INCREASING WATER SAVINGS WHILE RAISING RICE YIELDS WITH THE SYSTEM OF RICE INTENSIFICATION (SRI)

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Introduction

Competition among alternative uses for surface and ground water is beginning to affect the agricultural sectors of many countries in this new century. As the largest agricultural consumer of water, the rice sector is coming under increasing pressure to economize on water use. Finding ways to reduce the demand of rice producers for fresh water is thus a major concern for farmers, researchers, administrators, and policy makers.

The System of Rice Intensification (SRI) developed in Madagascar over 20 years ago (Laulanié, 1993) offers an opportunity for reducing the rice sector's demand for water while raising yields. By keeping paddy soil moist but not continuously saturated, either (a) by making minimum daily applications of water or (b) by alternately wetting and drying rice paddies, SRI cuts the water required for irrigated rice production by 25-50%. By creating more aerobic soil conditions that are beneficial for the rice crop, the combination of water reduction together with other SRI practices can increase paddy yields by 50-100% or more. By reducing the costs of production at the same time that they raise output, full and proper use of SRI practices enhances the profitability of irrigated rice production, which gives farmers financial incentive to undertake water-saving cultivation.

These positive-sum dynamics of SRI have seemed too good to be true, but SRI effects have now been demonstrated in 24 countries across Asia, Africa and Latin America, including the three largest rice-producing countries: China, India and Indonesia. This paper reviews the water-savings possibilities with SRI that can accompany increases in rice yield and profitability. An initial tradeoff/constraint has been the need for greater investment of labor while the new methods are being learned. However, several independent evaluations have shown that SRI can even become *labor-saving* at the same time that water, seeds, and production costs are saved.

An additional opportunity for increasing rice production is the development of *rainfed versions* of SRI in the Philippines, India and Myanmar. Adaptations of SRI concepts and practices to unirrigated upland rice production have given yields in the 4-8 t/ha range (Gasparillo, 2003; Kabir, 2006; PRADAN, 2006). However, this will not be addressed in this paper, which focuses on water savings in irrigated rice production. SRI should be regarded as a work in progress. It is an integrated crop management system still being adapted and further developed as more users and more researchers become involved in utilizing and elaborating on its insights and principles for attaining higher productivity of land, labor, capital, and (especially) water.

Balancing the Requirements of Soil, Water and Air

It has long been believed that rice "thrives on land that is water saturated, or even submerged, during part of all of its growth cycle… most rice varieties maintain better growth and produce higher grain yields when grown in a flooded soil than when grown in nonflooded soil" (De Datta, 1981: 41, 297-298). However, rice grown in soil that is moist but not continuously saturated can in fact give higher yields, as indicated by the title of a literature review by IWMI staff members, *Producing More Rice with Less Water in Irrigated Systems* (Guerra et al., 1998).

Rice plants grown conventionally but under well-drained soil conditions can give a yield 5-10% higher than if flooded, and sometimes more (see e.g., Ramasamy et al., 1997; Lin et al., 2005). However, managing water carefully so as to maintain an optimum balance between water and air in the soil is more costly in terms of labor time and often money. For any given porosity of the soil, the amounts of these two elements, air and water, which are both necessary for plants' growth and health, will be inversely related in the soil. Maintaining an optimum balance between the two is not automatic or easy. For farmers to change their long-standing water management practices -- making more effort to control water levels than is required just to keep fields flooded -- there needs to be some incentive to invest resources in this aspect of irrigated rice production, an incentive that is now available with the advent and spread of SRI.

2. The System of Rice Intensification

SRI has been characterized in various publications (Laulanié, 1993; Stoop et al., 2002; Uphoff, 2003; Horie et al., 2005), so only a brief description is needed here. Table 1 contrasts SRI practices with common rice-growing methods. When these alternative practices are employed, *different, more productive phenotypes* can be induced from most genotypes of rice (*Oryza sativa*), as seen graphically in Figure 1. The various changes observable and measurable with SRI are described in Table 2. The specific comparison of phenotypical differences shown in Figure 1 is from studies conducted at the China National Rice Research Institute where the same rice variety was grown under SRI and control (CK) conditions, respectively (Tao, 2004). SRI methods by altering plants' growing conditions evoke tillering and grain filling responses that are quite different from those produced by conventional practices, as evident from Table 2.

[Tables 1, Table 2 and Figure 1 about here]

SRI has sometimes been considered too labor-intensive for widespread adoption (Moser and Barrett, 2003), but this appears to be a time-dependent assessment. A number of evaluations have shown that SRI can become *labor-saving* once methods and skills have been mastered (e.g., Anthofer et al., 2004; Li et al., 2005; Sinha and Talati, 2005). Even though the effects reported in Table 2 are not yet accepted in all quarters, SRI practice is beginning to spread rapidly in a number of countries, and its benefits have now been seen and documented in 24 nations.

3. SRI Results in Irrigated Rice Production

Typical effects of SRI practices on yield, water requirements, costs of production, and net farmer incomes are summarized in Table 3, from evaluations done in various countries covering >4,800 on-farm evaluations. The agencies conducting these evaluations had no stake in the validation of SRI; they included the India and Sri Lanka programs of the International Water Management Institute (IWMI); the German development agency GTZ; the Japanese consulting firm Nippon Koei; China Agricultural University, Tamil Nadu Agricultural University and Andhra Pradesh Agricultural University (ANGRAU); and Syngenta Bangladesh Ltd. from the private sector.

The average increase in paddy yields across all these evaluations, even with farmers not necessarily using all of the recommended practices or using them as recommended, was 52%. This increase was accompanied by water savings assessed at farm level ranging from 25 to 50%, with an average reduction in water use of 44%. At the same time, because of reduced reliance on external inputs, farmers' costs of production were reduced on average by 25%. This financial saving when coupled with higher yield produced an average increase in net income per hectare from rice production of 128%. A benefit for millers and consumers, if not necessarily for farmers, was a higher milled rice outturn from SRI paddy, about 15%. Some of this increase in net rice productivity can be captured for farmers if and when a higher price is paid for SRI paddy.

[Table 3 about here]

In regions such as central and southern India where water scarcity is becoming a major constraint on the production of paddy rice, the potentials for water saving are a stronger impetus for SRI adoption than either yield or profitability considerations (Murthy et al., 2006). In Andhra Pradesh, where SRI was first introduced in 2003 -- and where the results shown in Table 3 are becoming widely known -- SRI methods were used on 40,000 ha three years later, according to Dr. Jagannadha Reddy, ANGRAU, in a report to a meeting on SRI convened at ANGRAU, 29 June 2006. An NGO working with the Andhra Pradesh Department of Irrigation on introducing SRI to farmers reports that SRI methods reduce demand for scarce water by 50% in most cases, and by up to 70% in some cases, while paddy yields are generally doubled (Jalaspandana, 2006).

The range of water saving achieved or attainable with SRI will vary of course according to many factors: the extent of current (over)use, soil characteristics, climate, physical control structures, and water management capabilities at the farm, channel and system levels. Because SRI results depend on the appropriate management of plants, soil, water and nutrients to capitalize upon biological processes and potentials -- rather than on applying external inputs or introducing new genotypes -- results can be quite variable, influenced by interactions between the plants and the soil systems in which they grow. The figures cited above and in Table 3 are averages.

If water supplies are not controlled, i.e., if continuous inundation of soil creates hypoxic conditions that adversely affect root growth and functioning and also constrains biodiversity in the soil, we cannot expect particularly impressive results with SRI. Nor can good results be expected if soil management practices and the application of agrochemicals inhibit or impair the functioning of soil biota. These diverse, interacting organisms are largely ignored in conventional rice science analyses; however, they become central figures in SRI evaluation and practice (Randriamiharisoa et al., 2006).

SRI results underscore that the age-old practice of always flooding rice crops has negative consequences. However, if other adverse practices are followed, e.g., high plant density, use of older seedlings, or traumatizing of roots during transplanting, this consequence may not be very evident. One can readily discern the negative effects of flooding on rice plants by observing a poorly-leveled rice paddy, with some areas within the field being higher and others lower. Those plants growing in the elevated areas usually prosper compared to those in the low-lying patches.

While rice is physiologically able to survive in saturated soil, it does not thrive under those conditions. The roots of inundated rice plants degenerate (Kar et al., 1974; Kirk and Bouldin, 1991), and this makes the plants dependent upon exogenous provision of (inorganic) nutrients. Such root systems cannot themselves avail the plant of nutrients from organic sources and through biological processes, reviewed in Randriamiharisoa et al. (2006).

The statements made about water saving with SRI refer at present only to *field-level* reductions. Making *system-level* savings based on SRI methods will depend on large-scale adoption so that total volumetric issues to command areas can be cut back. This should be possible once there is large-scale conversion of production systems and appropriate changes in the control capabilities and management of irrigation systems.

SRI will probably gain widest acceptance and give the most benefit where rice is irrigated with groundwater. When irrigation water is pumped to fields, there is both more economic incentive and greater infrastructural ability to reduce applications and to coordinate water deliveries.

It is also possible that future water savings with SRI methods will be still greater than measured to date. The standard SRI recommendation on water management has been to apply minimum amounts of water to the crop during the vegetative growth phase, but then to maintain a shallow layer of water (1-2 cm) after panicle initiation. Farmer experiments and subsequent evaluation are indicating that continuing alternate wetting and drying of the paddy throughout the entire crop cycle may meet crop water requirement and reduce total water applications. This, however, will probably not be successful on certain clay soils which become unmanageably hard if they ever dry out completely during the crop season. Such considerations necessarily qualify any SRI generalizations.

4. Discussion

Water management in particular is a subject within SRI on which much systematic research remains to be done -- and under a wide variety of soil conditions to determine variations and ranges of practices, rather than offer any one-size-fits-all conclusions. With SRI, the water regime recommendations need to be adapted to local differences in soil structure, water-retention capacity, physical means of water control, the reliability of continuing water supply, and costs of labor.

While the elements of SRI are each rather simple, putting them together and using them requires analysis, experimentation and evaluation, by farmers as well as (other) professionals. This is what makes SRI management-intensive as an alternative strategy to input-intensity. SRI promotion is intended to upgrade the human resources involved in agriculture as well as the productivity of all resources employed. The efforts made with, for and by farmers to engage them in this process is not considered just as a cost, however, but also as a benefit – an investment – in the modernization of agriculture.

As noted already, SRI is work in progress. No single or simple conclusions are warranted at this stage as the data base is not yet extensive enough. We can say that almost all evaluations have found SRI methods to raise the *factor productivity* of the land, the labor, the water, and/or the capital utilized in irrigated rice production. Increasing the productivity of resources used to grow rice is the real objective – more than raising yield as such. While agronomists vie to set yield records, farmers are concerned with the net productivity – and specifically, the net income earned – from their agricultural practices.

The controversy raised recently by McDonald et al. (2006) over whether SRI yields surpass those of 'best management practices' (BMP) is a fruitless diversion. Apart from the fact that their data base did not represent 'a synopsis of the empirical record,' as claimed, and their criteria for what constitutes SRI and BMP were neither defensible nor consistently applied, the comparison made – which considered neither water saving nor effects on farmers' income – is irrelevant to farmers and policy-makers alike. There is more than enough evidence from a variety of reputable sources (Table 3) that SRI methods are beneficial for farmers and for the environment and farmers are taking up these methods at an accelerating rate.

The challenge for scientists is to engage with the new practices and their results in a realistic way, looking for their limits and flaws, as well as for possible future emergent problems. No claim is made that SRI is a solution for all rice sector challenges, but it can probably meet the multiple objectives that IRRI has mapped out for the sector for the 21st century better than any other path of innovation on the horizon.

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Table 1: SRI methods contrasted with conventional practice

Conventional Practices	SRI Methods
Relatively mature seedlings are transplanted at 3-4 weeks of age	**Very young seedlings**, 8-12 days old, are transplanted; maximum of 15 days old, i.e., before the start of the 4^{th} phyllochron of growth (Nemoto et al., 1995)
Multiple seedlings (3-4 per hill) are transplanted in clumps, usually plunging them deep into flooded (hypoxic) soil	**Single seedlings** are transplanted quite shallow (1-2 cm) into a muddy but not flooded field after being uprooted gently from an unflooded, garden-like nursery
Large plant population is established in rows, with a seed rate of 50+ kg ha^{-1}	**Sparse plant population**, widely spaced in a square pattern (at least 25x25 cm) with a seed rate of only 5-10 kg ha^{-1}
Soil inundation with rice paddies kept flooded throughout the growing cycle	**Soil aeration** is maintained during the vegetative growth period, no continuous soil saturation; after panicle initiation, shallow flooding, 1-2 cm; in some soils, alternate wetting and drying throughout cycle is preferable; some SRI farmers continue AWD throughout the crop cycle
Weeds are controlled by flooding and also by hand weeding and/or **herbicides**	**Weeds are controlled with a rotary hoe** that aerates the soil as it eliminates weeds; weeding 2-5 times before the canopy closes
Chemical fertilizer is applied, providing up to 100-150 kg ha^{-1} N; organic fertilizer is optional; little/no attention to soil biota	**Compost** is recommended, as much as possible, to build up soil organic matter; this supports larger populations of soil biota; fertilizer can be used with other SRI methods, but compost gives best results

Adapted from Randriamiharisoa et al. (2006).

Table 2: Phenotypical differences in rice plants and grains associated with SRI practices

Measured/Observable Differences:
• **Tillering:** 30-50 tillers plant^{-1} are common with SRI methods, but 100 or more can be attained with good use of the methods and with biologically-enriched soil
• **Root Growth:** larger root systems, with healthy white coloration; root-pulling resistance (RPR) is increased by 5-10 times per plant
• **Grain Filling:** *positive* correlation between number of panicles and size of panicles; this is contrary to typical rice phenotypes grown with continuous flooding, for which the correlation is *negative*; usually the percentage of unfilled grains is much reduced
• **Grain Weight:** an increase of 5-15% is common, which contributes to higher yield; this can occur without an increase in grain size, because of greater grain density
• **Reduced Time for Maturation:** often 1-3 weeks less time for the same variety to ripen if SRI methods are used – while simultaneously giving higher yield
• **Grain Quality:** ~15% higher outturn of milled rice from SRI paddy, due to less chaff (fewer unfilled grains) and less shattering (fewer broken grains) during milling, a reflection of the higher grain density; also less chalkiness of grains (Jun, 2004).
Reported Differences:
• **Resistance to Pests and Diseases:** it is widely reported by farmers that pests and diseases do not cause enough damage to warrant the use of agrochemical biocides
• **Resistance to Drought, Wind and Rain Damage, and Cold Temperatures:** larger root systems appear to account for the resistance to drought and cold as well as little or no cyclone and typhoon damage (observed in India, China and Sri Lanka); with SRI, despite larger panicles, lodging is rare even under extreme weather conditions

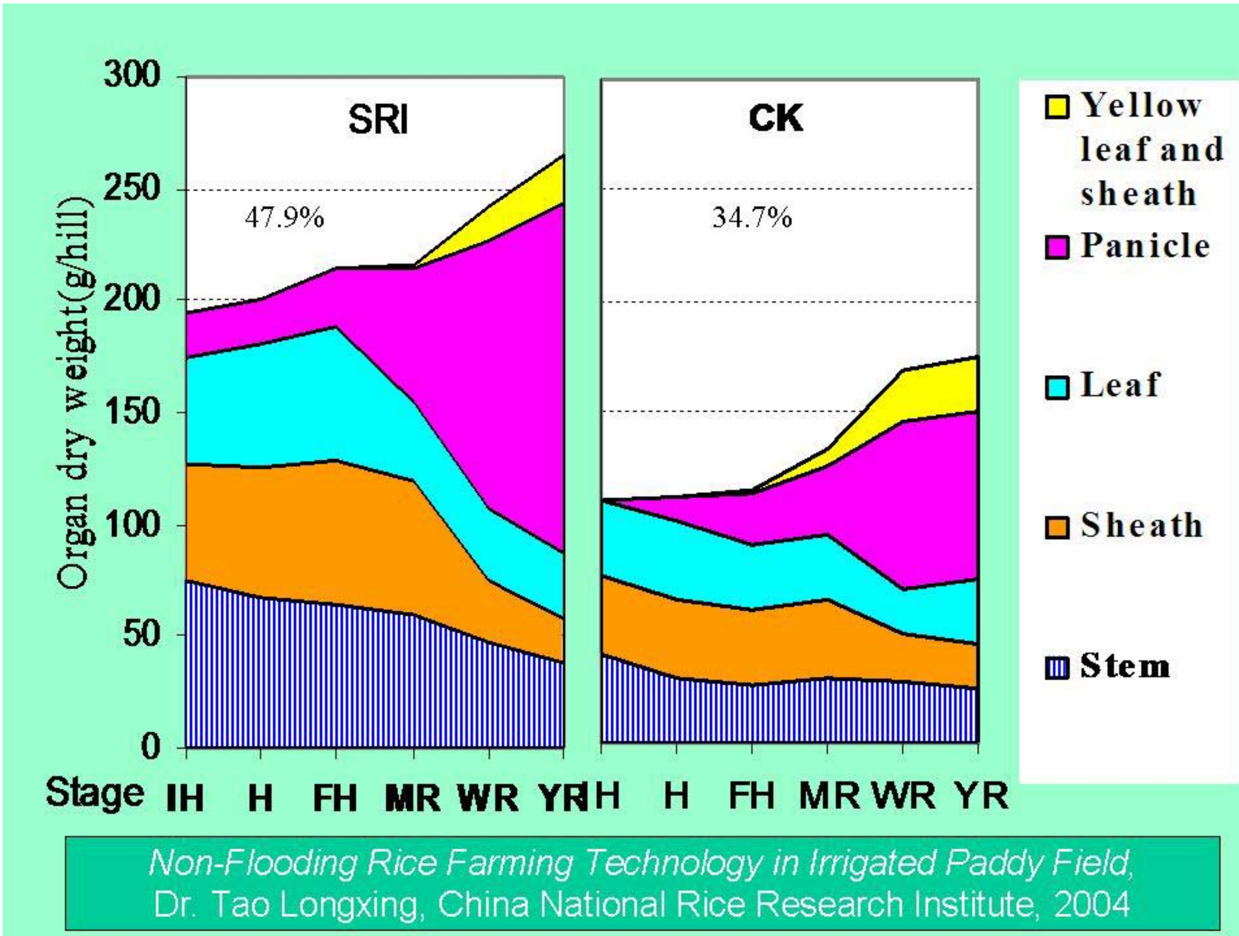
Adapted from Randriamiharisoa et al. (2006).

Table 3: Summary on SRI effects on yield, water saving, cost reduction, and net income

Country	Evaluation done by/for:	Yield Increase	Water-Saving	Reduc-tion in Costs	Increase in Net Income	Data Base and Comments
BANGLA-DESH	BRAC/SAFE/ POSD/BRRI/ Syngenta-BD Ltd., funded by IRRI Bangladesh prog. (Hossain, 2004)	**24%**	Not meas-ured	**7%**	**59%** (32- 82%)	On-farm evaluations (N=1,073), funded by IRRI PETRRA project
CAMBODIA National survey covering 5 provinces	GTZ commissioned evaluation (Anthofer et al., 2004)	**41%**	Flooding at TP from 96.3% to 2.5%	**56%**	**74%**	Random sample survey of 400 SRI users and 100 non-users (N=500)
Long-term SRI users: 36 villages in 5 provinces	CEDAC (Tech, 2004)	**105%**	**50%**	**44%**	**89%**	Farmers who had used SRI for 3 years (N=120)
CHINA Xinsheng village, Sichuan province	China Agricultural University (Li et al., 2005)	**29%**	**44%**	**7.4%**	**64%**	SRI use in village had gone from 7 in 2003, to 398 in 2004 (N=104)
INDIA **Tamil Nadu:** Tamiraparani river basin	Tamil Nadu Agricultural University (Thiyagarajan et al., 2005)	**28%**	**40-50%**	**11%**	**112%**	On-farm trials supervised by TNAU and state ext. service (N=100)
Andhra Pradesh: All 22 districts	Andhra Pradesh Agric. University (ANGRAU) (Satyanarayana et al., 2006)	**38%**	**40%**	**NA**	**NA**	On-farm trials supervised by ANGRAU and State ext. service (N=1,525)
West Bengal: Purulia district	IWMI-India (Sinha and Talati, 2005)	**32%**	Rainfed version of SRI	**35%**	**67%**	SRI use in demo villages had gone from 4 farmers to 150 in 3 seasons
INDONESIA S. Suluwesi and Nusa Tenggara provinces	Nippon Koei-Decentralized Irrigation Systems Irrig.Mgmt. Project (Sato, 2006)	**84%**	**40%**	**24%**	**412%**	3 years of on-farm evaluation trials on 1,363 ha (N= 1,849)

NEPAL Morang district	Morang District Agricultural Development Office (Uprety, 2005)	**82%**	**43%**	**2.2%** Rotary hoes not yet widely available	**163%**	SRI users in the district went from 1 in 2003 to >1,400 in 2005 (for data: N=412)
SRI LANKA Ratnapura and Kurunegala districts	IWMI (Namara et al., 2004)	**44%**	**24%**	**11.9-13.3%**	**90-117%**	Survey of 60 SRI users and 60 non-users, randomly sampled (N=120)
VIETNAM Dông Trù village, Hanoi province	National IPM Program (Uphoff, 2006)	**21%**	**60%**	**24%**	**65%**	Record-keeping by Farmer Field School alumni on SRI results
AVERAGE		**52%**	**44%**	**25%**	**128%**	

Figure 1: Comparison of Organ Dry Matter in SRI vs. Conventionally-Grown Rice Plants at Different Stages of Growth in the Crop Cycle



Source: Tao (2004).