THE SYSTEM OF RICE INTENSIFICATION DEVELOPED IN MADAGASCAR

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A concern with how biophysical conditions in the tropics affect, condition or constrain agricultural productivity in these regions focuses attention on the impacts of *environmental variations at the macro scale* on the expression of *genetic potential at a micro scale*. This is an important subject that throws interesting light on current efforts and opportunities to use biotechnology to modify genetic endowments for productivity gains.

In the past, genetic strategies to improve agricultural output have often proceeded with little regard for environmental factors, as they sought better genomic "packages" that could succeed across a wide variety of ecological conditions. Indeed, the strategy of the Green Revolution was premised on finding genotypes that would yield productive phenotypes across a wide range of microenvironments.

It is hard to make a persuasive case that the Green Revolution did not produce important benefits for the world, including for the world's poor. But it is also hard to make a case that all genomic research, including genetic modification, be halted or put on hold. Genomic research with priorities determined by considerations of profitability is not likely to reduce significantly the problems of world hunger and malnutrition. But there is probably potential in genetic research that could benefit large numbers of persons if directed toward that purpose.[1]

This paper will give an example – of rice -- where the modification of plant growth environments *on a micro scale*, particularly within the rhizophere (root zone), can greatly increase production, not just by increments but by multiples. This is done by capitalizing upon *existing genetic potentials* that have for thousands of years been suppressed by crop, soil, water and nutrient management practices when growing irrigated rice.

Since most research and investigation these days focuses on changing genetic potentials, it is not possible to say how many benefits from changing management, rather than genes, are attainable with other crops. This paper suggests that amidst the current enthusiasm for genetic research -- focused at microscopic levels -- there is good reason to continue research on crop management at organismic and field levels.

[1] See Ruttan (1999). About 40% of current biotechnology research is focused on herbicide-tolerance, for example. While this can reduce the cost of weed control , it adds little to crop yields.

The simple scientific reason for this is that we live (and die) according to phenotypes, not genotypes. And phenotypes are the product of GxE interactions – interactions between genetic endowments and environments -- with many of the most important effects coming from these interactions rather than from the addition of genetic and environmental influences separately (see Lewontin 2000; and van de Weele 1999).

The System of Rice Intensification (SRI) in Madagascar

This is not the occasion or the place to present a full-scale description of this methodology for growing rice, developed by a French priest, Fr. Henri de Laulanié, S.J., in the early 1980s in Madagascar, after 20 years of working with farmers to assess and learn from their rice-growing practices. This methodology, different from a standard kind of technology, has been presented elsewhere (Uphoff, 1999 and 2002; also Stoop et al., 2002). It will thus be described here only in brief. The purpose of this paper is to make the case that attention to management and to whole organisms and their interactions with their environments is worthy of attention.

With SRI methods, farmers in Madagascar – where rice yields average about 2 tons per hectare (t/ha), even with irrigation – have been able to get yields averaging around 8 t/ha, with top yields in the 15 to 20 t/ha range, above what has usually been considered to be the biological maximum (Khush and Peng 1996). This is done without new seeds or chemical fertilizers, and with considerably less water, a remarkable example of achieving 'more with less.' With SRI methods, the productivity of land, of labor, of capital, and of water is increased concurrently. This sounds 'too good to be true,' but results from as many as 15 countries now supports SRI's validity.

CIIFAD began working with Association Tefy Saina (ATS), a small Malagasy NGO, in the peripheral zone around Ranomafana National Park in 1994. Our challenge, under a USAID-supported conservation and development project, was to give farmers there an alternative to continuing to grow slash-and-burn upland rice. So long as farmers there could get only about 2 t/ha from their limited irrigated lowland, they would need to continue encroaching on the park's precious rain forest ecosystem. (The world average rice production presently is about 3.7 t/ha.)

The first year (1994-95), 38 farmers averaged over 8 t/ha, which seemed too good to be true. Indeed, for the first two years, I gave such results little credence, but they continued through a third and a fourth year. When we calculated yield figures over four years, with 275 farmers using SRI methods in 1997-98 on over 50 hectares of land, the average came to **8.8 t/ha**, with some farmers in the 14-16 t/ha range.[2] This was on soils that NC State researchers had concluded were some of the poorest in the world.[3]

In 1994-95, 108 farmers in two regions on the high plateau, over 1200m (whereas the elevations around Ranomafana ranged from 400m to 1200m), tried SRI methods under the supervision of a French technical assistance advisor. The typical yields there, higher than around Ranomafana

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[2] North Carolina State University in previous efforts to raise rice yields around Ranomafana, using new seeds (high-yielding varieties) and chemical fertilizer, had gotten average yields up to 3 t/ha, with a maximum of 5 tons (del Castillo and Peters 1994).

[3] Johnson (1994) found the soils to be very acidic (pH 3.8-4.5), with low cation-exchange capacity, extremely deficient in phosphorus (exchangeable P only 3-4 ppm), and exhibiting serious iron and aluminum toxicity. Johnson's conclusion was that yields could be increased only with use of fertilizer, not compost or other organic inputs, because of low inherent soil fertility.

because more modern practices were already being used, were 3.2 to 3.9 t/ha. The average yields in the two regions were **6.4 to 8.0 t/ha** (MADR/ATS 1996).

When the World Bank held a symposium on rice in Madagascar in 1996, two private companies reported on their yields achieved on farmers' fields with "modern" inputs, mostly improved seeds and chemical fertilizer – 4.8 and 6.2 t/ha (Rakotonirina 1996; Tang-Po 1996). Almost as asides, both reports mentioned that farmers who were using SRI in their areas (Marovoay and Andapa) were averaging **7.1** and **10.2 t/ha** -- 48 to 64% higher without using any purchased inputs. Indeed, Tang-Po said that four farmers around Andapa planting improved variety IR-46 averaged 13.7 t/h, and one reached 16.3 t/ha

More recently, a report on the rice sector in Madagascar done for the French development agency (Hirsch 2000) reported average yield differences for SRI compared to the government-recommended "improved" technology (SRA) and peasant practices (PP) for farmers growing rice in small-scale irrigation schemes (perimetres) that the agency had helped improve in two high-plateau regions. The five-year averages (1994-95 to 1998-99) were as follow:

	Antsirabe	Ambositra
PP	2.47	2.24
SRA	3.95	3.58
SRI[4]	**7.91**	**9.18**

In the 1999-2000 season, our CIIFAD staff at the Beforona research station east of the capital Antananarivo planted rice with SRA and SRI methods in adjacent fields. Where peasant practices produced about 2-2.5 t/ha, SRA yielded 5.2 t/ha while SRI methods got **10.1 t/ha**.

Yields are bound to differ, from area to area and from year to year. Soil and other local factors differ between locations, over distances of tens of meters, and between years, given climatic and other variations. With SRI, another factor affecting yields is the *skill* and *knowledge* with which farmers manage the plants, soil, water and nutrients. Thus one should not expect the same results everywhere from any given set of practices. But the pattern and range of SRI results is quite common across time and space in Madagascar, showing about a four-fold increase in production over present average levels, and more than double the present world average.

SRI Yield Results in Other Countries

It has been difficult to get researchers outside of Madagascar to take SRI seriously enough to give it proper evaluations. The three trials that have not shown superior results with SRI methods (the first trials with SRI at the West African Rice Development Association in the Ivory Coast; CIIFAD trials in Nepal; and IRRI trials in Madagascar) were all conducted with the rice paddies flooded during the growth phase, which is contrary to SRI theory and methodology. Where the methods have been tried according to the theory and recommended practices, there have been very positive results.

In 1999, researchers at Nanjing Agricultural University in **China** tried SRI and got yields between **9.2** and **10.5 t/ha**, the higher yields with the wider spacing (30x30 cm). At the

[4] The area under SRI went from 22.55 ha in 1994/95 to 66 ha in 1998/99 around Ambosita; it went from 11.85 ha to 476.75 ha during this same period around Antsirabe.

Sukamandi research station in **Indonesia**, where Green Revolution technologies have been tested and disseminated, SRI methods in 1999 wet season yielded **6.8 t/ha**, and in the following dry season, **9.5 t/ha**. This compares with a national average yield of 4.2 tons, and yields of about 5 t/ha in that area.

NGOs have been quicker to show interest in SRI than have regular rice researchers. In the **Philippines**, the Consortium for Development of Southern Mindanao Cooperatives reported carefully measured yields of **4.95 t/ha** on farmers' fields last year, noting however that SRI methods were not followed in all respects; keeping fields unsaturated goes against farmers' instincts. But farmers were so impressed by the results that they intend to follow the methods more carefully this year, since their yields with SRI were two to three times their usual level. The Philippine national average is 2.8 t/ha.

In **Cambodia**, farmers cooperating with CEDAC have gotten **6-8 t/ha** with SRI, and even higher yields are now expected from the best farmers using these methods. Cambodian average yields are about 1.7 t/ha. We are only starting to get results from **Sri Lanka**, but the Ministry of Agriculture reported that the first harvests from farmers' fields this past season averaged about 8.5 t/ha, with one farmer reaching over 15 t/ha. (A former Minister of Lands himself got over 12 t/ha average on his fields near Batalagoda, with one plot reaching 17 t/ha; he has become a strong supporter of SRI extension.)

The **Bangladesh** Rice Research Institute recently reported that it got 1 t/ha more yield (**5.3 t/ha**) with SRI methods in the wet (*aus*) season than a high yield with the standard improved production methods. While this is not a big increase compared to what we have seen in other countries, researchers considered this a "radical change" and want to experiment more with SRI. The CARE program in Bangladesh reported a 40% increase in yield with SRI methods during the past *aus* season. Both sets of researchers expected they could get considerably higher yields with SRI during the next dry (*boro*) season. Farmers working with the Department of Agricultural Extension in Kishoreganj district have averaged over 7 t/ha., and those working with CARE in the same district have average 6.5 t/ha So there is considerable potential there.

In other countries, as varied as Myanmar, The Gambia, Sierra Leone and Cuba, we are finding SRI methods increasing yields for poor farmers by 2 to 3 times, without requiring purchased inputs and using less water. These are changes that are very much welcome, as the SRI methods were developed to be particularly accessible to resource-limited households.

The conclusion that I draw from these diverse results from different countries, obtained mostly on farmers' fields under widely varying and non-comparable conditions, is that this methodology shows promise of increasing production substantially -- not by changing the genome of rice plants or by using agrochemicals to boost output. However, we do not want to present SRI as an alternative to genetic improvement, since some HYVs respond most prolifically to SRI methods. The National Center for Hybrid Rice Research and Development in China has begun testing SRI methods to raise the yields of its hybrids, and has gotten very favorable results. The very highest yields with SRI methods, from 12 to 20 t/ha, have been achieved with improved varieties such as IR-15, IR-46, Taichung 16, and BG-358.

The SRI Methodology

By now, readers must be very curious about what methods can give these very positive results. The first thing to stress is that SRI is a *combination* of practices (a) that need to be used with *appropriate adaptation to local conditions*, and (b) that have *synergistic effects* on one another. The extent and mechanisms of such synergy have not been well studied, so what is reported here comes mostly from observation, though there are some thesis research projects that have given some precise and systematic measurements, which support what has been observed.

The basic strategy with SRI is to create soil, water and nutrient conditions for the young plant that are so favorable that its growth, when handled carefully, is accelerated. There are three dramatic observable and measurable effects:

(1) There is much greater **root growth**, which supports (2) and (3). A test of *root resistance*, which is a proxy for measuring total root development (O'Toole and Soemartono 1981), found that it took *more than 5 times* as much force (53 kg) to uproot a single SRI rice plant as to pull up a clump of three rice plants conventionally grown (28 kg) (Joelibarison 1998).

(2) There is much greater **tillering**, with SRI plants having 30, 50, even 80 or 100 or more tillers, compared to the more common number of 5 to 10. Why rice plants have so many more tillers with SRI management methods can be explained by the physiology of rice, like other grain-producing members of the *gramineae* (grass) family, in terms of *phyllochrons*. These are intervals of plant vegetative growth discovered in the 1920s and 1930s by a Japanese researcher (Katayama 1951). Unfortunately, they are little known in the English-speaking world (Allaby 1998; but see Nemoto et al. 1995).

(3) With SRI methods we find a reversal of **the relationship between number of tillers per plant and number of grains per panicle** (fertile tiller). This has been previously reported in the literature to be *negative* (e.g., Ying et al. 1998; also Khush and Peng 1996). But with massive root growth, rice plants become "open systems" and contravene the law of diminishing returns. With SRI-grown plants, the relationship observed (now in three different analyses) is *positive*, reversing the sign previously observed. This is what makes possible going from 2 t/ha to 8 t/ha.

The practices that bring about this different rice plant phenotype in physiological and morphological terms are simple, but they change radically a number of things that rice farmers have done for several thousand years. These practices made sense because they appeared to reduce risk, but in fact, we now believe, they suppress productive potential.

(1) Instead of transplanting rice seedlings from a nursery into the paddy field when the plants are relatively mature, 3 to 4 weeks old, as is common practice around the world (DeDatta 1987: 230), with SRI **seedlings are transplanted before they are 15 days old** (before the fourth phyllochron), even 8 or 10 days old. This preserves the plants' potential for massive tillering if the other practices are followed.

(2) Instead of transplanting seedlings in clumps of 3 or 4, as is almost universally done (DeDatta 1987: 230), with SRI **seedlings are transplanted singly**, so that there is no competition among plant roots to inhibit growth. Seedlings are transplanted carefully and quickly after removal from

their nursery, and with their roots carefully laid into the soil so that the tip is well-positioned to resume downward growth. The 1-2 week period of plant recovery after "normal" transplanting (Kirk and Solivas 1997) deprives the plant of its most prolific intervals of tiller growth.

(3) Instead of planting seedlings densely, as is common because having more plants seems likely to produce more rice, with SRI **seedlings are planted widely spaced**, in a square pattern (to facilitate weeding as well as to give more space between plants), 25 by 25 cm or more widely, up to 50 by 50 cm. It seems counter-intuitive that fewer plants should give much more yield (seeding rates with SRI are 5-10 kg/ha compared to over 100 kg/ha with traditional methods). Yet innovative farmer practices for growing wheat in Mexico, documented by CIMMYT, show that wide spacing can give much better yields (Sayre and Moreño 1997).[5] Plants with more room to grow, have a larger root system and better exposure to light and air.

(4) Instead of keeping paddy fields continually flooded, with SRI **soils are kept well-aerated during the vegetative growth phase**. They are periodically irrigated to keep the soil usually moist, but it should not become saturated (hypoxic). Periodic drying, even to the point of cracking, is recommended, quite in contradiction to common recommended practice.[6] During the reproductive phase, after panicle initiation, a thin layer of water (1-3 cm) is kept on the field.[7]

As noted, these four practices seem terribly risky and violate thousands of years of experience. For the first six week, an SRI field looks terrible, with neither much green from plants nor any blue (sky reflected off the standing water); it looks only muddy brown. But then the field literally explodes with growth as exponential tillering kicks in after the eight phyllochron.

Stimulated by favorable growing conditions, the rice plant exhibits a very different architecture above ground and below. The length of the phyllochron is shortened, and tiller and root growth are accelerated, by wider spacing, better root positioning, and soil conditions that induce growth rather than inhibit it.

Much more could be said about SRI, though there still needs to be much research done to establish and understand the mechanisms that contribute to such growth, such as the possibilities of biological nitrogen fixation in the mixture of aerobic and anaerobic soils (Döbereiner 1987; Magdoff and Bouldin 1970). SRI is still evolving as a methodology. We would like scientists from a variety of disciplines to join in helping to understand and explain how SRI works.[8]

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[5] With wide-spacing and well-aerated soil, due to furrow rather than flood irrigation, 25 kg/ha of seed can produce as more as or more than 200 kg/ha of seed.

[6] DeDatta, who was head of IRRI's agronomy department for more than a decade, writes that "most varieties maintain better growth and produce higher grain yields when grown in flooded soil than when grown in unflooded soil" (1987: 297-298), and "rice thrives on land that is water-saturated, or even submerged, during most of all of its growth cycle (p. 43). SRI experience flatly contradicts this.

[7] Farmers are modifying SRI recommendations in some useful ways to suit their conditions and in some ways to improve upon the initial methodology. Many Madagascar farmers instead of this non-flooding system use an alternating wet-dry system of irrigation, such as flooding the field for 4 days and then draining it and keeping it dry for 4 days, with good effect. Much more experimentation needs to be done to optimize water applications.

[8] Faculty at Wageningen University in the Netherlands have gotten funding from the Dutch government to evaluate SRI as a methodology for growing rice with less water. Other institutions participating in this collaborative project include Nanjing Agricultural University in China, Tamil Nadu Agricultural University in India, the Agency for Agricultural Research and Development in Indonesia, and the University of Antananarivo, Madagascar.

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