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Opportunities to Achieve Resource-Conserving Increases in Agricultural Production: Learning from the System of Rice Intensification (SRI)

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Summary

Sustainable development involving conservation of natural resources and equitable access that reduces poverty and food insecurity will become more attainable if we can produce more agricultural output with reduced inputs. The methods of the System of Rice Intensification (SRI) developed in Madagascar now being extended to other countries and other crops are showing that production can be increased with

- Reduced seed requirements by making large reductions in plant populations;
- Less water by stopping continuous flooding; and
- Reduced agrochemical inputs as organic inputs are increased and as crops become more resistant to pests and diseases. Also, crops with larger root systems are better able to resist adverse effects of climate change

This all sounds too good to be true, but the enhanced productivity of SRI's alternative methods for managing crops, soil, water and nutrients is giving farmers more productive phenotypes from practically all genotypes evaluated so far. This has been seen now in more than three dozen countries

across Asia, Africa, Latin America and the Middle East (http://ciifad.cornell.edu/sri/).

Introduction

Getting more productivity from our available resources will be needed for 21st century agriculture to meet the world's food requirements under conditions of production that are becoming foreseeably less favourable.

- **Land resources** continue to decline. By 2050 we will have only one-third as much arable land *per capita* as in 1950. Land degradation is accelerating and reducing both the quantity and quality of land through erosion, salinization, compaction, and loss of fertility. Also, productive area is being lost to urbanization.
- **Water** will become a more limiting factor of production, both in its amount and in its reliability. Chemical and other pollution is diminishing water quality, and competing demands are constraining the availability of water for agriculture.
- **Climate change** is adding more constraints as 'extreme events' have more dire effects on agriculture than other sectors. High/low temperatures and increased/reduced rainfall can be disruptive, even disastrous for farming operations.
- **Energy costs** will probably be considerably higher in this century than the preceding one. This will make large-scale mechanized production and long-distance trade in agricultural products less economically profitable.
- **Environmental considerations** will constrain current exploitative practices because agriculture will increasingly have to account for its negative externalities

There are two main strategies for intensification to achieve agricultural production objectives:

1. **Intensification of *inputs*** – more water, chemical fertilizers, agrochemicals, etc. – with modifications in *genotypes* through breeding programs to raise the productivity of inputs. The Asian Green Revolution followed this strategy using high-yielding varieties supported by greater investment of resources to achieve higher returns
2. **Intensification of *management*** – investing more knowledge and skill in improving the combinations of inputs (kind, amount, sequence, timing, etc.) – in order to capitalize on biological processes and already-existing potentials. The aim is to achieve more productive phenotypes from any and all genotypes. One always wants to start with the best available varieties, to be sure, but they are only part of the productivity equation

Figure 1. Rice plant (cv. Ciherang) having 223 tillers, grown with SRI methods in Panda'an, East Java, Indonesia, and presented to author in 2009. (Picture by author.)

This latter strategy has been characterized as 'sustainable intensification' (Royal Society, 2009) and as 'low-input intensification' in a study commissioned by the European Parliament (Meyer, 2009).

Input intensification in the 20th century has been driven particularly by the disciplines of engineering, chemistry and genetics, while management intensification is guided more by biological and ecological knowledge. The latter involves a 're-biologization' of agriculture that draws on frontier advances in microbiology, soil ecology, plant physiology, phytohormones, and epigenetics, as discussed in my other paper for the proceedings (pages 00–00).

Experience with SRI is directing attention to the management of rice plants' environments and to comprehending what activates SRI-grown plants' expression of previously unrealized genetic potential. The rice plant shown in (Figure 1) above was grown by SRI farmers in East Java, Indonesia, from a single seed. It was presented to me during a visit in October 2009, so I have held it in my hands. I have also held in my hands, in Sri Lanka, a panicle of rice with 930 grains on it. (Unfortunately I could not take a picture of it because I had no camera with me; 200 grains would be considered a very good panicle, and 300 grains is considered remarkable.)

While it is true that this was the Sri Lankan farmer's best panicle, this does not detract from the evident potential for greater productivity that it represents, available for tapping by improving the way that plants, soil, water and nutrients are managed, to elicit bigger and better root growth as well as a larger and more diverse soil biota. The farmer in this case, W.M. Premaratna, had been farming organically for 10 years, and this was his third year using SRI methods. He was capitalizing on the soil-plant-microbial interactions that are the foundation for this strategy for 'intensification,' promoted by management methods that change long-standing practices.

These results are admittedly hard to believe, since they diverge so much from usual experience, increasing production often by multiples instead of increments. It took me three years to accept that the results of SRI practices were genuine. CIIFAD, the institute at Cornell of which I served as director (for 15 years), was assisting in implementing a USAID-funded project in Madagascar, intended to help save the endangered rainforest ecosystems within Ranomafana National Park.

In the 1994/95, 1995/96 and 1996/97 seasons, poor households cultivating in the peripheral zone around the park—who learned to use SRI methods from the NGO Association Tefy Saina—had paddy yields averaging 8 tons/ha, four times more than their previous usual yields of 2 tons/ha. After seeing such results for three years, it was evident that this large difference was not due to measurement error; both averages were calculated by the same methods. From 1997, I became interested, first, in getting the new methods better understood and, then, getting them evaluated and demonstrated in other countries.

I learned subsequently that a French-funded irrigation improvement project had documented similar results over this same period on the High Plateau in Madagascar. From 1994 to 1999, within small-scale irrigation schemes assisted by the project, SRI use expanded from 34.5 ha to 542.8 ha—with no organized extension effort. The project's data showed SRI yields averaging 8.55 tons/ha, while average yields with farmer practice were 2.36 tons/ha and 3.77 tons/ha with 'improved' practice, using fertilizer, flooding and new varieties (Hirsch, 2000).

Such remarkable differences were subsequently reported from countries outside Madagascar. These were most impressive where small and poor farmers were involved, for whom four-fold increases in production could be transformative. In central Cambodia in 2006, LDS Charities assisted 146 rainfed rice farmers whose conventional yields averaged 1.06 tons/ha. By using SRI methods, they averaged 4.02 tons/ha (Lyman et al., 2007). In Aceh province of Indonesia, where the Catholic charity CARITAS introduced SRI methods in 2005 after the tsunami devastation, small-farmer paddy yields went from 2 tons/ha average to 8.5 tons/ha (Cook, 2009).

Not all increases are as dramatic as these, but 50–100% increases are reasonably common. They suggest that we are dealing with something that can probably be best understood with fresh eyes and fresh ideas, even as it needs to be (and can be) explained with methods and theory that are accepted in contemporary agronomic science (see below).

The System of Rice Intensification

SRI was developed in Madagascar in the 1980s, after two decades of observation and experimentation (Laulanié 1993). Although devised to improve the productivity of smallholders' resources (land, labor, water and very little capital), the insights and idea on which SRI is based are now being adapted to *upland* (rainfed) conditions where farmers have no irrigation and thus little control over water.

There are also *direct-seeded* adaptations and *zero-tillage* (raised bed) adaptations, so the system is still evolving and diversifying. Of perhaps most interest, the results seen with SRI management have prompted farmers and others in several countries to begin extending the concepts and techniques, with appropriate modifications, to *other crops* such as wheat, sugarcane, finger millet, and even vegetables.

SRI methods move away from input intensification in that they do not require farmers to adopt 'improved' varieties, buying new seed, or to purchase inputs like fertilizer and crop protection sprays. It is true that the best SRI yield results have been attained with hybrids or high-yielding varieties. Plant breeding can boost yield. But with SRI methods, farmers can get increased production from almost any variety, and often their preferred varieties command a higher price in the market because of consumer preferences. So it can be more profitable to cultivate local or traditional varieties with SRI methods. SRI makes conservation of rice biodiversity more tenable.

Using synthetic fertilizer together with SRI management does give higher yields as a rule. Indeed, SRI was developed by Fr. Henri de Laulanié, SJ, in the 1980s using chemical fertilizer at first—until government subsidies were withdrawn and fertilizer became too costly for the farmers with whom he worked. It was found that compost could raise yields even more than fertilizer, with less cash expenditure. Organic rice production thus can be more profitable even without premium prices. Further, while chemical applications can be used along with SRI methods to control rice pests and diseases, farmers commonly find that SRI plants organically grown have enough natural resistance to pest and disease damage (Chaboussou, 2004) so that agrochemical protection is not necessary or not economic.

These advantages from a farmer's perspective have not made SRI popular with promoters of 'modern' agriculture, however. There has been controversy (Dobermann, 2004; Sheehy et al., 2004) and some resistance even to evaluating SRI methods in a systematic way (Sinclair, 2004; Sinclair and Cassman, 2004). The prevailing paradigm expects higher yields to be attained by improving genotypes and increasing external inputs, so it is understandable that a strategy which just changes the management of plants, soil, water and nutrients would seem inadequate.

For some years, there were only observations of the differences that SRI practices induced in the phenotypical expression of plants' genetic potential to consider. The larger and healthier root growth on SRI plants was very evident and visible (Figure 2), and an accompanying increase could be seen in the number of tillers per plant (Figure 3). There are now are a number of well-designed and controlled comparative studies published in the peer-reviewed literature which confirm the field observations, going beyond documentation of changes in the numbers of tillers, size of panicles, and root system growth. These studies provide measurements of significant differences between SRI and conventionally-grown plants on for parameters like leaf area index, tiller angle, light interception, rates of root exudation, photosynthesis and transpiration, chlorophyll levels, water-use efficiency, nitrogen uptake, and delayed senescence, e.g., Mishra and Salokhe (2008), Lin et al. (2009), Zhao et al. (2009), and Thakur et al. (2010). Such research helps to explain the success of SRI methods which have been shown to improve rice phenotypes in dozens of countries across Asia, Africa and Latin America. The three most recent countries from which

Figure 2. Comparison of roots and culms of rice plants, same variety and age. On left is plant grown with recommended SRI methods; on right is one grown with conventional (flooded) practices. Color of the roots of plant on right indicates necrosis from lack of oxygen. (Picture courtesy of Bahman Amiri Larijani, Haraz Technology Development Center, Amol, Iran.)

Figure 3. Individual rice plant grown with SRI methods in Baghlan province, Afghanistan, which has 133 tillers at 72 days after transplanting. The farmer's yield on this field was 11.56 tons/ha. (Picture courtesy of Ali Mohammed Ramzi, Aga Khan Foundation-Afghanistan Program.)

SRI effects have been reported are Kenya, the Democratic People's Republic of Korea, and Panama.

Changes in the Management of Plants, Soil, Water and Nutrients

How are these differences in the phenotype achieved? By changing certain practices that have long prevailed in rice culture. They are summarized as below, with the caveat that the practices are not absolute or sufficient just by themselves. There are basic principles that justify each practice, and these principles are explained to farmers, not just telling them what practices to follow. Farmers are expected to make their own experiments, modifications and adjustments to their local conditions to get best results. We stress that SRI is not a technology with no 'transfer' expected. SRI is a knowledge-based innovation, not relying on material inputs (although a simple mechanical weeder that aerates the soil as it controls weeds is highly recommended). Accordingly, farmers' understanding is the key to SRI, not just doing the practices themselves.

SRI, in terms of practices, is represented by the following recommendations:

1. If establishing the rice crop through transplanting,[1] transplant young seedlings while still in the 2–3 leaf stage, usually 8–12 days old – usually seedlings 3–4 or more weeks old are used, which have lost much of their growth potential for tillers and roots.
2. Avoid trauma to the roots – transplant quickly and shallow, *not inverting root tips which halts growth* – conventional transplanting causes 'transplant shock' and suspends growth for 7–14 days.
3. Give plants wider spacing – *one plant per hill* and in *square pattern* to achieve the "edge effect" everywhere – rather than plant seedlings in clumps of 3–6 per hill, and space hills 10–20 cm apart *vs.* 25 cm or wider with SRI.
4. Keep paddy soil moist and mostly aerobic—rather than continuously flooded and saturated as is the common practice now.[2]

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[1] Direct-seeding has become an option for SRI in some places, where farmers have adapted the other practices to this alternative method for crop establishment, to save labor. This opens up SRI application to much larger scale.

[2] Note that the other SRI methods have been adjusted to unirrigated, rainfed rice production with good results.

5. Actively aerate the soil as much as possible with mechanical implement (rotating hoe or conoweeder) – rather than weed by hand or use chemical herbicides.
6. Enhance soil organic matter as much as possible – while fertilizer can be used with the other SRI methods, the best SRI results have come from compost applications

These methods are not all that is required for rice production, but rather are the main changes made with SRI. Land preparations is necessary, with good land levelling advised when young seedlings are use. The nursery should be dry (not flooded), like a garden, but seedlings, much reduced in number, can even be raised on small trays, for easy transport to the field. Careful seed selection is possible when the seed rate is reduced by 80–90%, and this contributes to higher yield.

Results in a Variety of Agroclimatic Environments

One of the initial verdicts on SRI was that if it has merit, this applies only under certain growing conditions, making SRI a 'niche innovation' (Dobermann, 2004). Yet, the innovation has been found to raise yields in a wider variety of circumstances and also to be adaptable to larger scale.

- *Indonesia:* The results obtained by small farmers in the tropical environment of Aceh were reported above, getting 8.5 tons/ha where they had previously produced 2 tons/ha (Cook, 2009). In Eastern Indonesia, an evaluation of SRI methods over 9 seasons under a large Japanese-aided irrigation management project found that farmers (N=12,133) had averaged 78% higher yields with 40% less water and a 50% reduction in their fertilizer use (Sato and Uphoff, 2007).
- *Bhutan:* An agricultural extension agent assigned after graduation from the College of Renewable Natural Resources, where he had learned SRI methods, reported on a series of trials on farmers' fields in a mountainous district, Deorali Geog, in 2009. Standard practice gave 3.6 tons/ha; SRI methods with random spacing gave 6 tons/ha; SRI with 25x25 cm spacing gave 9.5 tons/ha; and these methods with 30x30 cm spacing gave 10 tons/ha (http://ciifad.cornell.edu/sri/countries/bhutan/bhDorjiDaganaRpt09.pdf).
- *Afghanistan:* The Aga Khan Foundation introduced SRI in Baghlan District in 2007. The initial yield was low because planting was one month late, and the northern location and high elevation made for a short growing season. In 2008,

six farmers, impressed by the tillering they had observed the year before, tried the new methods, and their yield was 10.1 tons/ha compared with 5.4 tons/ha on adjacent comparison plots. In 2009, the 42 farmers who used SRI methods averaged 9.3 tons/ha, compared to 5.6 tons/ha yields on their comparison plots using their usual methods. The six farmers in their second year averaged 13.3 tons/ha compared to the 8.7 tons/ha that the 36 first-year SRI farmers got. (http://ciifad.cornell.edu/sri/countries/afghanistan/AfgreportAKF_APMIS09.pdf).

- *Mali:* In 2007/08, the NGO Africare did first SRI trials with farmers on a small scale in irrigated perimeters in the Timbuktu region, on the edge of the Sahara Desert. The yield was 8.98 tons/ha, 34% more than the best yield obtained with other methods. The next year, 12 villages nominated 5 farmers each to evaluate SRI methods in a systematic way with side-by-comparison plots. These farmers' SRI plots produced 9.1 tons/ha compared to 5.49 tons/ha with their best methods; neighboring farmers in averaged 4.86 tons/ha (http://ciifad.cornell.edu/sri/countries/mali/MaliAfricare%2008and09.pdf). We see these kinds of gains in productive very often with SRI management, even under unfavourable local conditions.

Growing Support and Acceptance

SRI was initiated as a civil society innovation; however, it has been gaining support from a wide range of institutions: governments, donor agencies, universities, research institutions, foundations, international and grassroots NGOs, community organizations, and private sector. That productivity gains such as those reported above are achieved with *lower* water requirements in a world where water is becoming a more critical constraint has evoked growing interest in governments and donor agencies:

- For example, on the eve of a visit to India, the World Bank president wrote: "Everyone cites India's Green Revolution. But I'm even more intrigued by what is known as SRI, or system of rice intensification, and I know this is also an area of interest for [Prime Minister] Manmohan Singh. Using smart water management and planting practices, farmers in Tamil Nadu have increased rice yields between 30 and 80 per cent, reduced water use by 30 per cent, and now require significantly less fertilizer. This emerging technology not only addresses food security, but also the water scarcity challenge that climate change is making all the more dangerous. These are all lessons for our world." Robert Zoellick, *Hindustan Times*, December 2, 2009[1].

- Speaking at an SRI harvest festival in Cianjur in July 2007, the President of Indonesia, S.B. Yudhoyono, observed: "There are many methods of increasing rice production, and certainly they increase the production of rice, but it is the intervention of too much chemical fertilizer that we are witnessing. The result is an increase in productivity, but then the environment is badly damaged. ... this SRI method, according to my observation, fulfills both purposes: productivity is increased, and at the same time the environment is saved." (Speech is reported on his website at: http://www.presidenri.go.id/index.php/fokus/2007/07/30/2084.html; with English translation: http://ciifad.cornell.edu/sri/countries/indonesia/indopresident073007.pdf).
- The Worldwide Fund for Nature (WWF) in a collaborative program with ICRISAT on Food, Water and Environment has been supporting evaluations and dissemination of SRI methods in India to reduce conflicts over water there between agriculture and natural ecosystems (see http://assets.panda.org/downloads/wwf rice report 2007.pdf). The two organizations are also jointly promoting an adaptation of SRI concepts and practices to sugarcane, which is a heavy consumer of water and user of agrochemicals. See manual on applying SRI ideas to sugarcane: http://assets.panda.org/downloads/ssi manual.pdf

Conclusions

Being able to raise agricultural production with lower demands on land, labor, capital and water opens new opportunities for 21st century agriculture. This is all the more important as climate changes are likely to lead to greater abiotic and biotic pressures on crop production. So far, SRI plants have been found to be more resistant to the effects of drought, lodging (storm damage), cold spells, and losses from pests and diseases.

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[1] The Prime Minister endorsed "better agronomic practices like the System of Rice Intensification method of rice cultivation" in an address to senior Cabinet members and Chief Ministers of India's states on reducing food prices (April 8, 2010). See World Bank Institute website: http://info.worldbank.org/etools/ docs/library/245848/index.html and also the World Bank's India website on its positive experience with SRI in Tamil Nadu state of India:: http://www.worldbank.org.in/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/INDIAEXTN/0,,contentMDK:21789689~menuPK:64282138~pagePK:41367~piPK:279616~theSitePK:295584,00.html

There could even be some net reduction in greenhouse gas emissions with SRI conversion to aerobic soil conditions not relying on heavy applications of inorganic nitrogen. Methane emissions from rice paddies can be reduced by stopping their flooding, and so far, evaluations have indicated that there are not offsetting increases in N_2O emission (Yan et al., 2009).

SRI methods have validated now in 41 countries, but they will not be appropriate under all agroecosystem conditions, e.g., where soils cannot be maintained in mostly aerobic conditions, or where there is limited biomass availability for compost making (although chemical fertilizer can be used with the other SRI methods). While SRI was initially considered labor-intensive, farmers are finding that its methods can become labor-saving, once mastered. Also, mechanization of different SRI operations is now starting to be used to reduce labor requirements (http://www.google.com/search?hl=en&source=hp&q=FarmAll+MSRI+Pakistan). So, the main obstacles to further adoption and spread continue to be attitudinal than material. Like all innovations, SRI should be put to empirical tests. So far, when the methods are used as recommended with some experimentation and adaptation (part of the recommendation), they have proved to be productive under a wide range of circumstances.

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