha) was 7.61 t/ha, i.e., 78% higher than the yield for conventional methods (non-SRI) of 4.27 t/ha (all weights are adjusted to a standard 14% moisture content). Paddy yields in Nusa Tenggara

[5] These problems were: (a) stoppage of irrigation water supply in the Kelara Karalloe scheme (7,004 ha) in South Sulawesi due to damage to the main canal caused by a landslide, and (b) serious water shortages in central Lombok, West Nusa Tenggara.

were 8.02 t/ha for SRI vs. 4.19 t/ha for non-SRI, a 91.4% increase on 2,450 ha; while in Sulawesi, the average SRI yield was 7.44 t/ha vs. 4.32 t/ha for non-SRI, a 71.3% increase on 6,979 ha. Adding all of these trials together, a total of 31,500 tons (3.34 t/ha x 9,133 ha) of paddy were produced additionally without raising production costs and with less water requirement, discussed below. At $120/ton, this represents a net addition to farmer income of at least $3.75 million just on the trial plot areas. Given a 20% reduction in costs of production, this figure could have reached $4.5 million.

The yield data for conventional cultivation contain results from both transplanting and direct-seeding methods of crop establishment. The latter method prevails in large irrigation schemes in South Sulawesi such as Sadang (58,000 ha) and Awo (5,500 ha). Paddy yields from areas using conventional transplanting and direct-seeding show no significant difference, however, so this did had no impact on the comparative evaluation of SRI effects under DISIMP.

Average yields analyzed by cropping season showed wet-season yields to be higher than dry-season yields for both SRI and non-SRI, as seen in Table 3. However, yield *increases* with SRI are higher in dry-season cropping, as also seen in this table, so SRI methods are relatively more beneficial in the dry season, perhaps because aerobic soil conditions can be better maintained then. We also see from this table that SRI yields are higher on average in Nusa Tenggara than in Sulawesi.

In 2006, SRI was introduced in Bali province by farmers' initiative. One of the areas (Gianyar) where hybrid rice was grown with SRI methods produced unusually good results. SRI methods gave an average yield of 13.3 t/ha on an area of 42 hectares, compared with 8.4 t/ha achieved with hybrid rice cultivated by non-SRI methods. This confirms that favorable genotypes make significant contributions to improved rice production, but also that a large effect can be achieved with alternative management practices, in this instance, almost 5 t/ha.

Table 3: Average Paddy Yields by Season and by Region under DISIMP, 2002-2006

Cropping season	Region	SRI area		Average paddy yield		
		Farmers (no.)	Area (ha)	SRI (t/ha)	Non-SRI (t/ha)	Increase (%)
Wet season	Nusa Tenggara	1,286	757.4	8.02	4.54	76.9%
	Sulawesi	4,235	3,622.3	7.73	4.56	69.5%
	Total DISIMP	5,521	4,379.7	7.78	4.56	70.8%
Dry season	Nusa Tenggara	3,531	1,692.4	8.00	4.01	99.5%
	Sulawesi	3,081	3.357.0	7.20	4.04	78.0%
	Total DISIMP	6,612	5,049.4	7.47	4.03	85.2%
Total	Nusa Tenggara	4,817	2,449.9	8.01	4.17	91.9%
	Sulawesi	7,316	6,979.3	7.47	4.31	73.3%
	Total DISIMP	12,133	9,429.1	7.61	4.27	78.0%

4. SRI Practices under DISIMP

SRI methods are expected, indeed intended, to be adapted to local conditions, so that the best possible growing conditions are created for the rice plants and for the soil organisms that interact with them. According to DISIMP experience, some adjustments have been made in the original SRI practices, e.g., most Eastern Indonesian farmers continue to use some chemical fertilizer but they are usually reducing its application by 50%. We have found most farmers there reluctant to give up fertilizer up entirely, and many do not have access to enough biomass or to enough labor to convert it into compost. So some accommodation was necessary. We anticipate that there is still considerable room for making further productivity improvements since not all of the SRI practices that have been validated by factorial trials are yet being used by farmers in DISIMP (Randriamiharisoa and Uphoff, 2002).

In this section we discuss how SRI has evolved under DISIMP, also discussing things that have been learned from practice, to help other SRI users further evolve their own use of the basic concepts. Table 4 presents the modal practices used, respectively, for SRI and non-SRI production. Detailed data have been collected on all the practices and their variations and are available on the web (http://ciifad.cornell.edu/sri/countries/indonesia/ indodsimpdata 06.xls).

Landholding size affects farmers' selection among SRI practices. Within the study region, average cultivation area was 0.78 ha. In Nusa Tenggara, where average holding size is around 0.5 ha, we found transplanting used for both SRI and non-SRI cultivation; in Sulawesi, on the other hand, where holdings average ~1.0 ha, direct-seeding methods are more often used. Use of portable plates for growing and transporting seedlings was readily accepted by farmers in Nusa Tenggara, but not in Sulawesi; there farmers continued to use a corner of their main paddy field for the nursery bed. To control weeds, farmers in Sulawesi having larger plots have tended to use herbicides while in Bali and Nusa Tenggara, farmers with smaller holdings have chosen means other than herbicide. It is thus important to allow alternative measures that farmers can select according to their preferences at each location.

Table 4: Standard Paddy Cultivation Practices for SRI and Conventional Method under DISIMP Irrigation Schemes

Practices	SRI methods under DISIMP	Conventional methods (irrigated)
Land preparation (LP)	2 times: 1st LP for plowing, and 2nd LP for puddling and leveling No standing water after 2nd LP	2 times: 1st LP for plowing, and 2nd LP for puddling and leveling Keep standing water after 2nd LP
Seed		
❑ Quality	80-100 % certified seed	20-40 % certified seed
❑ Quantity	Transplanting @ 5-8 kg/ha	Transplanting @ 30-50 kg/ha, or Direct seeding @ 60-100 kg/ha
❑ Seedling age	8-12 days at transplanting	21-30 days at transplanting
Transplanting		
❑ Seedling no.	1 seedling in each hill, 1-2 cm deep	3-5 seedlings in each hill
❑ Spacing	30 cm x 30 cm (standard) with regular distances	15 to 20 cm spacing at random intervals
Irrigation		
❑ Vegetative growth stage	Intermittent irrigation with wet-dry cycle, little standing water (± 2 cm) in wet period	Continuous irrigation, keeping 5-10 cm deep standing water
❑ Reproductive stage	Continuous irrigation, keeping 2-5 cm of standing water	Continuous irrigation, keeping 5-10 cm deep standing water
Weeding		
❑ Method	Rotary weeder, weeding tools, or manual weeding	Weeding tools, or manual weeding
❑ Frequency	2-3 times during vegetative growth stage	1-2 times during vegetative growth stage
Fertilizer use		
❑ Type	Chemical fertilizer plus organic inputs	Chemical fertilizer
❑ Amount	Recommend 150 kg/ha urea and 100 kg/ha SP36. Otherwise farmers still follow guidelines of district agricultural office	Follow guidelines of district agricultural office

4.1 Land Preparation

In DISIMP schemes, land preparation (LP) has been done twice before transplanting, the first time (LP-1) for plowing, and the second time (LP-2) for puddling and leveling. There was no real difference between LP for SRI and conventional cultivation. However, for SRI after LP-2, standing water is kept shallow (± 2 cm or less). One lesson learned about LP is that maintaining standing water for a week immediately after LP-1 is quite effective for reducing weed growth after transplanting. If no standing water is maintained after LP-1 and paddy field is left to dry, weeding control subsequently becomes a heavy burden, especially with SRI practices.

For SRI, it is recommended that after land preparation, temporary ditches be dug within the paddy field inside the bunds and across the center part of field, to facilitate within-field drainage. Drainage can be further promoted by digging temporary ditches across the field at 5 to 10 m intervals, with depth and spacing varied according to soil type and size of plot. As a rule, temporary ditches should be dug at 5 m intervals for clay soil and at 10 m intervals when soil is well-drained, but these are initial recommendations, to be varied according to experience.

4.2 Seedling Preparation

4.2.1 Selection of good seeds

For SRI, transplanting a single seedling per hill is one of the key concepts. Selection of good seed is therefore highly important. In DISIMP, the procedure of seed selection with salt solution has been adopted as a ‘must.’ SRI farmers have performed this practice easily and properly.

4.2.2 Age of seedlings

Age of seedlings for transplanting is an important and sensitive parameter. Very young seedlings of 7-14 days are generally used with SRI. When seedlings older than 15 days are used, SRI benefits are reduced drastically, and with older seedlings the SRI effect cannot be seen any more. This can be attributed to the dynamics of plant growth explained in terms of phyllochrons (Stoop et al., 2002). Within DISIMP, the recommended age of seedlings is 8 days. However, farmers in many areas have preferred to use seedlings 10 to 14 days old, mainly due to a perception that bigger seedlings are more reliable. In the Tiu Kulit scheme in West Nusa Tenggara, farmers have gradually accepted the consultants’ recommendation, reducing seedling age for transplanting from 14 days to 10 days since the 2004/2005 cropping season. As more experience is gained and results are demonstrated, we expect that farmers will over time accept a seedling age closer to 8 days so as to realize the SRI effect more fully.

4.2.3 Nursery management

Two types of nursery for SRI seedling preparation have been practiced under DISIMP.

- F-type is where seedlings are grown in nursery beds set in the corner of the main paddy field. This has been common practice in Sulawesi, whereas in Nusa Tenggara, this was practiced during the first SRI stage until the introduction of P-type nurseries in 2004. Because F-type is very similar to the conventional method, it is familiar to farmers and easy to follow.
- P-type is where seedlings are grown on portable plates (plastic plates, bamboo colanders, banana leaves, etc.), placed on a nursery rack installed near farmers’ houses, as seen in Figures 1 and 2. This methodology was first introduced in Nusa Tenggara after training by the organic SRI consulting group in West Java headed

by Mr. Alik (section 3.1 above). Most SRI farmers there now prefer P-type due to its easier control over seedling preparation which can be done near their houses and which makes transport of seedlings to the main paddy fields for transplanting easier.


Figure 1: Vertical SRI nursery with racks for seedling trays.


Figure 2: Trays for SRI seedlings.

4.3 Transplanting

Under DISIMP, transplanting for SRI has been practiced with plant/hill spacing of 30 cm x 30 cm from the beginning. This has been confirmed as optimal through field tests that compared different intervals: (a) 20 cm x 20 cm, (b) 25 cm x 25 cm, (c) 30 cm x 30 cm, and (d) 40 cm x 40 cm. Results from the Batu Bulan irrigation scheme in Sumbawa, West Nusa Tenggara, in the 2005 dry season are shown in Table 5.

Table 5: Comparison of Seedling Hill Distance for Transplanting in Batu Bulan Scheme, West Nusa Tenggara, 2006 Dry Season

	Spacing for Transplanting			
	20 x 20 cm	25 x 25 cm	30 x 30 cm	40 x 40 cm
No. of tillers per hill	29	35	49	50
Panicle weight (grams)	4.6	6.4	7.0	6.8
Paddy yield*	7.6	8.1	8.4	8.2

*Note: * = moisture content 18%*

This confirms that spacing of 30 cm x 30 cm can produce the best paddy yields under Eastern Indonesian conditions, and therefore this has been the recommended spacing under DISIMP. However, if field conditions change and soil fertility changes, what is optimal spacing should be re-considered. According to information obtained from the organic SRI consultant group in West Java, wider spacing of 40 x 40 cm can give higher paddy yields than 30 x 30 cm spacing after paddy soil texture has been improved by application of organic fertilizer 5 times or more. Shallow transplanting (only 1-2 cm deep) is also important for best results.

Just before starting transplanting, a grid 30 x 30 cm is marked out on the field's surface using hand-made tools of wood or bamboo (Figure 3). According to farmers, SRI transplanting quickly becomes easier and quicker than conventional transplanting due to the smaller seedling size and the lower number of seedlings (reduced by 80% or more). Farmers find that their costs and time for transplanting are much less with SRI than with conventional methods as experience and skill make SRI transplanting (Figure 4) quicker and easier. Farmers need to be cautioned, however, that for the first month, their transplanted field will look rather barren and unpromising (Figure 5). This changes once exponential tillering begins from about the fifth week.

Figure 3: Marking field with rake to imprint a grid pattern for transplanting.

Figure 4: Transplanting young seedlings in grid pattern.

Figure 5: SRI field after transplanting, with tiny seedlings widely and regularly spaced. What appears to be 'wasted' space becomes filled when plants begin to tiller exponentially.

4.4 Intermittent Irrigation

The main recommendation for SRI is alternated wetting and drying of the fields, flooding them and then letting them drain, with a maximum depth of 2 cm standing water. The best length for the dry period differs by location, soil condition (permeability, water-holding capacity, etc.), plot size and shape, availability of irrigation water, rainfall pattern, etc. In DISIMP schemes, the dry period for intermittent irrigation is always decided empirically. The indicator for re-starting irrigation is determined visually, by the appearance of cracks of certain sizes on the surface of paddy field soils. In practice, the length and proportions of the wet-dry cycle of intermittent irrigation is also influenced by the availability of irrigation water, especially in the dry season. If paddy soil is heavy clay, care must be taken not to let the soil dry out too much before rewetting.

Table 6: Example of Actual Practice of Intermittent Irrigation for SRI under DISIMP Schemes, 2006 Dry Season Cropping

Province	Scheme	SRI area (ha)	Intermittent irrigation	
			Irrigation (days)	No irrigation (days)
West Nusa Tenggara	Jurang Batu (Lombok)	100	1	14
	Tiu Kuli (Sumbawa)	41	8	7
	Batu Bulan (Sumbawa)	73	6	4
	Moyo Kanan (Sumbawa)	645	8	7
East Nusa Tenggara	Malaka (Timor)	48	10	4
South Sulawesi	Sadang	344	8	6
	Kelara Karalloe	277	4	3
	Tabo Tabo	23	8	4
Central Sulawesi	Karaopa	1,306	10	6

The actual practice for intermittent irrigation for SRI under DISIMP is quite variable by scheme and by season as seen from Table 6. For example, the Jurang Baru scheme located in the downstream area of a large integrated irrigation system in Lombok, West Nusa Tenggara, had a limited irrigation water supply in the 2006 dry season. The intermittent cycle there became 1 day of irrigation followed by 14 days with no irrigation. On the other hand, in Sadang scheme, Sulawesi, which has ample water supply even in the dry season, the cycle was 10 days of irrigation followed by 4 days with none. This was changed to an 8-day/6-day cycle at the suggestion of the consultants.

Figure 6: SRI field allowed to become cracked. Soil is not continuously flooded, but instead is kept moist enough to sustain plant growth, not suffocating roots or aerobic soil biota.

Water-saving by SRI methods can be achieved during land preparation, during nursery preparation, and during the intermittent-irrigation regime in the vegetative growth stage of paddy. The amount of water saved by SRI cultivation vs. non-SRI practices – usually about 40% -- has been confirmed by field tests in DISIMP schemes. At present, SRI plots and non-SRI plots are mixed within an irrigation scheme like ‘patch work.’ The availability of reliable water supplies for irrigation is a condition for farmers to accept the drying up of their paddy fields during an intermittent-irrigation regime. Therefore, a prime condition for introducing

SRI practices should be that the irrigation scheme is in relatively good condition and is operating reliably. Once all of the paddy fields served by a single off-take are cultivated under an SRI schedule, it should be possible to reduce considerably the total amount of water supplied to them. To assess the most preferable irrigation intervals for achieving both high paddy yield and water-saving simultaneously, field tests are being carried out in 2007 in an SRI research station established in Lombok, West Nusa Tenggara.

4.5 Weeding

When SRI methods are introduced, weeding seems to be the biggest problem that farmers encounter, and this can increase their labor burden. For SRI practice under DISIMP, weeding is practiced 3 times during the vegetative growth stage (up to about 2 months after transplanting). The methods of weed control differ from scheme to scheme, as noted above. Chemical weed control by herbicide has been practiced in Sulawesi where farmers' landholdings are larger, while in Nusa Tenggara, practically no herbicide is used, and instead weeding is practiced using a rotary weeder and weeding tools, or by manual operations. Most farmers have yet to see and understand the benefits that active soil aeration will give them, creating incentives over time to move away from herbicides or manual weeding to simple mechanical weed control.

Figure 7: Weeding with a rotary weeder, in perpendicular directions, to aerate soil as well as control weeds.

Lessons learned to mitigate the burden for weeding include:

- During land preparation, keep standing water on the field for a week immediately after the first step (plowing and harrowing) as this will suppress weeds.
- The first weeding should be done within 10 days after transplanting, even though weeds have not yet grown up much, since this early weeding greatly reduces the need for further weeding.
- Use of rotary weeders not only makes weeding easier, but also improves soil texture and increases soil aeration, supporting root development and more abundant aerobic soil biota.

4.6 Fertilizer Application

DISIMP consultants have proposed a standard chemical fertilizer application rate of 150 kg/ha of urea and 100 kg/ha of super-phosphate (SP36). This is about half the quantity now being recommended by the government's agricultural office. Most of the farmers in Sumbawa, West Nusa Tenggara, are now following the consultant's alternative recommendations. However, many farmers still tend to follow the government recommendation due to the established system of subsidies, which provides fertilizer to farmers at below-market prices. The consultant team, however, is strongly recommending reduced chemical fertilizer application, and at the same time, working more organic matter into the soil. Prevailing practice represents a large waste of resources because the additional fertilizer does not increase yields or improve grain quality. More efforts are necessary to explain to farmers that reducing fertilizer applications can generate more SRI benefits for them.

When all of these methods are put together effectively, eliciting a more robust and productive phenotype from existing rice genotypes, the result is a rice crop that surpasses present crop production levels. Figure 8 shows a farmer from Lombok holding two rice plants of the same variety, grown with SRI and conventional methods, respectively.

Figure 8: Rice plants of same variety and age, grown with SRI methods on left and standard methods on right.

5. Labor Requirements

One of the main reservations that farmers and researchers have had about adopting SRI has been its identification as 'labor-intensive' (Moser and Barrett, 2003). Like any agricultural practice, some time is required for learning the new methods and for gaining confidence in them so that they are used quickly and proficiently. It is not clear why farmers in Madagascar have considered SRI to be more labor-intensive than do most farmers in other countries, including Indonesia. Even in Madagascar, data have shown that beyond the third year, farmers practicing SRI reduce their labor inputs, as well as their seed, water and cash requirements (Barrett et al., 2004).

Labor requirements for SRI cultivation were assessed though interviews with SRI and non-SRI farmers in the Batu Bulan scheme in Sumbawa, West Nusa Tenggara at the end of the 2006 dry season cropping. Table 7 compares the labor requirements of SRI vs. non-SRI in this season using transplanting as the means of crop establishment.

Table 7: Example of Actual Labor Requirements for SRI vs. Non-SRI in Batu Bulan Scheme in West Nusa Tenggara, 2006 Dry Season Cropping

Type of farming activities	Labour requirement (days/ha)		
	Non-SRI	SRI	Difference
Digging temporary ditch	-	1	+ 1
Grid marking	-	1	+ 1
Seedling preparation	5	3	- 2
Transplanting	32	16	- 16
Weeding	20	33	+ 13
Irrigation water management	5	8	+ 3
Fertilizer application	6	3	- 3
Pest control	4	2	- 2
Harvesting	34	40	+ 6
Total	106	107	+ 1

Note: Comparison of 0.35 ha landholding farmers for both non-SRI and SRI

While these data show labor requirements for SRI to be higher than non-SRI for land preparation, weeding, irrigation management, and harvesting, they are less for seedling preparation, transplanting (including transportation of seedlings), fertilizer application, and pest control. Overall, no significant difference in total labor requirements was seen in this cropping season between SRI and non-SRI using transplanting methods. Other evaluations have similarly shown SRI to be labor-neutral or even labor-saving.[6]

Moreover, the present labor requirements for SRI are being continually reduced by farmer-designed tools and implements that make transplanting and weeding quicker and easier. Also, in several countries SRI crop establishment is shifting from transplanting to direct-seeding, which reduces labor requirements by as much as 40% (Ramasamy et al., 2006). This underscores that SRI is not a fixed technology but rather an evolving set of practices based on a core of agronomic insights and principles that change the way rice is cultivated, not just under irrigation but also in upland areas under rainfed conditions (Sinha and Talati, 2005; Kabir and Uphoff, 2007). Instead of labor-intensity being a barrier to SRI adoption, labor-saving is thus becoming an incentive to use and adapt SRI methods.

6. Economic Evaluation

To assess the benefits of SRI versus non-SRI cultivation, a calculation of crop budgets was made for the 2006 dry-season crop, again taking data from the Batu Bulan scheme in Sumbawa, West Nusa Tenggara as an example. This was done without considering any changes in irrigation cost. If the SRI cost-savings from irrigation reduction had been

[6] An evaluation done in Cambodia for GTZ based on random samples of SRI and non-SRI farmers in five provinces (N=500) found no difference overall in labor inputs/ha between SRI and non-SRI cultivation; new SRI farmers needed more than the average and more experienced ones less than the average (Anthofer, 2004). An evaluation of rainfed SRI in West Bengal among upland tribal communities there conducted for the International Water Management Institute (IWMI) documented an 8% reduction in labor needed per ha, with a 67% increase in net income per hectare -- with half of the sample having been subject to serious drought that year (Sinha and Talati, 2005). Researchers from China Agricultural University evaluating SRI adoption in a Sichuan province village, where SRI use had gone from 7 farmers in 2003 to 398 in 2004 found these farmers considering labor-saving the most attractive feature of SRI, more than their water saving (42%) and increased income (38% at constant prices) (Li et al., 2005).

incorporated into this calculation, the economic benefits of SRI would be further increased, well beyond the 174% increase shown.

Table 8: Crop Budget Analysis of SRI vs. Non-SRI Paddy Cultivation, Batu Bulan Scheme, West Nusa Tenggara, Dry Season, 2006*

Item	Units	Unit Price	Non-SRI		SRI	
			Quantity	Amount	Quantity	Amount
A. **Inputs per ha**						
1. Labour						
a. Human	days	20,000	106	2,120,000	105	2,100,000
b. Animal	days	25,000	16	400,000	16	400,000
2. Material						
a Seeds	kg	3,500	50	175,000	7	24,500
b. Chemical fertilizer						
- Urea	kg	1,200	250	300,000	140	168,000
- TSP/SP36	kg	1,600	100	160,000	50	80,000
- KCL	kg	1,800	50	90,000	0	0
- ZA	kg	1,500	50	75,000	0	0
c. Pesticides	lit	112,000	3	336,000	1	112,000
d. Herbicide	lit	37,000	0	0	0	0
3. Sub-contract						
a. Transportation (paddy)	kg	20	4,100	82,000	7,900	158,000
4. Others	L.S.	40,000	1	40,000	1	40,000
Total cost for inputs				**3,798,000**		**3,082,500**
B. **Value of production**	kg	2,200	4,100	**9,020,000**	7,900	**17,380,000**
C. **Net return per ha (B-A)**				**5,222,000**		**14,297,500**

* All costs shown in Indonesian Rupiah: US$1 = 9,100 Rp. at end of 2006

Table 8 shows the production cost for paddy cultivation under SRI to be about 21% less than that for non-SRI cultivation. This due mostly to the decreased cost of material inputs, most notably, 86% reduction for seeds, and 50% reduction for chemical fertilizers and pesticides. The net returns from SRI were about 2.7 times more than with standard rice cultivation methods. These are currently not very profitable, both because of the lower paddy yields and the high cost of agrochemical inputs. Under current economic conditions in Eastern Indonesia, the paddy yield increases of 50% or 100% that SRI can generate will give farmers 2 times or 3 times higher net return, respectively, in comparison with using standard non-SRI practices. Such economic benefits will generate increasing incentives for the uptake and adaptation of SRI methods.

7. Issues for SRI Dissemination

7.1 Differentiating SRI vs. Organic SRI

In Eastern Indonesia, the preparation and use of organic fertilization for SRI is not easy for many farmers to undertake, even though it has additional benefits. When Laulanié synthesized the SRI methodology in 1983 in Madagascar, using organic fertilizer was not part of the system. Only chemical fertilizers were used because it was believed they are necessary to get higher yield. However, when the government changed its policy and cut fertilizer subsidies, Laulanié started using organic fertilizers so that poor and marginal farmers would not be set back. It turned out that such fertilization could give even higher yields, and certainly higher net cash income.

SRI was developed empirically and incrementally (Laulanié, 1993). Accordingly, we expect that its practices will be responsive to changing situations. To facilitate dissemination of SRI, it is important that recommendations meet farmers' expectations and are acceptable to them. Thus DISIMP has adopted a step-by-step approach as follows:

- SRI = Initial stage for SRI, following the original SRI concepts of transplanting single, very young seedlings, with wider spacing, applying intermittent irrigation, and using reduced quantities of chemical fertilizer.
- Organic SRI = A more advanced stage of SRI, using the original practices plus relying only on application of organic fertilizers and organic pesticides.

Some farmers will move quickly to this more advanced stage, while some will remain always with the first stage. This will be a matter of choice: how they want to use their time and resources. However, we see some pressures and incentives building that will make organic SRI more attractive to farmers. Building up the soil's fertility with organic practices improves its structure and makes crops more resistant to biotic and abiotic stresses by, among other things, improving its capacity for water-absorption and -retention. This will encourage farmers over time to move toward more intensive management of plants, soil, water and nutrients in ways that make their crops more resilient as well as more productive and profitable. Also, if consumer demand for chemical-free rice continues to grow and its price rises, this will also reinforce the process of moving away from chemical-dependent rice production. 'Organic SRI' thus has a promising future, although it will not be appropriate for all farmers.

7.2 Extension of SRI Methods

We have found in DISIMP that after almost 5 years of trials and dissemination of SRI methods, despite demonstrations of dramatic increases in yield on many schemes, many farmers are still reluctant to give up their traditional methods and adopt SRI. Most SRI production is on relatively small blocks by individual farmers willing to be innovative, spread out within larger irrigation scheme areas. Exceptions are Kelara Karalloe in South Sulawesi (2,249 ha in the wet season 2005/06) and Karaopa in Central Sulawesi (1,306 ha in the dry season 2006). Both of these schemes have good irrigation infrastructure with enterprising farmers. In both schemes, the initiative for extending SRI has been rapid and farmer-driven, needing only encouragement and advice from consultants and local government.

The conclusion from DISIMP experience is that the SRI method should not be regarded like a conventional agricultural technology innovation, but as a whole cultivation system involving the integration of technical, managerial, social and agricultural variables:

- Good irrigation infrastructure is essential for efficient operation and maintenance, as is whole-hearted participation by farmers.
- Good management and O&M of the irrigation scheme is essential to ensure good farmer participation to facilitate water-sharing and intermittent irrigation.
- Strong and vigorous farmer groups, dynamically interacting and participating in O&M of the main system, are essential for introducing sophisticated intermittent-irrigation techniques.
- Motivated farmers are essential, with high levels of agricultural skills and an acute awareness of possibilities for innovation and increasing yields and crop area. Otherwise, agricultural conservatism will rule, and traditional practices will continue to be used.

Extension of SRI methods is likely to be quickest and most successful on schemes where the above-listed factors are present. The process should be farmer-driven and should be allowed to develop at a pace and rate that farmers are comfortable with. Adaptations should be encouraged to suit local conditions. Experience in DISIMP and other countries indicates that the introduction of SRI itself helps to improve farmers' motivation and desire for new knowledge and skills. Once they see that their previous practices, in which they have had so much confidence, can be surpassed by simple but profound changes in their methods of production, this is a real mind-opener, for many if not all. Also, there should be more than continuous field trials or research. Continuous publicity campaigns by poster, lectures, and other means of communication are also needed, not only at the field level, but at all levels of national, regional and local government that are involved in paddy rice cultivation.

REFERENCES

Anthofer, J. (2004). Evaluation of the System of Rice Intensification (SRI) in Cambodia. Report prepared for GTZ, Phnom Penh [http://www.tropentag.de/2004/abstracts/full/399.pdf].

Barrett, C.B., C.M. Moser, J. Barison, and O.V. McHugh (2004). Better technologies, better plots or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *American Journal of Agricultural Economics* 86: 869-888.

Bonkowski, M. (2004). Protozoa and plant growth: The microbial loop in soil revisited. *New Phytologist* 162: 616-631.

Chaboussou, F. (2004). *Healthy Crops: A New Agricultural Revolution.* Jon Carpenter Publishing, Charnley, UK.

Dazzo, F.B. and Y.G. Yanni (2006). The natural rhizobium-cereal association as an example of plant-bacteria interaction. In: N. Uphoff et al., eds., *Biological Approaches to Sustainable Soil Systems*, CRC Press, Boca Raton, FL, 109-127.

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

Doebbelaere, S., J. Vanderleyden and Y. Okon (2003). Plant growth-promoting effects of diazotrophs in the rhizosphere. *Critical Reviews in Plant Science* 22: 107-149.

Feng, C., S-H Shen, H-P Cheng, Y-X Jing, Y. G. Yanni and F. B. Dazzo (2005). Ascending migration of endophytic rhizobia, from roots to leaves, inside rice plants and assessment of benefits to rice growth physiology. *Applied and Environmental Microbiology* 71:7271-7278.

Gani, A., T. S. Kadir, A. Jatiharti, I. P. Wardhana and I. Las (2002). The System of Rice Intensification in Indonesia. In: N. Uphoff, E. Fernandes, L.P. Yuan, J.M. Peng, 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.

Kabir, H. and N. Uphoff (2007). Results of dissemination the System of Rice Intensification with farmer field school methods in Northern Myanmar. *Experimental Agriculture* 43, forthcoming.

Kar, S., S.B. Varade, T.K. Subramanyam and B.P. Ghildyal (1974). Nature and growth pattern of rice root system under submerged and unsaturated conditions. *Il Riso* (Rome) 23: 173-179.

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

Li, X-Y., X-L. Xu and H. Li (2005). A socio-economic assessment of the System of Rice Intensification (SRI): A case study from Xinsheng Village, Jianyang County, Sichuan Province. Center for Integrated Agricultural Development, China Agricultural University, Beijing.

Margulis, L. and D. Sagan (1997). *Microcosmos: Four Billion Years of Microbial Evolution*. University of California Press, Berkeley.

McDonald, A.J., P.R. Hobbs and S.J. Riha (2006). Does the System of Rice Intensification outperform conventional best management? A synopsis of the empirical record. *Field Crops Research* 96, 31-36.

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.

Neupane, R.B. (2003). System of Rice Intensification (SRI) – A new method of rice cultivation. National Wheat Research Programme, Bhairawa, Nepal.

Ramasamy, S., C. Susheela and K. Satyamoorthi (2006). 'Direct Planting System' – Energy-Saving, High-Output Rice Establishment Technique for Lowland. Poster for 2nd Intl. Rice Congress, New Delhi, October 9-13, submitted from Tamil Nadu Agricultural University.

Randriamiharisoa, R. and N. Uphoff (2002). Factorial trials evaluating the separate and combined effects of SRI practices. In: N. Uphoff, E. Fernandes, L.P. Yuan, J.M. Peng, 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. 40-46. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY (http://ciifad.cornell.edu/sri/proc1/sri_10.pdf)

Randriamiharisoa, R., J. Barison and N. Uphoff (2006). Soil biological contributions to the System of Rice Production. In: N. Uphoff et al., eds., *Biological Approaches to Sustainable Soil Systems*, 409-424. Boca Raton, FL: CRC Press.

Rickman, J.F. (2003). Preliminary results: Rice production and the System of Rice Intensification. International Rice Research Institute, Los Baños, Philippines.

Rosenzweig, C., A. Iglesias, X.B. Yang, P.R. Epstein and E. Chivian (2001). Climate change and extreme weather events: Implications for food production, plant diseases, and pests. *Global Change and Human Health* 2:2, 90-104.

Sheehy, J. E., S.B. Peng, A. Dobermann, P.L. Mitchell, A. Ferrer, J.C. Yang, Y.B. Zou, X.H. Zhong and J.L. Huang (2004). Fantastic yields in the system of rice intensification: Fact or fallacy? *Field Crops Research* 88, 1-8.

Sato S. (2006). An evaluation of the System of Rice Intensification (SRI) in Eastern Indonesia for its potential to save water while increasing productivity and profitability. Paper for International Dialogue on Rice and Water, IRRI, Los Baños, March 7-8 (http://ciifad.cornell.edu/sri/ countries/indonesia/wwfindosato06.pdf).

Satyanarayana A., T. M. Thiyagarajan and N. Uphoff (2007). Opportunities for water-saving with higher yield from the system of rice intensification. *Irrigation Science*, 25: 99-115.

Sinclair, T.R. and Cassman, K.G. (2004). Agronomic UFOs? *Field Crops Research* 88: 9-10.

Sinha, S.K. and J. Talati (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 Report 47. International Water Management Institute, India Program, Anand.

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

Surridge, C. (2004). Feast or famine? *Nature* 428, 360-361.

Uphoff, N. (2003). Higher yields with fewer external inputs? The System of Rice Intensification and potential contributions to agricultural sustainability. *International Journal of Agricultural Sustainability* 1, 38-50.

Uphoff, N. (2006). Increasing water savings while raising rice yields with the System of Rice Intensification (SRI). Paper for 2nd International Rice Congress, New Delhi, October 9-13.

Uphoff, N., A. Ball, E. Fernandes, H. Herren, O. Husson, M. Laing, C. Palm, J. Pretty, P. Sanchez, N. Sanginga and J. Thies, eds. (2006). *Biological Approaches to Sustainable Soil Systems*, CRC Press, Boca Raton, FL.

Uphoff, N. (2007). The System of Rice Intensification: Using alternative cultural practices to increase rice production and profitability from existing yield potentials. *International Rice Commission Newsletter*, No. 55, Food and Agriculture Organization, Rome.

Uphoff, N., A. Kassam and W.|S. Stoop (2007). Comparing the System of Rice Intensification vs. best management practices: A review of diverse errors. Paper submitted to *Field Crops Research*.