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SRI 1.0 and Beyond: Understanding the System of Crop Intensification as SRI 3.0

Norman Uphoff

SRI-Rice, Cornell University, USA

Corresponding author email: ntu1@cornell.edu

Abstract

The System of Rice Intensification (SRI) and the System of Crop Intensification (SCI), which has developed from SRI experience, should not be understood as technologies like those of the Green Revolution. Thinking of them as methodologies is more appropriate, in part, because they keep evolving rather than being something fixed and given. This paper reviews and organizes the many versions of rice and other crop management that have emerged from SRI, using the computer software convention of numbering successive versions with a series of ascending numbers, 1.0, 2.0, 3.0, etc. SRI 1.0 is the original set of practices developed and recommended by Fr. Henri de Laulanié in Madagascar some 40 years ago. As SRI has spread to over 60 countries, they have proved to be generally quite effective. Happily, as the experience was gained with these practices, their underlying principles were discerned and systematized, as discussed in the paper. SRI 2.0 is a set of adaptations of the original practices to be effective under different constraints or opportunities. The principles remain the same – rainfed SRI, direct-seeded SRI, mechanized SRI, etc. SRI 3.0 is the extension and adaptation of SRI ideas and principles to other crops – wheat, ragi, sugarcane, mustard, etc. – in other words, the System of Crop Intensification. SRI 4.0 is the integration of SRI ideas and practices into farming systems, going beyond mono-cropped rice production. SRI 5.0 is the use of SRI for purposes beyond agricultural production like reducing emissions of greenhouse gases, climate-proofing crops against the hazards of climate change, improving women's conditions of work, increasing the nutritional quality of grains and other foods, and other 'externalities'. SRI 6.0 is the research that scrutinizes SRI practices and results to advance scientific understanding that will benefit crop science, soil science, microbiology and other disciplines. These versions are not sequential as all are currently operative, and none displaces the others.

SRI has shown the prime importance of two factors: plant roots' growth and functioning; and the soil's life – the myriad organisms from microbes to earthworms that improve soil and crop performance. SRI seeks to elicit the genetic potentials that already exist in crop plants and in soil systems. By getting the fuller expression of this potential, SRI and SCI evoke better, more robust phenotypes from a given variety (genotype). Particularly as Indian and other farmers must cope with the adverse stresses of climate change, it will become important to grow crops with better, bigger root systems in soil systems that have greater abundance, activity, and diversity of beneficial soil organisms. This suggests that SRI and SCI alternatives will better suit the farmers' and the country's needs over time than past and present agricultural technologies.

Keywords: SRI 1.0, SRI 2.0, SRI 3.0, SRI 4.0, SRI 5.0, SRI 6.0, System of Crop Intensification, root systems, soil microbes

From its beginning, the System of Rice Intensification (SRI) has been understood as something different from the kind of agricultural technology exemplified by the Green Revolution. Such technology was *input-dependent* rather than being *idea-dependent* like SRI. It sought to raise production by *changing the plant* while SRI focused on *changing the plant's growing environment*, above- and especially below-ground.

SRI seeks to capitalize on genetic potentials that already exist rather than changing these. It aims to produce from any plant variety (genotype) actual plants (phenotypes) that are more productive and robust. SRI is not variety-dependent, although some varieties respond better to SRI management practices than do others. The highest SRI yields have been achieved with hybrids or improved varieties, but the yields from traditional varieties can be doubled or more, so since their market value is often higher, when SRI methods are used and production costs are lowered, they can be more profitable than HYVs or hybrids.

There are two basic consequences of following SRI principles and practices that are not easy to see: (a) greater growth of *root systems*, and (b) increased *life in the soil*, from microbes to earthworms. We refer to SRI as a methodology rather than as a technology because it is more mental than material. It relies more on ideas, insights and skills, than on physical inputs like new seeds, more fertilizer, more water. It has been a mistake to try to pour 'the new wine' of SRI into 'the old bottles' of Green Revolution technology.

To elaborate on this topic, I would like to use *the terminology of computer software*, where successive versions are given ascending numbers, 1.0, 2.0, 3.0, 4.0, etc.

SRI 1.0

This is *the original set of practices* that were assembled and validated by Fr. Henri de Laulanié in Madagascar over his half a lifetime of living and working with small, poor farmers there. SRI was put together inductively, created from observations and measurements, not guided by theory or preconceptions. It was thoroughly inductive and empirical. As Fr. Laulanie stated humbly but aptly, the rice plant was his teacher. He wrote in French that the rice plant was '*mon maître*,' meaning that it was his "master."

SRI became known and was initially propagated in terms of certain practices, most of them counterintuitive -- like planting fewer plants, planting very young seedlings, and not keeping rice paddies flooded. Those of us who have learned from Fr. Laulanié's work and have worked with his ideas and insights have synthesized from the success of these practices a set of principles that constitute 'SRI,' although number and wording can vary. From having read Laulanié's papers after he died in 1995, I am sure that he would have approved this progression from practices and methods to principles and concepts.

As I currently understand SRI, I would summarize the core of this methodology in the four principles stated below Also, as a preface, I would like to suggest that wen SRI is introduced to farmers, they should be informed not only about what is being recommended (various practices), but also why these are being recommended, and the interactions among them. This will assist farmers in taking ownership of the methodology and in making appropriate adaptations that suit their local conditions and constraints.

1. **Reduce plant density, so that each plant can express its maximum potential. How to do this?**

- **Plant single seedlings per hill**, not clumps of seedlings, so that plant roots and canopy can spread and grow, with little competition for sunshine, nutrients and water, and with no shading. If the soil is not very fertile, two plants per hill may give more yield at first, but this number can usually be cut back to one per hill as the soil's fertility improves as a result of following SRI principles.

- **Space the hills wide apart**, in a square pattern for mechanical weeding; 25x25 cm is usually optimal, but closer or wider spacing of hills is better initially with poorer or better soil. SRI practices reduce by 80-90% the plant population (and seed requirement) per m^2, while giving greater yield.

2. **Establish the crop carefully and well, paying attention to minimize any trauma to the plant roots.**

- For irrigated rice production, transplant young seedlings at the 2-3 leaf stage (8-15 days old) and plant them soon after removal from nursery as well as very carefully and gently. Minimizing 'transplant shock' will enable the transplants to resume their growth quickly.

  Note: Direct-seeding of the crop is an alternative way to establish the rice crop, with the other SRI principles being applied.

3. **Manage water and soil to optimize and balance the provision of water and oxygen to the soil.** Plant roots and most beneficial soil organisms need both. There should be no continuous flooding because too much water in the soil reduces or eliminates the oxygen required by roots and the soil biota. Continuous flooding suffocates both plant roots and soil organisms.

- Where there are irrigation facilities, practice alternate wetting and drying. If the rice crop is rainfed, on the other hand, do not hoard rainfall in the field during the early part of the season. This will cause the roots to deteriorate, and then when the water recedes, the plants will have less root growth and will become more water-stressed.

- Apply just enough water to meet the needs of the plants and soil biota. Laulanié advised giving "*le minimum de l'eau*." Some amount of water stress promotes more and deeper root growth.

- By not flooding rice paddies, their soil is aerated passively. By using a mechanical weeder to control weeds, the soil is actively aerated, stimulating the growth of roots and the life in the soil.

- **Active soil aeration** from doing multiple mechanical weedings, as many as 4, can usually raise the crop yield by 1-2 tons per hectare, compared with doing just a single weeding.

4. **Use organic fertilization in preference to inorganic fertilizers**. Compost does more than just provide nutrients for plants. It 'feeds the soil,' meaning the life in the soil, this in turn makes the soil better able to feed the plants. Increasing soil organic matter will improve the structure and functioning of the soil system, thereby supporting the growth of both plant roots and soil inhabitants.

- Organic and inorganic sources of nutrients can be combined to optimize soil nutrient supply or to remedy particular soil nutrient deficiencies where these are present (*aka* Integrated Nutrient Management). Inorganic fertilizer and chemical pest control should not be used where, and to the extent that, they adversely affect the soil's biodiversity and degrade soil and human health.

Note: all of these principles for good crop performance can be extended or adapted to *other crops beyond rice*. This is the foundation for the System of Crop Intensification (SCI), as discussed below**.** Note also that good SRI practice involves several other things like soil leveling, seed selection, having an unflooded, sparsely-sown nursery, and maybe also seed priming or inoculation with beneficial microorganisms like *Trichoderma* or Indigenous Microorganisms (IMOs). But these are practices not unique to SRI, so they are not considered to be part of SRI as such. On the central importance of roots and the soil biota for SRI effectiveness, see Chapters 4 and 5 of Uphoff (2022).

SRI 2.0 – Modifications of SRI 1.0 that Deal with Local Conditions and Constraints

After the use of SRI practices moved outside of Madagascar, to farmers cultivating under different circumstances than those with whom Laulanié had worked, various adaptations have been made over time:

SRI 2.1. Rainfed SRI: SRI practices have been adapted by farmers for unirrigated rice cultivation, first in upland areas in Madagascar, but then in the Philippines, Cambodia, Myanmar, India (Purulia district in West Bengal) where farmers were managing rainfall rather than irrigation water. Rainfed SRI was extended within four Southeast Asian countries under an EU-funded project (Mishra *et al.,* 2021). While rainfed SRI has modified some practices of SRI 1.0, it remains clearly part of the SRI 'family.'

SRI 2.2. Mechanized SRI: Where agricultural labor supply was limited or too expensive or to be able to use SRI on a larger scale, various equipment and implements have been devised and introduced to reduce labor requirements and also reduce the drudgery and other undesirable features of labor in rice production. SRI does not have to be labor-intensive and small-scale as the principles are scale-neutral.

SRI 2.2.1. Direct-seeded SRI: Transplanting seedlings is not required for SRI if it is understood in terms of core principles rather than just SRI 1.0 practices. If a high germination rate can be achieved, plant density can be reduced with spacing that permits soil-aerating weeding, e.g., drum-seeding developed in Chitoor, Andhra Pradesh, India; and in Vietnam (SNV, 2015); also, broadcasting rice seed and then thinning it with a mechanical weeder at 10 days to have plants in a geometrical pattern, developed in Sri Lanka.

SRI 2.2.2. Mechanical transplanting with SRI spacing and density: First developed by Oscar Montero in Costa Rica (Montero, 2009); since then, other mechanical transplanters have also been developed.

SRI 2.2.3. Motorized weeding: Multi-row, engine-powered weeders have been developed in many countries to save time and labor, first in the Philippines and Sri Lanka. There are even some solar-powered weeders now. This speeds up and makes easier the most laborious part of SRI operations.

SRI 2.2.4. Full mechanization: Crop establishment, weeding, and harvesting can all be mechanized. Smaller-scale mechanization has been developed in Nepal by Rajendra Uprety. In Pakistan, Asif Sharif in the Punjab province has developed large-scale mechanization, with laser-leveling and raised beds. This can reduce both labor and water requirements by 70%, with 12 t/ha yields (Sharif 2011).

SRI 2.3 SRI for cold climate: In the Heilungjiang province of northern ***China***, a system known as 3S was developed in the 1990s by Prof. Jin Xueyong, following most of the

SRI principles. Because temperatures there are so low, with rice seedlings started in heated-greenhouse nurseries while snow is still on the ground, seedlings are transplanted when 45 days old, widely-spaced, not flooded, and with more organic matter (Uphoff, 2004, pp. 1-4).

SRI 2.4 Other variations: Research by Amod Thakur and colleagues at ICAR-IIWM in Bhubaneswar has shown that land and water productivity can both be raised under SRI by continuing alternate wetting-and-drying throughout the whole rice crop cycle rather than just until panicle initiation, thereafter maintaining a thin layer of water (1-2 cm) on the field during the reproductive phase, as has been recommended with SRI 1.0. This finding (see Thakur, 2018) may depend upon soil type and climate, so further evaluations should be done before making this a generalized practice. Other variations could be noted, but these examples suffice to give an overview of SRI 2.0, showing that (and why) SRI 1.0 was not something 'set in stone' as some skeptics have expected or would have preferred it to be.

SRI 3.0 – Modifications of SRI Extended to Other Crops to Improve Their Performance

These constitute **SCI, the System of Crop Intensification**, which in Bihar is called the System of Root Intensification, another 'SRI.' My PPT presentation of this paper focuses on these extensions of SRI 1.0. The listing below of crops, countries, and initial contributors to each crop unfortunately cannot be complete. It indicates that India has been the main source of SCI innovation thus far (Abraham *et al.,* 2016; Adhikari *et al.,* 2018).

- **Finger millet/ragi** – ***India*** (Jharkhand /PRADAN, Bihar /PRAN, Odisha/PRAGATI); ***Ethiopia*** (Tigray/ ISD).
- **Wheat** – ***India*** (Madhya Pradesh/MPRLP; UKD-HP/PSI, Bihar/PRADAN-PRAN), Mali (Africare) (PRADAN, 2012a; Dhar *et al.,* 2015); ***Ethiopia*** (ISD); ***Afghanistan*** (AKF-FAO); ***Nepal*** (FAYA)
- **Sugarcane** – ***India*** (Andhra Pradesh –farmers, ANGRAU, and AgSRI); ***Cuba, Kenya, Tanzania, Uganda,*** and ***Philippines*** (AgSri)
- **Maize** – ***India*** (UKD-HP/PSI); ***Pakistan*** (PEDAVAR)
- **Mustard** – ***India*** (Bihar/PRADAN-PRAN) (Sathpathy, 2009; PRADAN, 2012b)
- **Teff** – ***Ethiopia*** (Oxfam) (Berhe *et al.,* 2017)
- **Pulses** – ***India*** (red gram, groundnuts, black gram, etc. – PSI and many others)
- **Vegetables** – brinjal, tomatoes, etc. -- PRAN/Jeevika, Bihar, ***India***; green leafy vegetable/mallow – ENGIM, ***Sierra Leone***; carrots, onions, etc. – Lookfar Farms, ***USA***
- **Spices** – turmeric – Thumbal SRI Farmers Association, Tamil Nadu, and cumin and coriander – AKRSP-I, Gujarat, ***India*** (Baskaran, 2012)
- **Other crops** – orchards/horticultural SRI, Lookfar Farms, ***USA***; chickens/avian SRI, CEDAC, ***Cambodia***; lac production/entomological SRI, farmers and PRADAN, Jharkhand, ***India***. Note that all of these different versions of SCI are elaborated in Chapter 14 of e-book (Uphoff, 2022).

SRI 4.0 – Integration of SRI into Cropping and Farming Systems

As SRI principles have become better understood and more widely used, they have been used to intensify and diversify a number of kinds of farming systems, going beyond growing monoculture cropping.

- **Convergence of SRI with Conservation Agriculture** – This synthesis was begun in Pakistan in Punjab province – Sharif, 2011; and PQNK website); and in China in Sichuan province (Lu *et al.,* 2019). Much more remains to be done to further this convergence.
- **Integrating SRI with horticulture and fish culture** – in both Cambodia (CEDAC) and Indonesia (Khumairoh *et al.,* 2012). I have myself observed a SRI rice-duck combination by farmers in Zhejiang province of China. An important scientific evaluation of SRI rice combined with fish culture and horticulture had been done at ICAR-IIWM in India, showing a phenomenal increase in the productivity of rainfall cycled through this integrated farming system (Thakur *et al.,* 2015).
- **Rotation with horticulture** – e.g., SRI rice alternating with no-till potatoes in Vietnam (Phu and Ha, 2022). I have observed a very profitable farming system developed by farmers in Sichuan province of China, alternating SRI rice with mushroom production (Uphoff, 2004, pp. 8-9).

- **Intercropping with legumes** – SSI sugarcane in Andhra Pradesh (Gujja *et al.,* 2009) and SRI rice with beans in Kashmir (Shah *et al.,* 2021). The latter has given 33% higher yield with 40% water saving, 65% fewer weeds, and 57% higher income per ha -- both India.

Because SRI 4.0 is still in its early stages, we expect that there will be many more versions and variations of such integration, e.g., SRI with agroforestry, in the future.

SRI 5.0 – Scientific Explanations

Work in this area began after SRI 1.0 became known, but it has accompanied all of the succeeding versions that followed, not being a sequential aspect of SRI. Here are some examples.

- **The effects of SRI practices on microbial populations** -- in the soil rhizosphere around plant roots, in the phyllosphere around plants, and in the endosphere within plants. The first study on this was done at TNAU, and it was then taken further at ICRISAT and IARI (see Doni *et al.,* 2022).
- **Plant-microbial interactions** – this is a large subject with ongoing research, e.g.:
    - o Inoculation of SRI plants with beneficial microbes, e.g., with *Trichoderma*, to enrich crops' plant-soil microbiomes. Studies have been done in Malaysia, Nepal, and India (Doni *et al.,* 2018; Khadka and Uphoff, 2019).
    - o The effects of endophytic microbes on plants' expression of their genetic potential. This could be a partial explanation for SRI improvement of plant phenotypes. Some transcriptomic studies of SRI have been started in Malaysia, but this subject is only beginning to be examined.
- **Effects of mechanical weeding on root performance.** Does root pruning by weeders induce deeper plant root growth? This simple subject should be studied rigorously. What can account for the profuse root growth with SRI management? This will become increasingly important to understand to prepare cropping for future water stress.
- **Nutrient enrichment of grains.** Why do SRI-produced grains have higher micronutrient content? Three studies in India have shown this to be greater with SRI management (Adak *et al.,* 2016; Dass *et al.,* 2017; Thakur *et al.,* 2019). This is probably associated with microbial activity, but mechanisms should be further studied.

Another whole paper could be presented on the scientific aspects of SRI, what has been learned so far and what remains to be assessed. The SRI-Rice website maintains a large collection of research papers on SRI, journal articles, and theses: http://sri.ciifad.cornell.edu/research/JournalArticles.html, and all can be accessed on line by joining the SRI Research network (free).

SRI 6.0?

From the start, we have recognized that SRI is 'a work in progress,' something not yet finished. We have no idea whether or when it will be finished, if it ever is. Clearly, SRI is not a technology like the Green Revolution. It is an assembly of ideas and insights that has shown potential to change the paradigm for contemporary agriculture, not just for the monocropping of irrigated rice. SRI capitalizes upon productive processes and potentials that already exist within crop plants and within the soil systems that support them.

We hope that farmers, scientists, extensionists, civil society actors, administrators, and businessmen will all work together with mutual respect and with productive curiosity to further advance the knowledge and practice set in motion by the development of SRI 1.0 some 40 years ago in Madagascar.

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