Agriculture *for* Development

Tropical Agriculture Association

No. 15 Spring 2012

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The TAA is a professional association of individuals and corporate bodies concerned with the role of agriculture for development throughout the world. TAA brings together individuals and organisations from both developed and less-developed countries to enable them to contribute to international policies and actions aimed at reducing poverty and improving livelihoods. Its mission is to encourage the efficient and sustainable use of local resources and technologies, to arrest and reverse the degradation of the natural resources base on which agriculture depends and, by raising the productivity of both agriculture and related enterprises, to increase family incomes and commercial investment in the rural sector. Particular emphasis is given to rural areas in the tropics and subtropics and to countries with less-developed economies in temperate areas. TAA recognizes the interrelated roles of farmers and other stakeholders living in rural areas, scientists (agriculturists, economists, sociologists, etc.), government and the private sector in achieving a convergent approach to rural development. This includes recognition of the importance of the role of women, the effect of AIDS and other social and cultural issues on the rural economy and livelihoods.

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ISSN 1759-0604 (Print)

ISSN 1759-0612 (Online)

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How rice will be produced in the future - based on learning from the System of Rice Intensification (SRI)

Introduction

The System of Rice Intensification was developed by Fr. Henri de Laulanié while working with resource-poor farmers in Madagascar. By manipulating agronomic and water management factors he was able to achieve substantial yield increases with the available *local* varieties. He called this alternative rice production approach the *Système de Riziculture Intensive*, or 'System of Rice Intensification' (SRI). (Laulanié, 1993). The basis and development of SRI has previously been reviewed in the journal (Uphoff and Kassam, 2009a). This is an abridged version of a recent paper by the authors that provides more details of the potential of SRI.

SRI practices

SRI modifies management of soil, water and nutrients while reducing inputs such as seeds, inorganic fertilizer, water, and (where water is pumped) fuel to increase rice productivity. SRI practices make soil conditions more aerobic and promote greater root growth (Fig. 1) and more tillering (Fig. 2), as well as increasing beneficial soil biota. These below-ground changes support more productive phenotypes above-ground for practically all rice cultivars tested so far, with supporting evidence accumulating both from scientific institutions and field applications as documented in a special issue of the journal *Paddy and Water Environment* (9:1, 2011).

Fig. 1. Stronger, healthier root system of SRI rice (on left) being shown in Punjab.

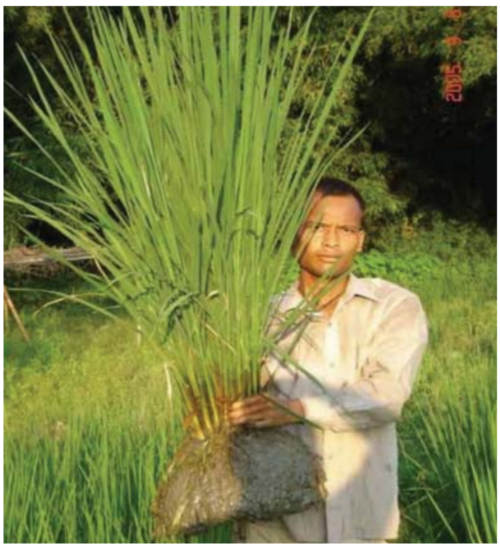

Fig. 2. Single rice plant grown with SRI methods, Morang district, Nepal.

The specific operational practices that derive from Laulanié's work can be summarized as follows (Uphoff and Kassam, 2009b; Uphoff *et al.*, 2010):

- Transplant *young seedlings*, preferably 8-12 days, while still at the 2-3 leaf stage, and within 15 days of nursery sowing.
- Transplant *quickly*, within 30 minutes of gently removing seedlings from their nursery, *carefully and at a shallow depth* (1-2 cm), so as to avoid root damage and resultant 'transplant shock'.
- Transplant just *one seedling per hill*, and space the hills widely, in a *square pattern*. 25 x 25 cm was recommended as a typical square planting distance for SRI (Fig. 3).
- Apply only a *minimum of water* during the plants' vegetative growth stage, wetting the field daily but with several drying periods ranging from 3 to 6 days, or following a regime of alternate wetting and drying (AWD) to maintain mainly moist (aerobic) soil conditions.
- Weed control using a *mechanical hand weeder* (rotating hoe) (Fig. 4.) is recommended. Weeding should start 10-12 days after transplanting, to pre-emptively curb weed growth and to aerate the soil and enhance nutrient mobilization. This should be done several times before the canopy closes.
- The above SRI methods were initially accompanied by use of inorganic fertilizer, but the use of *compost* gave even better results than mineral fertilizers when it was used with the other practices.

Fields should also be very level for planting very young seedlings and for minimum water usage; seedling nurseries also need to be managed like gardens, with well-drained soil and no flooding.

SRI can also be applied to directly seeded rice crops and to rainfed rice, so early transplanting and irrigation is not necessary to benefit from SRI practices. In fact SRI can be seen in terms of agronomic principles rather than as a set of fixed practices.

Yield increases and additional benefits from SRI

Although yield information is variable both between and within countries, overall the average SRI yield advantage is over 60% (Kassam et al., 2011). This ranges from 11% in Chinese on-station trials to 220% in an on-farm, innovative mechanized version of SRI in Pakistan. In eastern Indonesia, the average SRI yield advantage across eight provinces was 78% and ranged from 38% in Bali, where highest yields with conventional practice had already been attained, to 158% in Goroantalo. With reductions in cost, about 20%, farmers would gain even more economic profitability than their increase in agronomic output (Sato and Uphoff, 2007).

SRI yield advantages occur across different agroecosystems and with traditional local varieties as well as modern improved cultivars. With SRI management, yield with local varieties increased from 40% in Panama to 66% in Afghanistan; with 'modern' varieties, the range was from 18-48% in India to 204% in The Gambia; and with hybrids, the yield increases ranged from 11% in China to 220% in Pakistan. Not surprisingly, the highest yields as well as the greatest increases achieved with SRI methods were seen with improved genetic potentials.

Although obtaining higher rice yields is not dependent on the introduction of new, improved varieties, it is clear that the best SRI results can come from 'improved' varieties. With SRI management, hybrid varieties averaged 13.3 tha^{-1}, while modern varieties yielded 9.9 tha^{-1} in Bali. Conventional methods produced 8.4 tha^{-1} from hybrids and 7.2 tha^{-1} from inbred modern varieties. Significant further yield improvements should be possible if new rice varieties were to be bred by selection for tillering ability under SRI conditions, e.g., with wider spacing and better aerated soils.

Additional benefits from SRI include:

- Saving of water (20-50%).
- Reduction in seed (80-90%).
- Reduction in mineral fertiliser (50-100%).
- Resistance to biotic stresses and abiotic stresses
- Shorter crop cycle
- Higher milling outturn
- Reductions in labour requirements
- Lower costs of production (10-20%)

SRI concepts and methods are now being extrapolated and extended to other crops.

Principles accounting for the recommended SRI practices

These principles have solid ecophysiological and agronomic foundations and can be presented in terms of the following half dozen principles, with some appropriate, empirical qualifications. Summary of SRI principles and practices (from Uphoff et al., 2010).

Principles and associated practices	**Elaborations on how the principles are translated into specific practices under various conditions**
1. *Start with young seedlings*, if the rice crop is being established by transplanting. The best growth will come from seedlings just *8-12 days old*, and not older than 15 days, as these will retain most of the rice plants' potential for the growth of roots and shoots.	Physiological age is more important than calendar age, so technically transplanting should be at the *2-3 leaf stage*, i.e., before start of the 4th phyllochron. This leaf stage applies across all climates. In cold regions, the age of 'young seedlings' can be 15-20 days, or even more. Increasingly, farmers are turning to *direct-seeding* to save labour, using other SRI principles. This is consistent with the 2nd SRI principle: avoid trauma to the roots. Transplanting itself is not a necessary practice to utilize and benefit from SRI concepts.
2. *Avoid trauma to the roots:* Transplant *quickly*, within 15-30 minutes of *gentle removal* from the nursery; transplant seedlings *shallow* (1-2 cm) and *take care* not to invert the roots' tips upward (plant profile should be L-shaped).	In conventional practice, seedlings are usually grown in a flooded nursery under hypoxic conditions. They are removed quickly (and roughly) at 3-6 weeks, with much trauma to the roots. They are then transplanted back into a hypoxic environment, being thrust >3-6 cm into the soil with their root tips pointing upward (J-shaped profile). These practices contribute to *transplant shock* (7-14 days) that sets back plant growth during a crucial early stage.
3. *Give optimally wider spacing:* Reduce plant population radically, by 80-90%, with *single plants* per hill and *square planting*. 25 x 25 cm is a good initial spacing, but according to soil quality, plants should be wider (in good soil) or closer (poor soil) (Fig. 3).	In less fertile soil, there will be higher yield (in the short run) from using SRI practices with somewhat closer spacing, e.g., 2 plants rather than 1 per hill, or 20 x 20 cm spacing. Over time, however, SRI practices usually improve soil conditioning, so that wider spacing becomes more productive (see 6.). There is a *range* of SRI spacings, even up to 50 cm with very fertile soil; but 25 x 25 cm spacing is recommended as usually the most productive spacing to start with. With young seedlings, no crowding and aerobic soil conditions, a high panicle-bearing tiller density (Fig. 2) can be produced with seed rates as low as 3-5 kg ha^{-1}.
4. *Avoid continuous flooding:* Rice plants cannot grow best under hypoxic soil conditions. Plants (and associated soil organisms) should be given *just enough water* to meet their requirements, but not so much that they suffocate. Maintain mainly moist (aerobic) soil conditions (Fig. 4).	Laulanié recommended using 'a minimum of water,' applying small amounts of water daily to a well-levelled field, except for some 3-6 day intervals when no water was added. Many farmers were able to get similar results, with less labour, by using longer time intervals between wettings (AWD). Optimum water management depends very much on soil characteristics, so experimentation with timing and amounts is advised, with close monitoring of plant responses.
5. *Actively aerate the soil*, as part of weed control, using a mechanical weeder (rotating hoe or cono-weeder) early and often. Stopping flooding gives passive soil aeration, to be improved upon by active soil aeration (Fig. 4).	With no flooding, weeds grow more aggressively. Mechanical weeding should be *preemptive*, starting 10-12 days after transplanting, and being repeated 1-4 times at 10-12 day intervals until the canopy closes. Each weeding adds to soil aeration, root growth, and beneficial soil organisms, and can enhance yield by several hundred kg ha^{-1} or even 1 or more tons ha^{-1} (see Afghanistan report in the PAWE issue). Churning weeds back into soil conserves and enhances the supply of soil nutrients.
6. *Enhance soil organic matter,* as much as possible, according to the principle: 'Feed the soil, and let the soil feed the plants.'	Using chemical fertilizer in conjunction with the other SRI principles will raise yield. However, the most productive strategy for fertilization over time is to apply as much organic matter (compost, manure, or mulch) as possible. This improves soil structure and functioning, mobilizing and/or recycling endogenous nutrients through the activity of larger, more biodiverse populations of beneficial soil organisms.

SRI's innovations appear to be against long-standing rice production practices; recommendations such as drastic reduction in plant populations and stopping continuous flooding go against established ideas in rice science but they have empirical justifications as pointed out below. These indicate that some basic agronomic assumptions about how best to boost wetland paddy rice productivity should be reconsidered.

Fig. 3. SRI field at 30 days with single plant per hill in wide square spacing in moist soil, Baghlan province, Afghanistan; at 72 days, single plants had as many as 133 tillers.

Fig. 4. Rotary-hoe weeding of SRI rice paddies in Madagascar.

SRI experience shows that it is possible to *obtain greater output* with reduced inputs, 'more from less.' Recent SRI research has shown significant differences in both morphology and physiology of rice plants depending on how they are grown. Tillering, root growth, larger leaf area, better canopy structure, higher chlorophyll levels, increased light interception, higher nitrogen and water use efficiency, improved yield components, are all affected by the growing environment. SRI plants are more efficient at acquiring soil nutrients and capturing solar energy as well as in converting inputs to outputs (Thakur *et al.*, 2010).

Wide adaptability of SRI principles

SRI methods, with appropriate adaptations, are effective in a wide variety of environments from humid, and sub-humid tropics, across the variety of environments found across Asia, arid and semi-arid areas in Africa to mountainous, high-altitude areas with a short growing season.

In each of these environments, farmers have found it possible, by modifying standard rice-growing practices according to SRI principles, to create microenvironments that are conducive to more beneficial expression of their rice plants' genetic potentials.

The degree to which SRI management is relevant to all rice production systems will vary. However, precise water control and meticulous land leveling are not required to get some benefit from the effects of enhanced soil organic matter and soil aeration or wider spacing.

Feasibility of zero-tillage and Conservation Agriculture with SRI

The principles that account for SRI performance are congruent with those that have given rise to Conservation Agriculture, even though SRI was initially based on standard land preparation practices, and recommended simple mechanical weeders. Convergent practices that combine SRI ideas and methods with zero-tillage precepts, using permanent raised beds are reported from Pakistan and on typical level fields in China. In Jiangsu province, the Center for Agroecology and Farming Systems is integrating SRI concepts into the wheat-rice rotational cropping system, using raised beds under an adapted Conservation Agriculture regime and obtaining 30-70% higher annual production from rice and wheat crops. Some innovative SRI farmers are developing crop rotations in raised beds, such as alternation of potatoes with SRI rice (Fig.5).

Fig. 5. Innovation with raised-bed, zero-till SRI field in Meishan, Sichuan, China where potato production is alternated with rice; measured paddy yield was 13.4 t/ha.

Where rice is sown directly or is transplanted without puddling the soil, and where the undisturbed ground is covered with a mulch layer of organic matter, the crop could be grown under a convergent SRI/CA system. Under conventional flooded conditions, paddy soils are destructured through intensive puddling and have impermeable hard pans to retain standing water causing anaerobic soil conditions that SRI research shows to be harmful to root growth. The introduction of zero-tillage into SRI could thus improve root performance but raises a number of issues that require more experimentation and evaluation to facilitate the transformation of SRI-based production systems into CA-based production systems under different agro-ecological and socioeconomic conditions.

Future prospects

After decades of searching for more sustainable crop and agricultural production systems, some new, agroecologically-based, and economically-profitable paradigms are beginning to appear, with SRI and CA as examples. These approaches have been characterized as 'low-input intensification' or 'sustainable intensification' and show potential for environmentally-benign productivity gains that could address the current global challenges pertaining to agriculture and food security.

Probably about 2 million rice farmers have already adopted SRI methods, in whole or in part, in the 42 countries across Asia, Africa and Latin America where these methods have been validated. SRI spread has relied on virtual modes of communication through email and internet, and farmer-to-farmer interaction given donor agencies' reticence to accept and support these new approaches with funding for active adoptions and dissemination.

However, governments in India, Indonesia, China, Vietnam and Cambodia are encouraging and supporting the transformation of their conventional flooded rice production systems to SRI management, based on their own assessments. There is now sufficient evidence for directing more research, policy and development resources to understanding, supporting and disseminating knowledge about SRI and other agroecological methods to improve agricultural production and sustainability.

As a result of SRI and CA, the way that rice is produced in the future is likely to be totally different compared with the way that it has been produced thus far. SRI represents a new agro-ecological paradigm, capable of offering many benefits to irrigated rice producers anywhere, as well as to consumers and the environment. Being a pro-poor innovation adds to its attractiveness. It and other agro-ecological innovations should have a major role in responding to the challenges and realities of the 21st century.

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