agronomy

MDPI

Review

SRI 2.0 and Beyond: Sequencing the Protean Evolution of the System of Rice Intensification

Norman Uphoff

SRI International Network and Resources Center, Cornell University, Ithaca, NY 14853, USA; ntu1@cornell.edu

Abstract: As the System of Rice Intensification (SRI) has evolved in many ways and in several directions over the past two decades, this review follows the software-naming convention of labeling SRI's different and subsequent versions as SRI 2.0, 3.0, 4.0, etc. In agroecology as with software, variants are not necessarily linear and can establish new directions as well as the further evolution of existing ones. This overview reviews how rainfed SRI, direct-seeded SRI, mechanized SRI, and other modifications of the initial SRI methodology have emerged since 2000, and how versions of SRI have been improvised to improve the production of other crops beyond rice, like wheat, finger millet, maize, and sugar cane. SRI thinking and practices are also being incorporated into diversified farming systems, broadening the logic and impact of SRI beyond monoculture rice cultivation, and SRI methods are also being used to achieve broader objectives like the reduction of greenhouse gas emissions and the conservation of biodiversity. SRI observations and research have been contributing to the crop and soil sciences by focusing attention on plant roots and soil ecology and by showing how crop management can elicit more desirable phenotypes from a given genotype. Cooperation regarding SRI among farmers, civil-society actors, scientists, private sector agents, governments, and funding agencies has begun introducing noteworthy changes within the agricultural sector, and this collaboration is expected to deepen and expand.

Keywords: system of rice intensification; system of crop intensification; greenhouse gas emissions; climate change; plant-soil microbiome; phenotypes; gene expression

check for updates

Citation: Uphoff, N. SRI 2.0 and Beyond: Sequencing the Protean Evolution of the System of Rice Intensification. *Agronomy* **2023**, *13*, 1253. https://doi.org/10.3390/agronomy13051253

Academic Editor: Jianbo Wang

Received: 8 March 2023
Revised: 7 April 2023
Accepted: 10 April 2023
Published: 28 April 2023

1. An Overview of the System of Rice Intensification (SRI)

SRI has progressed well beyond what it was when first assembled some 40 years ago by Henri de Laulanié, SJ, in Madagascar [1]. It has changed considerably since becoming known outside that country after 2000. Initially, SRI was understood and presented in terms of certain practices, some quite counterintuitive, for improving smallholder production of irrigated rice [2,3]. This original set of practices has been modified and improved upon by farmers cooperating with an increasing number of civil-society and scientific collaborators. As SRI methodology has been validated in over 60 countries [4,5], it has become less controversial, and it is becoming part of the operational agricultural landscape, used also by larger-scale farmers and for other crops besides rice.

1.1. Disaggregation and Schematization of SRI

Over time, the initial understanding of SRI as a set of recommended *practices* has evolved into a more broadly applicable set of agronomic *principles*, discussed in Section 1.3 below. Because SRI is more like 'software' than 'hardware' for agriculture, its progression and its serendipitous heterogeneity can be mapped by drawing on the terminology used for computer software, with successive versions numbered in ascending order—1.0, 2.0, 3.0, 4.0, etc.

This review maps SRI as I have observed its evolution over the past two decades. Unfortunately, some people became fixated early on on SRI as just a set of practices. As seen below, the utilization of SRI insights and ideas has become diversified in many fruitful ways, opportunities that would have been forgone if SRI had become encapsulated by reductionist thinking, with SRI regarded as *only* this, or as *always* that, or as *nothing more than* . . . . SRI's fluidity has posed a challenge to some rice scientists, but this has presented persons who work close to the ground with a great many opportunities.

SRI 1.0 = *the* ***original set of practices*** recommended by Henri de Laulanié [1]. The name System of Rice Intensification has been somewhat misleading because what SRI intensifies is not the use of external inputs, as the term 'intensification' has often implied, but rather an investment of more knowledge, effort, and management in rice production. Back in the 1980s, Laulaniè had his own reasons for his choice of nomenclature.

SRI 2.0 = *the* ***multiple modifications*** *of SRI 1.0* that have been introduced to make it more applicable and more productive under a variety of conditions, such as rainfed SRI where there is no irrigation, or direct-seeded SRI where this can save labor time and cost, or mechanized SRI where labor availability and cost are constraints on adoption.

SRI 3.0 = *adaptations of SRI 1.0 and 2.0 for* ***other crops***, such as finger millet, wheat, maize, sugarcane, mustard/rape/canola, teff, and various pulses and vegetables. This has been given the broad designation of SCI, the System of Crop Intensification [6,7].

SRI 4.0 = *the integration of SRI as a cropping system into* ***farming systems*** that are more complex and diversified. This takes SRI beyond its rice-monoculture origins and gets SRI users more involved in the broader management of soil and water resources.

SRI 5.0 = *applications of SRI 1.0 and 2.0 to achieve* ***goals beyond agricultural production***, such as water saving, improving soil health, crop resilience to the hazards of climate change, reduction of greenhouse gas emissions, improved conditions for women, greater micronutrient content in food grains, and helping to conserve biodiversity.

SRI 6.0 = *advancing* ***scientific understanding*** of how SRI methodology elicits more productive and robust crop phenotypes from given genotypes, i.e., varieties. SRI's challenge to some widely-accepted but incorrect beliefs about rice cropping has focused attention on plant roots and on the soil biota, both of which were mostly overlooked by the research that supported the Green Revolution.

These versions of SRI were not strictly sequential because SRI 6.0 commenced once SRI became known beyond Madagascar, and newer versions started before prior ones were completed. Of much significance was a consensus emerging from the first international conference on SRI, convened in China in 2002 and hosted by Prof. Yuan Long-ping, widely known as 'the father of hybrid rice'.

Participants were able to report on SRI experience and research already from 15 countries [8]. Since no negative effects had been identified regarding SRI use, in their concluding plenary, participants agreed that farmers, NGOs, governments and others should proceed in promoting this methodology as they had begun doing, with scientific examination being carried on concurrently.

Thus, field application and scientific evaluation were each expected to inform the other, which meant, to borrow a phrase from Mao Zedong, 'walking on both legs'. Research and practice would proceed concurrently rather than sequentially, not doing research first and then getting farmers to utilize practices prescribed by scientists.

1.2. SRI Regarded as a Methodology Rather Than a Technology

From the outset, the System of Rice Intensification (SRI) was said to be unlike other agricultural technologies, such as the Green Revolution. That strategy aimed to raise crop production by *changing the plants themselves*, specifically by modifying their genetic potential, their DNA. The SRI approach, on the other hand, was to *change the environments in which crop plants grow*, above-ground and especially below-ground. The changes made in crop management were intended to capitalize upon genetic potentials that already exist rather than trying to modify present potential. These approaches are not mutually exclusive; however, those who promoted the first were generally reluctant to embrace the second.

SRI management makes both 'improved' and 'unimproved' crop varieties more productive by providing rice plants with growing conditions that are closer to an optimum highlighted by SRI methodology and theory. The result is better phenotypes as documented in [9] in this special issue and as seen concretely in that article's Figures 3 and 4. These examples from Cuba and Indonesia show how responsive rice plants can be to more favorable conditions for growth, with better practices capitalizing on *GxE interaction*, i.e., the interaction between a plant's genetic potential and its environment.

Although the efficacy of SRI methods is not variety-dependent, it should be noted that some varieties respond to SRI management better than others. Genotype is not irrelevant for SRI as the highest SRI yields in India and elsewhere have been achieved with hybrids or improved varieties. This confirms the potency of plant breeding as an enterprise. However, it should also be noted that the yields from many 'unimproved' varieties i.e., traditional or local varieties, can be doubled or more with SRI practices. So, since their market price is often higher due to consumer preferences, under SRI management indigenous or heirloom varieties can often be as or more profitable than are HYVs or hybrids, as SRI has lower costs of production when fewer or no external inputs need to be purchased.

The two main consequences of applying SRI practices and principles are: (a) increased growth and performance of *plants' root systems*, and (b) enhancement of *the life in the soil*, augmenting the number, diversity and activity of soil organisms that range from beneficial microbes to earthworms. While (a) is easy to see, considerable effort is required to discern (b), even with instruments. This contributes to its being underappreciated.

That SRI methodology gets more output from available inputs, even from fewer inputs, makes it quite different from Green Revolution technology, which focused on the modification of crop genes and then use of inorganic fertilizer and other agrochemical inputs. The Green Revolution paid little or no attention to either plant root systems or to the soil biota. Conversely, SRI experience and research show that both of these factors have major impacts on crops' performance and production.

Laulanié assembled quite empirically the practices that initially constituted SRI, not deriving them from any theory or preconceptions, spending half of a long lifetime working with resource-limited farmers in Madagascar [10]. The practices that he recommended, based more on induction than deduction, have been confirmed by large-scale factorial trials [11] and by evaluations in countries as diverse as India, Indonesia, and Kenya [12–14]. Laulanié said humbly but proudly that the rice plants were his teacher ("*mon maître*," my master). By evaluating rice plants' performance in the field, he sought to learn how managing plants, soil, water, and nutrients differently could better elicit plants' inherent potentials. But good practice calls for corresponding theory to understand and improve the practices. So, for SRI the 'leg' of practice has been accompanied by the 'leg' of research (SRI 6.0) in tandem.

1.3. Framing SRI in Terms of Agronomic Principles Rather Than Specific Practices

As noted above, SRI was initially known and promoted in terms of certain changes to be made in often age-old practices, many of these changes being quite counter-intuitive. For example, planting many fewer plants m^{-2}, transplanting seedlings when very young, and not keeping rice paddies continuously flooded, which is standard practice around the world; all appear risky and make little sense until their rationale are explained and their results are seen.

Over time, those who sought to apply Fr. Laulanié's ideas and insights in the field have distilled from the success of these practices a few generalizable principles for more effective management of plants, soil, water, and nutrients. These principles now represent 'SRI' better than do the practices themselves [15]. Practice applying principles can vary, but the reasons for their success are broadly valid. There can be some variation in the number and wording of these principles because SRI has no orthodoxy, no curia or Vatican to determine dogma. But from Laulanié's writings it is clear that he would have approved of this progression from practices and methods to broader principles and concepts.

SRI's methodology can be summarized in terms of four broad principles listed below. To communicate the importance of these principles rather than just present certain practices for adoption, farmers should be told more than just *what* is being recommended, i.e., certain changes in practice. They should know *why* these changes are being recommended, e.g., what are the positive interactions between and among the practices. This will better prepare farmers to take ownership of the methodology and to *adapt* its practices appropriately to suit their local conditions, rather than just *adopt* them. Putting this in metaphorical terms, SRI should be presented to farmers as a *menu* with various options, rather than as a *recipe*, a set of directions. Unfortunately, most contemporary extension systems prefer to communicate in the latter mode and would rather be handling material inputs than conveying ideas.

1.3.1. Minimizing Competition between Plants

The first principle of SRI is to greatly reduce plant density so that each plant can express more fully its genetic potential for growing roots and tillers and for producing more and heavier grains. How is this done in rice cultivation?

Plant single plants per hill, not clumps of 3–4 seedlings or more. Both plant roots and canopies should have optimum space to spread and grow, with minimum competition among the plants for sunshine, nutrients, and water, and with no shading. If the soil is not very fertile, two plants per hill may give higher yield at first; but single plants per hill will be more productive once the soil's fertility has been improved by practicing SRI.

Space the hills more widely apart. Spacing of 25 × 25 cm between rice plants (16 plants m^{-2}) has been found to be usually the most productive, but if the soil is relatively poor in nutrients, closer spacing of hills, such as 20 × 20cm, can give a higher yield initially. In very fertile soil, on the other hand, wider spacing can give better results. In the most fertile soil, the best spacing between hills can be more than 30 × 30 cm. The number of plants m^{-2} is to be optimized according to local conditions, neither maximized nor minimized.

Spacing single plants widely greatly reduces both plant population and seed requirements, by as much as 80–90%. Present plant populations are usually 50–100 plants m^{-2} or even more. Although it is counterintuitive, having *lower* plant density will usually produce more productive tillers m^{-2} and give more grain per unit of soil, water, and labor input [9], if it is accompanied by the other recommended components of SRI.

What constitutes optimum spacing will be affected by climate, soil, and rice variety, among other factors. Determining what is optimum is an empirical matter, applying the principle of minimizing competition between plants. Establishing plants in a *square grid pattern* facilitates subsequent weeding with a simple implement that can aerate the topsoil on all sides of the plant (with perpendicular use), at the same time that it controls weeds.

1.3.2. Establishing the New Crop Carefully and Well

This principle focuses on avoiding trauma to the plants' roots because these are crucial for the success of any crop. While acquiring water and nutrients for plant growth, roots also enrich the life in the soil through their exudation.

For irrigated rice production, SRI recommends that *seedlings be transplanted at an early age*, at the 2–3 leaf stage when only 8–15 days old. After they are removed from the nursery, they should be transplanted carefully and quickly, not letting seedling roots desiccate. This will minimize what is called 'transplant shock,' which delays transplanted seedlings' resumption of growth for 5–7 or more days.

Alternatively, SRI rice crops can be established by *direct seeding*, as discussed below, following also the other principles of SRI. With direct seeding, there is no disturbance of or shock to the roots; and direct-seeding reduces labor requirements because there is no need for a nursery or for transplanting. But seed germination cannot be guaranteed, and seeds may be consumed by predators, so there are tradeoffs to consider. Although SRI began with the practice of early and wide transplanting of young seedlings, the operative principle was to *avoid trauma to the plant roots* so that they get well established in the soil for subsequent plant growth and vigor.

1.3.3. Balancing the Availability of Water and Oxygen in the Soil

Plant roots and beneficial soil organisms both need water and air to survive and thrive, so the water and soil in rice fields should be managed accordingly. When paddy fields are kept continuously flooded, this limits and even cuts off the oxygen that is required by plant roots and their associated aerobic soil biota.

Where farmers have access to irrigation facilities and water control, SRI paddy fields should be *alternately wetted and dried* (AWD), or periodically drained to let the soil dry out. If, on the other hand, the rice crop is rainfed, then rainfall should not be hoarded in the field during the early part of the season as is now common practice. Hoarding rainwater will suffocate the plant roots and cause them to degrade from hypoxia, as much as 75% by the time that grains start forming [16]. When the water eventually recedes, these plants will have diminished root capacity and will become water-stressed more easily than if their roots had developed more vigorously in soil that had more oxygen.

Provide just enough water to meet the needs of the plants and the soil biota. Laulanié advised farmers to give their rice plants only the minimum of water (*"le minimum de l'eau"*) [17]. When rice plants are under moderate water stress but not too much, their root systems are prompted, even impelled, to grow more deeply. Conversely, when plants have abundant water, their roots have less need to extend themselves; and roots that are inundated and deprived of oxygen are less able to grow deeply. The growth and functioning of root systems is as important for plants as is their producing abundant leaves to perform photosynthesis. There is positive feedback between both roots and leaves.

Alternate wetting and drying of rice fields aerates the soil passively. By controlling weeds with a simple mechanical push-weeder that disturbs the surface soil around the plants, SRI adds *active soil aeration*. This is beneficial for both plant roots and aerobic soil organisms. Farmers find that doing as many as four mechanical weedings in perpendicular directions before the canopy closes can increase their crop yield by several tons per hectare, compared with doing just 1 or 2 weedings for weed control [18]. The increase is not due to fertilizer, but to the rice plants developing larger, longer-lived root systems and to there being more beneficial life in the soil.

1.3.4. Building up Soil Fertility

SRI recommends providing more organic material (compost, mulch, etc.) to the soil, indeed as much as is practical and economically justifiable, in preference to relying on inorganic fertilizers. Maintaining the soil in well-aerated, uncompacted condition creates a better environment for roots to penetrate and spread, and for the soil biota to prosper. Inorganic fertilizer can supply, by volume, more nutrients to the soil than does compost. But compost and other organic materials do more than just provide nutrients to the plants, feeding the plant; they also 'feed the soil,' i.e., the life in the soil.

Increasing the amount of organic matter in the soil improves both its structure and its functioning. Greater soil porosity and more circulation of air and water within the soil support the growth of both plant roots and the soil's inhabitants [19]. Also, when abundant nutrients are provided exogenously, plant roots have *less need* to grow deeply, so, they remain nearer to the soil surface rather than growing down into lower horizons.

Organic and inorganic sources of nutrients can be combined with SRI to optimize the supply of soil nutrients or to remedy particular soil-nutrient deficiencies where these are present. This is referred to as Integrated Nutrient Management (INM). It should be stated that SRI is not necessarily an 'organic' methodology. However, it pays particular attention to all of the biological aspects of agricultural production.

SRI protocols should underscore that inorganic fertilizers and chemical means of pest or disease control should not be used where or to the extent that they adversely affect the life in the soil or degrade soil systems and impair human health. The fertility of the soil depends on more than its chemical content, being affected by the soil's physical structure and biological activity. Both of these are improved when the soil, water, plants, and nutrients involved in rice production are managed according to SRI principles.

It should be noted that SRI cultivation involves also other practices such as good leveling of the soil in the field; seed selection to start off with vigorous seedlings; and maybe also seed priming to improve germination, or the inoculation of the seeds or seedlings with beneficial microorganisms. Since these practices are not unique to SRI, they are not considered to be part of SRI, which focuses on *changes to be made in conventional practice* that can improve crop productivity, lower costs, save water, etc.

The four principles articulated above, based on experience with the growing of rice, can be extended and adapted to many other crops. This realization has led to development of what is called the System of Crop Intensification, discussed in Section 3. below.

2. SRI 2.0 = Modifications of SRI 1.0 for Diverse Conditions and Constraints

As the use of SRI practice spread beyond Madagascar, farmers who were cultivating rice under circumstances different from those with whom Laulanié had been working began to make adaptations of SRI 1.0. These versions of SRI are grouped and reviewed here under the heading of SRI 2.0. The main types of SRI 2.0 that have emerged as major adaptations of SRI 1.0 are numbered roughly in the sequence of their emergence.

2.1. Rainfed SRI

Although rice has long been thought of as an aquatic plant, it does not require standing water for its growth and should be regarded only as water-tolerant or water-friendly. Rice plants can *survive* under flooded conditions by forming air pockets (aerenchyma) in their roots. However, they do not *thrive* unless their soil is mostly aerobic. Over millennia, most rice cultivars, although not all, have developed the ability to grow in soil that is inundated; but root morphology when rice plants are grown in flooded vs. unflooded soil indicates that rice evolved as an upland crop that depended only on rainfall [20].

The practices of SRI 1.0 have been adapted and adopted by several million farmers who are cultivating rice in *upland, unirrigated areas*, first in Madagascar, then in the Philippines [21], Cambodia [22], Myanmar [23], and India [24]. SRI methods have been extended in rainfed areas within the four countries of peninsular Southeast Asia under a large project funded by the EU, 2015–2018 [25].

In 2004, a team from the International Water Management Institute carried out an evaluation of rainfed SRI in West Bengal, India. It found that even with drought affecting half of the farmers whom it surveyed and with few of the farmers using all of the recommended practices, use of adapted SRI methods had increased average yield of rice by 32%, with 5% lower costs of production ha^{-1} and 8% less labor ha^{-1}. Farmers' net return from their rainfed rice production was increased by 67% ha^{-1} with SRI [24,26].

Many millions of rice farmers have the challenge of managing rainfall rather than irrigation water in an optimizing way, sometimes heavy rainfall as in the case of monsoon rains. Rainfed SRI 2.1 modifies the water management component of SRI 1.0 to make the suite of practices appropriate for growing unirrigated rice. That it follows the SRI principles enumerated above makes it part of the SRI family and legacy.

2.2. Direct-Seeded SRI

When SRI is understood in terms of principles rather than the original set of practices, transplanting young seedlings becomes one version of the methodology. What is essential for SRI is that the methods used for crop establishment *should not diminish the plants' potential for growth*. Where agricultural labor is scarce or very costly, the amount of labor required for managing a nursery and then transplanting young seedlings carefully can be a barrier to the utilization of SRI.

It is possible to establish an SRI crop by direct-seeding with no nursery management and no transplanting, which greatly reduces the amount of labor required for capitalizing on SRI insights and principles. An evaluation done by researchers at Tamil Nadu Agricultural University in India found that one version of direct-seeded SRI reduces the labor required for managing an SRI crop by about 40% [27].

Success with the direct-seeding of rice depends, however, on good land preparation, having at least some water control, and on a high rate of seed germination. It is not difficult to reduce plant density when doing direct-seeding, but establishing single rice plants in a grid pattern that permits mechanical weeding in perpendicular directions usually requires some kind of mechanization (see Section 2.3 below).

The yields from direct-seeded SRI have thus far seldom matched those of well-transplanted SRI rice; but the reduced cost of labor can make up for a somewhat lower yield, making this practice profitable. More experimentation remains to be done for direct-seeded SRI, but with shortages and costs of labor increasing in most rice-producing countries, this method for establishing an SRI crop will probably displace transplanting in many regions in the coming decades.

2.3. Mechanized SRI

SRI 1.0 was developed to benefit smallholding farmers in Madagascar who had little capital and depended mostly on family labor for their farming operations, so it was a labor-intensive methodology at the outset. Researchers learned, however, that even in Madagascar, once farmers had gained experience with SRI practices, these could reduce the labor required ha^{-1} [28], while also saving water, seed, and other input costs.

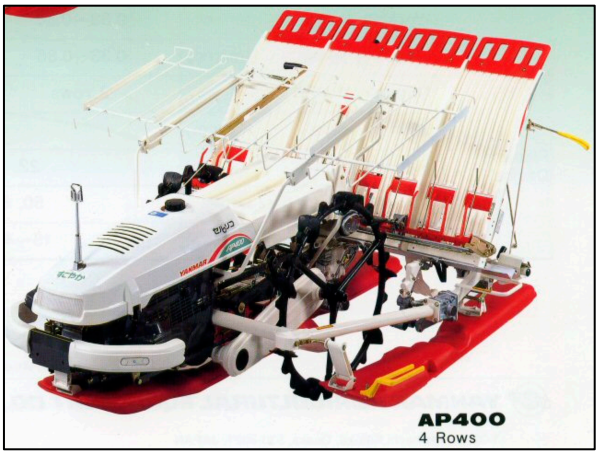
Since most rice (90%) is produced in Asia where current methods are still relatively labor-intensive, SRI 1.0 has the potential to be or become labor-saving for most rice farmers in the world. However, farmers everywhere like to reduce the amount of labor that they expend in crop production if possible. So, there is widespread interest in finding ways to mechanize SRI operations, if only to save time and reduce the drudgery of field work. Crop establishment and weeding are the operations that require the most time when changing from conventional to SRI management; field preparation and harvesting are essentially the same for either management system.

Where agricultural labor is of limited availability and/or is relatively costly, or in order to be able to apply SRI methods on a larger scale in commercial rice production, various kinds of machinery and equipment have been and are being devised to reduce the labor requirements of SRI. SRI does not have to be labor-intensive and limited to small-scale operations. What is needed is the design and fabrication of implements that can perform SRI operations mechanically rather than manually, applying fuel-based, electrical, or other power in place of human or animal energy. Such innovations can be grouped under the heading of SRI 2.3, which can be compatible with SRI 2.1 and/or SRI 2.2.

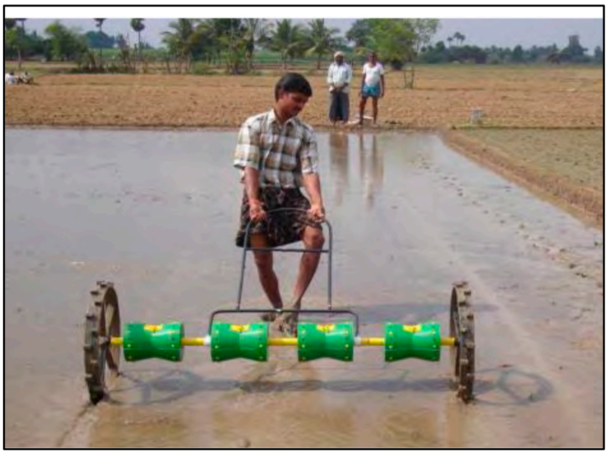
2.3.1. Mechanical Transplanting of Seedlings

This innovation for SRI was first introduced in Costa Rica in 2005 when a conventional rice-transplanting machine imported from Japan was adapted by Oscar Moreno to maintain SRI spacing (Figure 1a). This greatly reduced the time and labor needed for establishing his SRI crop, and Montero's grain yield was almost double the national average, so he was quite satisfied and is still promoting SRI to other farmers [29].

Since then, other mechanical transplanters have been developed or adapted for SRI use. Already, most machines for rice transplanting have been designed to use younger rather than older seedlings as this reduces the bulk of the planting material, but few available mechanical transplanters can handle very young seedlings without trauma to the roots. So, work is continuing to develop transplanting machines that are suitable for SRI crop establishment.



(**a**)



(**b**)

Figure 1. (**a**) Motorized, self-propelled Yanmar AP-400 transplanter for rice seedlings with spacing adjusted for SRI use in Costa Rica (Section 2.3.1); and (**b**) hand-drawn drum seeder developed in Andhra Pradesh state of India for establishing SRI with a simple hand-drawn implement (Pictures courtesy of Oscar Montero and P. Bala Hussein Reddy).

2.3.2. Mechanical Direct-Seeding

This approach to SRI crop establishment started by using a simple drum-seeder that could be pulled or driven across the field, as shown in Figure 1b, but there can be also more complicated and expensive machines that plant seeds according to SRI principles. The implement shown was developed in India in 2007 [30], but similar drum-seeders have also been developed in Vietnam [31] and elsewhere. Achieving precise spacing is not much of a challenge, but ensuring seed germination is.

Direct-seeding can enable farmers to apply SRI principles on a much larger scale than is possible with transplanting. Figure 2 shows a large tractor-mounted implement that has been developed in the state of Arkansas in the USA [15,32]. With air-pressure injection of seeds into the soil, the implement can plant 60 hectares in a day with precise plant spacing at the desired, shallow depth.

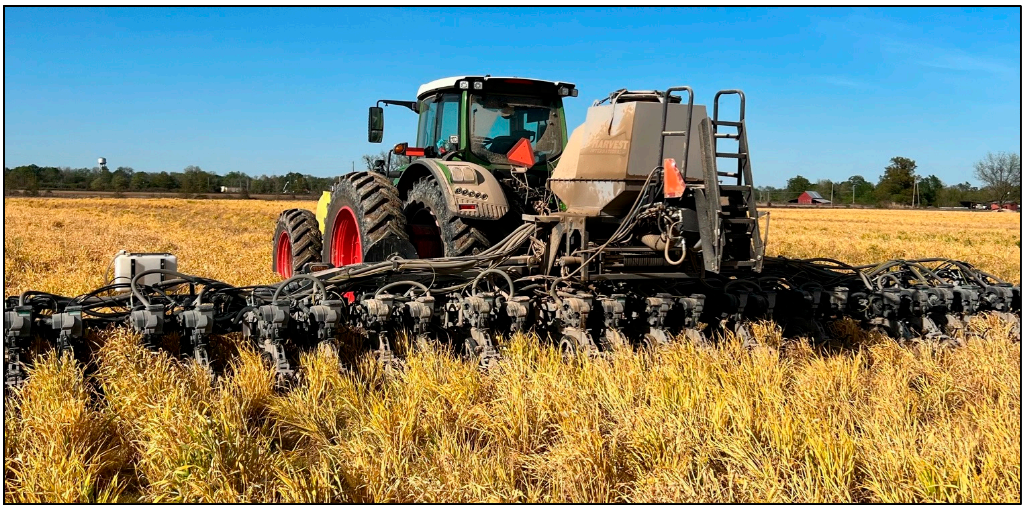


Figure 2. Tractor-mounted direct-seeder for large-scale establishment of SRI rice in Arkansas, USA, designed to plant seeds with SRI spacing through a cover crop or the residue of a previous rice crop. (Picture courtesy of Adam Chappell).

This implement was designed and adapted to plant rice seeds through crop-residue mulch or killed cover crops to get the benefit of ground cover, converging SRI with Conservation Agriculture (Section 4.1). The organic cover material suppresses weeds so that weeding and weedicides are not usually needed, provides nutrients to the soil, conserves soil moisture, and protects the soil from erosion. There will likely be further variations and development in such machinery as SRI is taken up more widely.

2.3.3. Motorized Weeding

In a number of countries, engine-powered multi-row weeders have been developed to save time and labor for weed control. In the Philippines, there have even been prototypes of solar-powered weeders designed that are suitable for SRI. Motorized weeders speed up and make this operation easier. The mechanical power from an engine improves upon the amount of energy that can be applied for churning up and aerating the soil with human propulsion. Herbicides are an option for weed control, but they are not recommended for SRI because of their adverse impact on the soil biota with no benefits from soil aeration, referred to as 'inter-cultivation' in India.

2.3.4. Full Mechanization

Crop establishment, weeding, and harvesting operations can all be mechanized. Extensive mechanization of SRI was developed in the Punjab province of Pakistan by Asif Sharif in 2010, integrating Conservation Agriculture practices with those of SRI. His mechanized SRI technology was evaluated on a large test plot (8 ha), laser-leveled with tractor-made raised beds. Laborers riding on a multi-functional machine designed by Sharif dropped 10-day-old seedlings into holes that the machine had punched into the beds with precise spacing as it drove along the raised beds. At the same time, it made microapplications of compost and some fertilizer in each hole, also filling each hole with water to make the dry soil habitable for the young plants [33]. Supplementary irrigation was provided for the crop flowing along the furrows between the beds, using siphons from the main canal so that no fuel or exogenous energy was needed. During the season, a tractor-weeder that could be operated remotely without a driver periodically eliminated weeds and aerated the soil between the rows, contributing to profuse tillering and root growth.

Compared to prevailing methods for rice cultivation in the Punjab, this mechanized production process reduced by 70% the amounts of both labor and water required. The resulting average grain yield, 12 t ha^{-1}, was about three times the usual yield in the region [33]. However, Sharif has now moved from transplanting to direct-seeding, seeking to further enhance the profitability of his operations. With further adaptations in the implements, this technology can improve the production of also other crops such as wheat, maize, sugarcane, potatoes, and carrots, creating mechanized versions of SRI 3.0 [7] (pp. 21–24).

Such mechanization runs counter to the stereotype of SRI as being necessarily or always labor-intensive. The costs of the machinery and equipment discussed here can be addressed in several ways. For smaller implements like mechanical weeders, groups of farmers or cooperatives can purchase and share the equipment. For more expensive machinery, private operators or government entities can provide machine services on a fee-for-service basis that covers both capital and variable costs. This can benefit farmers by saving them both labor and money. In many places, access to suitable machinery and equipment has been the main impediment for wider uptake of SRI.

2.4. Organic SRI

The original version of SRI developed in the 1980s included the use of inorganic fertilizer as this was understood to be necessary and desirable because of the poor nutrient status of soils in Madagascar. But in the latter 1980s the government removed its subsidy for fertilizer, and the resource-poor farmers with whom Laulanié was working could no longer afford it; so the use of composted biomass of any sort was recommended instead. (Most of these farmers were too poor to own any cattle, so they did not have much access to manure.)

It turned out that when all of the other SRI 1.0 practices were used, the results with compost were as good as, or better than, those with chemical fertilizer, so compost was recommended as part of SRI, although not exclusively. The NGO Association Tefy Saina considered organic fertilizer to be an accelerator of SRI, but not a necessary feature of it. Subsequent factorial studies showed that compost would outperform inorganic fertilizer if all the other SRI recommendations were followed—but if there was only partial use of SRI methods, inorganic fertilization could have some advantage [11].

As SRI has been extended to other environments, many of its proponents have preferred a purely 'organic' version of SRI, referred to here as SRI 2.4. But this may not be readily accepted by farmers. In eastern Indonesia, a technical team introducing SRI under a large irrigation management project found that most farmers there were resistant to giving up fertilizer and did not have much confidence in compost. A national campaign promoting Green Revolution technology had inculcated a strong faith in chemical fertilizers. Farmers were, however, willing to try the other recommended methods of SRI, which they did this with considerable success [13]. The technical team called this 'basic SRI' to distinguish it from 'organic SRI,' which was also promoted [34]. The latter was often more profitable because of its lower costs of production, and it was expected that over time, reliance on agrochemical inputs would recede on the basis of observed results.

In other Southeast Asian countries such as Cambodia, Philippines and Malaysia, the promoters of SRI have opted for 'organic SRI' because of concerns about soil health and human health. While some consider SRI to be necessarily or intrinsically 'organic', it makes more sense to understand 'organic SRI' as a second-generation version of the original system (SRI 1.0). As discussed above in Section 1.3.4, given SRI's emphasis on building up soil fertility, there is an emphasis on 'organic' crop management to nurture the life in the soil, and also to make environmental resources and ecosystems more robust and resilient. Usually with SRI management, there is little or no need for agrochemical crop protection, so this is another factor in support of SRI 2.4. That SRI is not necessarily or only 'organic' upsets some persons and relieves others.

2.5. SRI for Colder Climate

In the Heilongjiang province of northern China, a system known as '3-S' was developed in the 1990s by Prof. Jin Xueyong at Northeast Agricultural University in Harbin. This system of rice cultivation, based on Prof. Jin's own observations and experimentation, followed SRI principles without any prior knowledge of SRI. His greatest departure from SRI 1.0 practices was starting 3-S seedlings in heated greenhouse nurseries in March while there was still snow on the ground.

With low temperatures and short day-length, rice plants' phyllochrons of growth are longer and slower, so 3-S rice seedlings are transplanted when 45 days old, one per hill with wide spacing, no continuous flooding, and more organic matter provided to the soil [35] (pp. 1–4). Even with the short growing season in Heilongjiang, 3-S yields reach 11–12 t ha^{-1}, and this rice cropping system has been applied on 10s of 1000s of hectares there. The constraints of cold climate are dealt with by transplanting seedlings that are older in calendar days, but that are still relatively young in terms of biology and phenology.

Although the climate in Sichuan province lying to the south and west is not as cold as in Heilongjiang, it is still cooler than in China's main rice-growing areas further to the south and to the east. Experimentation in Sichuan found that SRI 1.0 practices could raise the already high yield there (8.65 t ha^{-1}), by 28% (to 10.4 t ha^{-1}). However, rice yield could be raised by another 28% (to 13.4 t ha^{-1}) by planting hills even more widely apart (spaced 35 × 40 cm, which cut the number of hills m^{-2} roughly in half) and by planting three young seedlings in each hill, in a triangle pattern, 7 cm between each plant [36]. This gave a plant density m^{-2} that was 50% greater than in SRI 1.0, but it still enabled the plants to grow larger roots and to tiller profusely.

According to Dr. Zheng Jiaguo, Sichuan Academy of Agricultural Sciences, who did this evaluation, this 'triangular SRI' which followed the principles of SRI 1.0 had practices better adapted to the cooler climate in Sichuan. The intra-hill spacing was enough to reduce inter-plant competition both below and above ground. This was an example of adjusting SRI's practices to local conditions in order to get the most benefit from its principles.

2.6. Ratooning

Because SRI methods induce greater and deeper root growth, ratooning becomes a more feasible option. Ratooning involves cutting rice plant stalks at a uniform height when harvesting the first crop so that a second crop re-grows from the same rootstock. This saves farmers the labor needed to re-plant the field for the next season, and it also shortens the next crop cycle. Unfortunately, a second yield is usually lower than the first; how much lower determines whether or not ratooning is profitable.

An experiment in Indonesia found that the first-season SRI yield with a given variety was 6.7 tons ha^{-1}, 28% more than the yield of 5.2 tons ha^{-1} produced from the same variety with conventional methods. When the SRI rice stalks were cut 3 cm above the ground, the second crop gave a yield of 4.6 tons ha^{-1}, 76% of the first harvest; while in plots where the stalks were cut at 15 cm, the yield was 3.8 tons ha^{-1}, 67% of the first crop [37]. With cutting at these respective heights, comparable trials with conventional methods produced ratoon yields of 3.3 and 2.8 tons ha^{-1}, too low to make ratooning worthwhile.

Where achieving the highest possible yield per unit of land is the prime objective, it makes economic sense to invest the labor and capital needed to re-plant the rice crop each season. But where labor is costly and/or where land is not the most limiting factor of production, SRI methods can make re-planting only every other season profitable for farmers because of the greater growth of plant roots.

2.7. Further Reductions in Water Use

Where water supply is limited, there is reason to minimize water consumption, and to maximize the productivity of water rather than that of land, by growing rice under water-stressed conditions. The recommendation of SRI 1.0 was for alternate wetting and drying of fields during the rice crop's period of vegetative growth (tillering), i.e., up to the stage of panicle formation. Thereafter, maintaining a thin layer of water on the field (1–2 cm) was recommended during the stages of grain formation and filling, until the grains matured and were ready for harvest. Through careful water management, water stress was to be minimized and even avoided.

Trials at the ICAR-Indian Institute of Water Management have shown, however, that it is possible to get both higher yield and greater water productivity by *continuing AWD on SRI rice fields throughout the whole crop cycle*, not just until panicle initiation [38]. Since this finding can be affected by soil type and climate, more evaluation should be done before this becomes a general recommendation for SRI practice, however.

Applying the SRI principle of giving rice crops only the minimum amount of water certainly needs to vary according to location. In water-scarce southern Iraq, researchers at the Al-Mishkhab Rice Research Station near Najaf have evaluated the impact of making large reductions in water provision at the same time that they assessed SRI methods more generally. It was found that putting SRI rice plants under greater water stress rather than just intermittent moderate stress did not lower the grain yield by very much, by just 13%, while it reduced the crop's water requirements greatly, by 75%. By practicing this kind of 'water-deficit SRI,' considerable water could be saved with only a small sacrifice of yield, provided that the other SRI practices were followed which enhanced root growth. The water saved under such an irrigation regime could be made available for enlarging the irrigated area or for other purposes, as discussed in [39].

So far, there has been little work done to add technology changes to the management mix for SRI. Both drip irrigation and sprinkler irrigation systems could be adapted to make SRI even more water-efficient, but there has been little experimentation on this, one exception being [40]. A caveat will always be that the water needs of the soil biota should be considered along with the needs of the rice plants.

It has always been expected that SRI practices will be adapted to local conditions. The examples of SRI 2.0 considered in this section show how and why SRI 1.0 was not something to be implemented and evaluated as single technology in terms of set practices. The complaint that SRI was not a fixed, invariant thing was a correct observation, but not a valid reason to dismiss or disparage the innovation.

What is referred to here as SRI 1.0 and its SRI 2.0 elaborations and variations reorient thinking and practice for agriculture, showing paradoxically how 'less can produce more' by making better use of existing biological processes and potentials in rice plants and the soil systems that support them. This diverges from current thinking regards improving and increasing exogenous inputs, particularly new-variety seeds, as the best and most expedient way to raise agricultural output.

3. SRI 3.0 = Extending Modifications of SRI 1.0 to Other Crops

These innovations are now referred to collectively as the System of Crop Intensification (SCI) [6,7], although in Bihar state of India these variants are referred to as the System of Root Intensification, another SRI. This section reviews crops and countries where SRI ideas and methods have been applied to other crops. It is more indicative than complete. It may be of interest that thus far, India has been the greatest source of SCI innovation.

3.1. Finger Millet

This cereal, known as *ragi* in India, was the first crop to which SRI methods were extrapolated, by farmers in Jharkhand state assisted by the NGO PRADAN (see Figure 3). Subsequently, I learned that there were farmers in Karnataka state of India and in Tigray province of Ethiopia who without any knowledge of SRI had learned by themselves that they could improve their production of finger millet with SRI practices ([41] (pp. 24–29) and [42]).

(**a**) (**b**)

Figure 3. Differences in finger millet phenotypes seen by farmers in Bihar state of India. (**a**) An improved-variety millet plant (A404) grown with adapted SRI practices on the left, compared with a local-variety millet plant grown with farmer methods on the right, and an improved-variety plant grown with these methods in the center. (**b**) shows phenotypic differences in root growth, the plant on left grown with wide spacing, transplanting young seedlings, more soil organic matter in soil, and the one on the right raised with farmer practices, starting with the broadcasting of seed instead of transplanting young seedlings. (Pictures courtesy of Binju Abraham, PRADAN).

Finger millet versions of SRI have been promoted by a number of NGOs in India, particularly in the states of Bihar [43] and Odisha [44], but also in neighboring Nepal [45]. As this cereal crop is hardy and drought-resistant and because its grains are very nutritious, finger-millet SCI could have a positive impact on the diets and income of millions of poor and vulnerable households in South Asia and Africa as this crop, now only marginally profitable to produce, can become quite profitable with SRI-adapted management.

3.2. Wheat

Applications of SRI ideas and methods to this major cereal crop have been reported from India [46], Mali [47], Ethiopia [42], Pakistan [7], Afghanistan [48], and Nepal [49] (see Figure 4). Adapting SRI ideas and practices to wheat has usually been at the initiative of farmers. Despite the positive results reported from various countries, there have been few scientific evaluations of the System of Wheat Intensification (SWI), one exception being a two-year study carried out at the Indian Agricultural Research Institute in New Delhi [50].

(**a**) (**b**)

Figure 4. (**a**) Adjacent wheat fields growing the same variety of wheat in Bihar state of India, SWI on left, and farmer methods on right, showing the more rapid growth and shorter crop cycle under SRI management. (**b**) Grain panicles of wheat (same variety) grown in a water-stressed environment near Timbuktu in Mali. On left, panicles grown with farmer-adapted SRI methods, and on right, panicles produced with farmer practices. (Pictures courtesy of Erika Styger, Cornell University).

3.3. Sugarcane

Extrapolation of SRI experience to improve production of this major crop, which consumes large amounts of water and fertilizer, began in India through farmer initiatives, although some precursor steps had been taken by researchers in that country [51,52]. What is being called the Sustainable Sugarcane Initiative (SSI) was launched in 2009 with a first manual published by a WWF-ICRISAT program [53], followed three years later by a revised manual [54].

In collaboration with sugar mills and farmers, SSI has been tested in all of the agro-climatic zones of India where sugarcane is grown, with substantial yield increases and cost savings. Field demonstrations of SSI have been conducted also in Cuba, Kenya, Tanzania, Uganda, and the Philippines through the efforts of AgSri, a pro-bono consulting organization that grew out of the WWF-ICRISAT program, operating from Hyderabad, India [55].

3.4. Maize

There has not yet been much application of SRI ideas to this major crop, unfortunately, but trials have been carried out with farmers in the Himalayan foothills of northern India guided by the People's Science Institute based in Dehradun, and also a mechanized version of SCI for maize in Punjab, Pakistan. These assessments have shown that the principles of SRI can be successfully applied to maize, with yield increases ranging from 25 to 75%, and with reduced costs of production increasing the profitability of this crop [7]. Given its significance, maize should be a priority for SCI experimentation and evaluation.

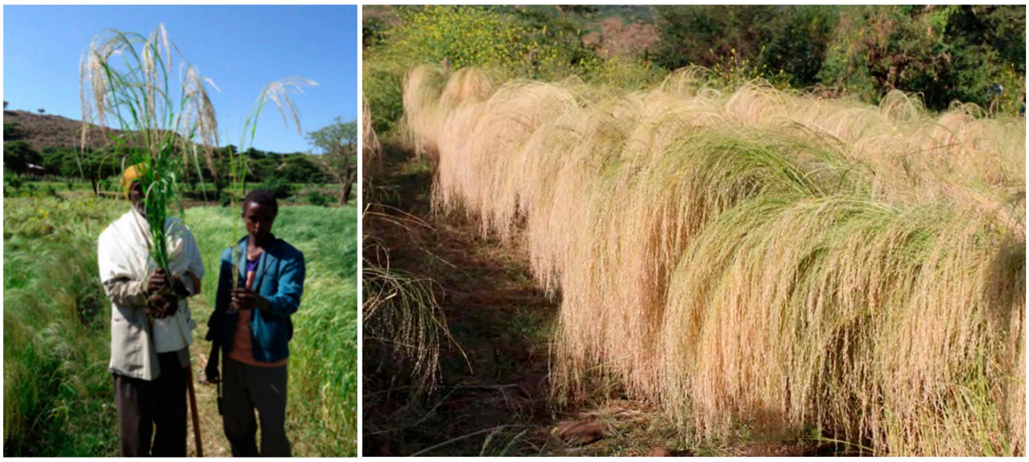
3.5. Mustard

Initially, this crop was thought not to be amenable to SRI management because mustard (also known as rapeseed or canola), unlike rice, wheat, millet, and maize, is not a member of the grass (*Gramineae*) family. However, by making appropriate adaptations of SRI methods, farmers in Bihar state of India and then elsewhere have been able to raise their yields of this crop several-fold, compared to what they achieve with their usual methods, which establish the crop by broadcasting seed rather than by transplanting [56].

Transplanting young seedlings grown from tiny mustard seeds seems like a foolish task, but when this is done along with wider spacing, increased soil organic matter, etc. the yields ha^{-1} of both mustard grain and straw are increased by as much as fourfold. Mustard SCI requires twice as much labor ha^{-1} as is usually invested in the crop, but the total cost of production kg^{-1} of mustard seed is cut by 60%. So, mustard, which is often only marginally profitable, can become a remunerative crop with agroecologically-based management.

3.6. Teff

This grain crop, small-seeded like mustard, is the main staple cereal in Ethiopia, while increasingly being consumed elsewhere as a health food. Although the plant grows quite differently from rice, teff has proved to be very responsive to adapted SRI management [57]. As with SCI mustard, carefully preparing the soil and providing it with organic matter to make it more hospitable for greater root growth transforms teff plant phenotypes dramatically (see Figure 5).



(**a**) (**b**)

Figure 5. (**a**) In Ethiopian highlands, a father, on left, is holding up a teff plant grown with SCI methods, while his son holds up a more typical teff plant for comparison. (**b**) Row of teff plants started from seedlings under SCI management with cascading grains in Tigray province of Ethiopia. (Pictures courtesy of Tareke Berhe).

Crop management of teff according to SCI principles, starting with the transplanting of young seedlings, can raise the grain yield by five times or more ha^{-1}, compared with the traditional crop-establishment practice of broadcasting. Wider spacing and increased soil organic matter contribute to higher yields based on greater, deeper root growth. In Ethiopia, even partial use of SRI principles and practices, now being promoted by the government, improves teff crop performance, with an average yield increase of 70% [58].

3.7. Vegetables and Pulses

Farmers and researchers in India have started growing a variety of food crops with SCI management, and this has been done also in Ethiopia under the rubric 'Planting with Space' [42]. Under a World Bank-supported project to improve rural livelihoods in Bihar state of India, over 60,000 households were trained in SCI methods during the early 2010s, applying these methods to their growing of groundnut (peanut), red gram (*dal*), black gram (lentils), eggplant (*brinjal*), potatoes, tomatoes, soya beans, and other crops [59].

This large project in Bihar reported that with SCI, vegetable yields were raised by 20% on average, not a huge increase. But with lower costs of production and higher market prices (better quality of produce), households' net incomes from their vegetable production went up by 47%. At the same time, with SCI management, households' yields of pulse crops rose on average by 56%, and their income from pulse production was increased by 67% [59].

SCI potential for improving pulse and vegetable production is only beginning to be tapped. In Sierra Leone, West Africa, SRI ideas have been applied to the widely-consumed green leafy vegetable known as *krain krain*, a mallow. While labor inputs for managing this crop more intensely are increased, by 40%, the weight of edible leaves harvested from a given area from one planting of *krain krain* can be increased by as much as ten-fold [60].

3.8. Spices

Improving spice production by using SRI/SCI concepts is touched on here just to show how widely SRI/SCI ideas are being extended. Farmers in Thambal village in Tamil Nadu state of India, who were the first in their country to form an SRI association for growing rice, extrapolated their SRI thinking and experience with rice to their off-season cash crop, turmeric (*Curcuma longa*), a root crop grown from rhizomes.

When reducing their planting material by 80% ha^{-1} and growing and transplanting healthy turmeric seedlings at wide spacing, quite similarly to SSI practices for sugarcane, Thambal farmers increased their turmeric yields by 25%. With the alternative methods lowering their costs of production by 20%, farmers doubled their net income ha^{-1} from this crop [61]. The manual that the Thambal farmers prepared on their System of Turmeric Intensification (STI) for others to learn from their innovation stated: "This increased income of Rs. 60,000+ [US$ 735 per acre] is because of our inspiration from SRI experience!"

In the Indian state of Gujarat, farmers working with staff of the Aga Khan Rural Support Programme who tried applying SRI ideas in their production of cumin and coriander were able to achieve substantial yield improvement for both crops. Net income ha^{-1} from cumin was increased by 33% [62], while that from coriander was more than doubled [63]. This gives a further indication of the extent to which the principles of SRI have relevance for agricultural production generally [6,64].

4. SRI 4.0 = Integration of SRI Rice into Farming Systems

As the principles constituting SRI have become better understood and more widely applied, a variety of initiatives have worked them into farming systems. This can diversify these systems at the same time that it intensifies them, taking SRI thinking and practice beyond its origins as a cropping system for rice.

SRI is best understood not as a stand-alone or unique innovation, but as part of a larger family of agroecological systems of production that build upon and capitalize upon biological processes and potentials that exist in nature. Examples of like-minded agricultural systems are Conservation Agriculture, integrated pest management (IPM), agroforestry, and integrated crop-livestock systems. Here are several cases where SRI ideas and practices have been extended into broader systems of production.

4.1. Convergence of SRI with Conservation Agriculture

What was initially called 'no-till agriculture' has evolved over the past 20 years into an alternative system for crop production known as Conservation Agriculture (CA). This is being practiced on some 180 million ha of farmland on all of the continents where agriculture is conducted, and its use is expanding by about 10 million ha yr^{-1} [65].

The essential practices of CA are: (a) minimizing or stopping mechanical disturbance of the soil, i.e., little or preferably no plowing of fields; (b) permanent vegetative cover on fields, with cover-cropping or mulch; and (c) diversification of species within the cropping system [66]. At first glance, these practices might appear to be incompatible with SRI methodology. However, with some modifications of practices that are consistent with the principles of both SRI and CA, there can be a merging of these agroecological systems [67].

Modifications include raising crops on permanent raised beds rather than on flat soil; providing irrigation water along furrows between the beds to have good water control and no submergence; crop establishment either by transplanting or direct-seeding depending on the crop; and following the principle of wider spacing in order to give individual plants plentiful room for their roots and canopies to grow.

The first integration of SRI with CA was in the Punjab province of Pakistan in 2009 [33]. After successfully growing SRI rice on raised beds, the highly-mechanized operations discussed in Section 2.3.4 above were adapted also for other crops, thereby achieving a convergence between SCI and CA [7] (pp. 21–24). The innovator of this merger, Asif Sharif, continues to refine and extend this synthesis in Pakistan under the Urdu acronym PQNK, pronounced 'picnic' [68].

Another convergence of SRI and CA has been made in Sichuan province of China. There, SRI methods for rice crop management were used with a thin plastic-film cover on raised beds that conserved water and suppressed weeds. Rice and mustard crops were grown in alternate summer and winter seasons, with their respective crop residues used as mulch for the following crop. This utilized the CA practice of maintaining continuous ground cover while rice was grown according to SRI principles [69].

With permanent raised beds, mechanical, soil-aerating weeding can be done in only one direction, not in two. In the Punjab case, soil between the rows was broken up by a specially-designed tractor-weeder as it eliminated weeds, moving along but not across the raised beds. Mechanical weeding is precluded by mulching or where inter-crops are being grown together with rice on raised beds. However, when soil organisms become more numerous and more active in response to CA and SRI practices, aeration of the topsoil can be achieved by biological rather than mechanical means. Much remains to be done to further the convergence of SRI and SCI with CA, however.

4.2. Linking SRI with Water Harvesting and with Horticulture and Fish Culture

The first example of this connection being made came from initiative by SRI farmers in Cambodia who were collaborating with a national NGO, CEDAC. These farmers found that SRI methods enabled them to greatly increase the yield of their rainfed rice crop. They could get more rice from just 60% of their land area than they had previously produced from their whole farm. So, they redeployed 40% of their farms' small land area (average—0.66 ha) so that they could take up other productive activities.

With their own labor and skills, these farmers reconfigured their land area by constructing a catchment dam and small canals on about 15% of it. Then they converted the remaining 25% of their land for horticultural production—fruits, vegetables, beans, squash, etc.—also rearing some small animals like chickens, ducks, or rabbits [70].

Having a pond that filled during the rainy season enabled these farmers to begin raising also fish, frogs, and eels, which commanded a good price in the local markets. Most of the food for these aquatic creatures could be supplied from plant residues from the surrounding area, so farmers' costs for producing them were kept quite low.

Farmers' average investment cost for converting monocropped rainfed land into a more diversified and intensified production system was about US$ 300. Such investment could be made by a rural household over several years, so it was not necessary to take out loans. The annual cash income resulting from this Multi-Purpose Farming averaged US$ 600 when calculated, three times more than their previous annual cash income from monocropping, a very good return on investment [70].

An unanticipated but very welcome additional benefit for farmers from this diversification strategy was that it generated income year-round rather than just twice a year when rice crops were harvested [71,72]. This redeployment of land and concomitant crop diversification, which resulted in much higher household income from the same amount of land, was made possible by the productivity gains coming from SRI crop management.

An evaluation of this kind of diversified farming system was done at the ICAR-Indian Institute of Water Management, where Amod Thakur and colleagues analyzed for two years four parallel farming systems, each conducted on an equal area of rainfed land. The trial plots were each 350 m^2, with each system having three replications each year, laid out according to randomized block design. As it happened, one of the two years was unusually water-stressed, so this gave additional insights into the performance of each system [73].

The research design compared (a) conventional rainfed rice production as practiced by farmers in the region; with (b) rainfed SRI (SRI 2.1); (c) rainfed SRI that had supplementary pump irrigation for the rice crop; and (d) rainfed SRI with a catchment pond that provided supplementary irrigation for rice and supported associated horticultural and aquaculture activities. The ponds for (d) were quite similar to those that were constructed for the Cambodian multi-purpose farming systems described above.

In the trials of (d), three-fourths of each plot area (270 m^2) was used for rainfed SRI rice cropping, with 10% of the area (35 m^2) repurposed to construct a pond that filled during the rainy season. Then, 15% of the area was devoted to horticulture, growing banana and papaya trees on the catchment area (45 m^2) that channeled rainfall into the pond. The pond itself was stocked with several species of Asian carp fingerlings to be raised for market sale and additional income.

First, the rainfed SRI plots (b) produced 52% more rice ha^{-1} than did those under conventional rainfed rice cultivation (a). (The SRI yield advantage was greater in the more water-stressed year, it turned out.) Supplementary pump irrigation (c) raised the SRI paddy yield by another 29%, and using pond water for supplementary irrigation (d) raised the average yield of rainfed rice by another 8%. Apparently, 'impurities' in the pond water supply provided some nutrients for crop growth.

As expected, the labor invested in managing the diversified system (d) was greater than for the other three systems evaluated. However, the returns from the fruit and fish produced, together with the greater income from producing more rice, made the diversified plots (d) 10 times more profitable than was earned from the same land area managed with current rainfed rice production methods (a). This increase in productivity can create remunerative employment opportunities in rural areas where these are scarce.

Even more impressive was the increase in the economic returns to water, most of which now goes unused in rainfed areas, running off the fields rather than being absorbed into the soil. In the SRI-based diversified farming system (d), the net income per unit of water (m^{-3} of rainfall) was increased immensely, almost 60-fold [73]. These kinds of productivity and profitability increases have been seen with intensification-cum-diversification trials in Indonesia, connecting duck rearing and other activities with the use of SRI for irrigated rice production, although the improvements were not as so dramatic [74,75]. Adding diversification to intensification with SRI methods can be a very profitable move that also enhances the local environment since ponds raise the water table in the surrounding area during the dry season.

4.3. Alternating SRI Rice with Growing Other Crops

An example of this kind of SRI 4.0 innovation is a rotational farming system developed and evaluated in Vietnam, where SRI rice cropping is alternated with no-till cultivation of potatoes [76]. There was demonstrable synergy from rotating rice in the summer with potatoes in the winter as soil quality was enhanced and pest pressure was reduced (by interrupting insect life cycles). The organizational model introduced for this farming system included establishing market connections for farmers with outside companies and agencies, negotiating and assuring higher prices for farmers' produce. This SRI 4.3 initiative thus led to socio-cultural as well as economic improvements for farm households.

Along similar lines, in 2004 I visited an innovative farming system developed by farmers in Sichuan province of China [36] (pp. 8–9). They showed me how they were alternating growing SRI rice in the summer with raising button mushrooms in the winter. The mushrooms, which commanded a very good market price for export to Japan, were grown under plastic cover on bamboo frames put up over the no-till raised beds where SRI rice had been grown in the preceding season.

Because SRI methods gave the farmers more straw, which is their substrate for growing mushrooms, this enabled farmers to double their previous mushroom-growing area. Also, the farmers told me that by stopping their use of chemical fertilizer and agrochemicals, as recommended for SRI, soil quality was improved for their mushroom production. Further, they reported that their mushroom cropping on the raised beds made the soil more fertile for the rice crop the next summer. How did they know this? Because, they said, with this rice-mushroom rotation their SRI rice yield was higher with 45 × 45 cm spacing between plants, rather than the recommended 25 × 25 cm. Thus, there was a profitable synergy when farmers rotated the two crops, with each crop improving the other.

4.4. Intercropping SRI or SCI with a Legume or Some Other Crop

In India, it has been found that when growing sugarcane with SCI methods (Section 3.3 above), the wider spacing between the rows of cane makes it possible to plant another crop such as a legume between the rows. This intercropping constrains the growth of weeds and enhances the level of nitrogen in the soil. The additional crop produces some additional income for farmers while enhancing their sugarcane production. Unfortunately, this has not been studied and reported systematically, however.

In Kashmir, proper trials have been conducted planting a crop of mungbeans (*Vigna radiata*) between the widely-spaced rows of SRI rice. By growing beans together with rice in this way, the yield of rice was increased by 33%, attributable to the increased nitrogen in the soil. The intercropping and wider spacing between rice plants contributed to higher levels of chlorophyll in their leaves, and the interplanting also reduced the incidence of sheath blight, a major disease for rice crops [77].

With such intercropping, the SRI rice plants required 40% less water compared to conventional practice because the bean crop reduced the evaporation of soil moisture. And by growing beans between the rows of rice, weed growth was reduced by 65%, which made mechanical weeding between the rows unnecessary. The reduction in labor requirements for weeding offset the additional work needed for doing the intercropping. Overall, this diversified system required fewer days of labor and had greater output of rice with lower costs of production. With the additional income from the bean crop, the income ha^{-1} was increased by 57% [77]. This is another example of synergy, suggesting that SRI rice improvement should be more than a single step toward better agronomics and economics.

4.5. Complementing SRI with Natural Resource Management Initiatives

The SRI 4.1 and SRI 4.2 discussed above respectively involve significant changes in land management and in water management. Changes in *both* land management and water management can be combined with SRI as is being done in a large project in West Africa that includes also the agroecological strategy of integrated pest management.

A four-year project financed by the Adaptation Fund, established for implementation of the Kyoto Protocol, was launched in January 2023 to extend SRI use to more than 150,000 farmers in 13 countries of West Africa [78] This project, Scaling Up Climate-Resilient Rice Production in West Africa with the acronym RICOWAS, is being implemented by the Sahara and Sahel Observatory based in Tunis, with technical support from the Climate-Resilient Farming Systems program at Cornell University [79].

RICOWAS' holistic approach builds upon the experience and networks from a preceding SRI initiative that operated in these same countries under the West African Agricultural Productivity Program, 2014–2016, supported by the World Bank. The WAAPP-SRI program by working with the respective national governments and through local 'champions' reached over 50,000 farmers in less than three years. Project training enabled farmers to achieve increases in rice yield that averaged 56% in irrigated areas and 86% in rainfed lowland rice production [80]. RICOWAS takes this prior initiative beyond rice farming, promoting SRI in connection with broader natural resource management.

As SRI 4.0 is still in its early stages, there will probably be more and different versions of this kind of SRI arising in the future, integrating SRI into farming systems and natural resource management, e.g., combining SRI with agroforestry or with water harvesting. Moving SRI beyond its initial focus on monocropped rice should be beneficial for more agroecological management of soil systems and for achieving convergence with Conservation Agriculture.

5. SRI 5.0 = Instrumental Uses of SRI

As seen already, although SRI was initially developed to reduce hunger and poverty among poor and marginalized communities (Sustainable Development Goals #1 and #3), its methods can contribute to achieving a number of goals beyond agricultural production. Indeed, its effects can contribute to achievement of almost half of the UN's Sustainable Development goals [81]. Increasingly, SRI is being re-purposed to produce more 'goods' than just agronomic benefits. As this happens, we expect that what is referred to as SRI will be further modified to maximize the achievement of other goals as discussed in this section.

5.1. Water Saving and Water Quality

By growing larger root systems and promoting better structuring and functioning of soil systems, SRI crops whether irrigated or rainfed can make better use of available water supplies. Increasing rice production's reliance on 'green' water with less dependence on 'blue' water [82] reduces the demands that rice cropping places upon available water resources in our increasingly water-short or water-uncertain world.

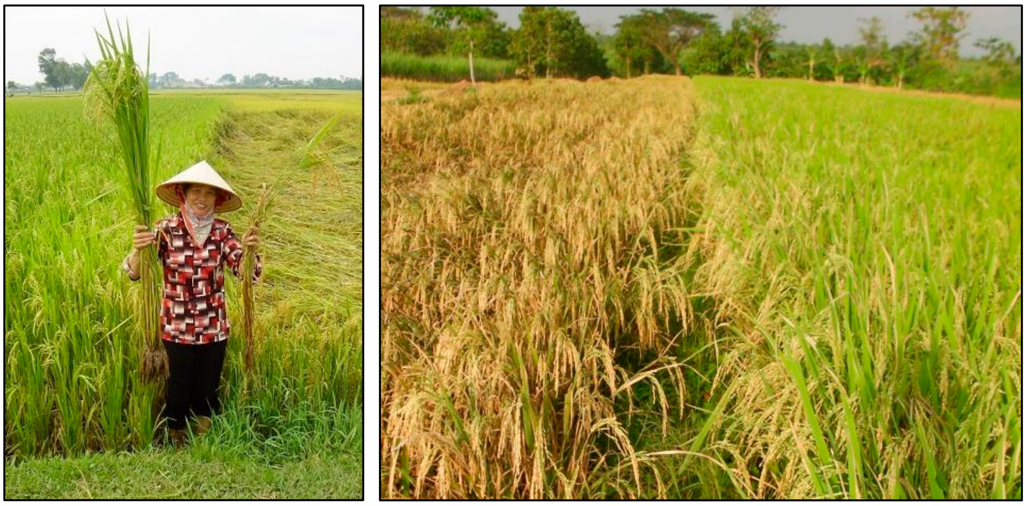
A meta-analysis was carried out in 2013 of all the published quantified assessments that could be found in the literature comparing SRI with conventional rice methods in terms of their water use and productivity (29 studies from 8 countries, with 251 comparison trials). Analysis of the data showed SRI methods giving higher rice yields while consuming 22% less total water ha^{-1} (rainfall plus irrigation) and 35% less irrigation water ha^{-1}. In terms of water productivity, rice plants under SRI management produced 50% more kg of rice per liter of total water available, and they were 78% more productive in terms of the amount of irrigation water consumed per kg of rice produced [83].

SRI can thus be promoted as a means of scaling back the agricultural sector's consumption of water as inter-sectoral competition for this scarce resource intensifies. This will make more salient the growing of SRI rice under water-stressed conditions (Section 2.6) as evaluated in Iraq [38]. Producing more food could become a 'bonus' where the dominant consideration is to save water, to make more of this resource available for other uses. Just changing to AWD methods will reduce water requirements for growing irrigated rice. But AWD can only assure farmers that there will be little or no decline in production, not giving farmers higher yield as an incentive for reducing their water consumption [84]. SRI productivity gains can make water-saving practices attractive for farmers.

Thus far, there has been little research on the impact of SRI management practices on water quality, although this can be expected where farmers cut back or stop their use of chemical fertilizer and agrochemicals. A study in Korea found that the major water pollutants that flow from rice paddies were 24–44% less from SRI rice fields than from conventionally-managed ones [85]. This is a significant consideration where water quality is a matter of public and policy concern. Water quality can be a motivating consideration for taking up SRI in countries where reducing water pollution is of more importance than achieving higher yields, e.g., Korea and Taiwan [86]. SRI undertaken with such a purpose would be somewhat different from where improved water quality is a collateral benefit.

5.2. Climate Resilience

Climate change increasingly threatens food security in countries where food production would otherwise be sufficient under 'normal' climatic conditions. There is accumulating evidence and many examples of crops under SRI and SCI management being more resistant to the hazards of drought, water stress, storm damage, flooding, and abnormal temperatures, as well as to pest and disease effects, many of these stresses becoming more pervasive with rises in temperature and humidity [87,88]. Figure 6 shows two iconic examples of SRI crop resistance to abiotic and biotic stresses associated with climate change.



(**a**) (**b**)

Figure 6. (**a**) A Vietnamese farmer in Dông Trù village near Hanoi shows rice phenotypes, SRI on left and conventionally-grown rice on right, in front of the fields in which they had been respectively grown - after a tropical storm had passed over the village, causing serious lodging in the field on right. Note the differences in size of the two plants' roots, in part explaining SRI resistance to lodging. (**b**) Adjacent rice fields in East Java, Indonesia, seen after both had been affected by a brown planthopper pest attack and then by a tropical storm. The field on the left had been planted with an improved variety (Ciherang) and received inorganic fertilizer and agrochemical protection; the field rice on the right was an aromatic traditional variety (Sintanur) grown organically with SRI methods. The field on left had little harvestable yield, while the one on right produced 800 kg from 1000 m^2 (8 t ha^{-1}), according to the farmer who managed it and took this photograph. (Pictures courtesy of Elske van Fliert, FAO/IPM, and Miyatty Jannah).

As climates become increasingly unstable, agriculture is the sector most seriously affected. Changing agricultural practices to make crops better able to withstand climate stresses—by having larger, stronger root systems and by having soils that absorb more rainfall and resist erosion—can be an objective in itself for policies and projects. This could encourage some modifications of SRI and SCI to make rice and other crops maximally successful in countering the constraints of adverse climate.

5.3. Greenhouse Gas Reduction

Climate change is known to be driven by increased anthropogenic emission of greenhouse gases (GHG), and rice production is one of the larger identifiable contributors to global warming through such emissions. Irrigated rice production is the second-largest source of GHG emissions from the agricultural sector, and it is responsible for about 10% of the total emissions of methane gas (CH_4) [89]. This greenhouse gas is synthesized in and emitted from flooded (anaerobic) soils by a certain class of soil microorganisms, methanogens, a category of archaea.

After a wide-ranging evaluation, Project Drawdown ranked SRI as one of most cost-effective, immediately-available means to begin moving the world toward zero net GHG emissions by 2050 [90]. A Life Cycle Analysis of emissions in Andhra Pradesh state of India, undertaken by researchers from Oxford University and India's National Institute for Rural Development, found that SRI management reduced net GHG emissions ha^{-1} from flooded rice paddies (global warming potential) by 40%, with net emissions per kg of rice produced lower by 60% or more [91,92]. SRI methods can also reduce the net emissions of GHG from unirrigated production of upland rice, apparently because of SRI's curbing the use of inorganic nitrogen fertilizer, which is a substrate for microbial synthesis of some GHGs [25].

Reducing methane emission is a matter of immense urgency. Although over a 100-year time span, carbon dioxide (CO_2) has a greater impact driving global warming, within a 20-year time span, CH_4 has 80 times more global warming potential than CO_2 [93,94]. Taking a century-long perspective has little relevance for the world if the current acceleration in global temperature rise driven by methane emissions is not halted within the next decade or two.

Mitigating CH_4 emissions sooner rather than later has worldwide significance, and there are other important benefits from SRI such as food security, water saving, and soil health. If reducing GHG emissions is a primary concern, the scope of rice crop management should be extended to include post-harvest activities, for example, proscribing the burning of rice straw and introducing uses of crop residues that minimize methane emissions. The boundaries of SRI would be expanded to encompass the whole cropping cycle if emissions reduction is a criterion of success.

5.4. Gender Effects

Women contribute most of the labor that is expended to produce the world's rice supply, and under conditions and imperatives that impose on them significant drudgery, pain, disease, and even bodily deformities [95,96]. While SRI methodology benefits both men and women, the latter generally get the greater benefit from its adoption. In addition to eliminating the need to work in flooded fields with hands and legs constantly immersed in standing water, having much smaller nurseries to manage and many fewer and lighter seedlings to transplant alleviates the physical burdens of these operations which are almost always assigned to women.

SRI also reduces the time and bodily discomfort of repeatedly having to weed the rice fields after transplanting. In some cultures, weeding when done mechanically rather than by hand becomes men's work, which is a boon for women. Even when this task continues to be carried out by women, they find that the simple implement introduced with SRI reduces the time and effort required for weeding rice paddies. A study in India that undertook to measure this effect concluded that with SRI, there was a 78% reduction in women's labor time required for rice weeding, and also less physical discomfort [97]. SRI can thus be introduced as a means for advancing gender equity; or this effect can be considered as a bonus on top of the other benefits.

5.5. Improving Food Quality as well as Quantity

Three studies done in India have shown that when rice is grown with SRI methods, the levels of micronutrients (Fe, Zn, Cu, Mn) in the grain are significantly higher than when conventional methods are used [98–100]. Table 1 summarizes the findings from one of these studies. This effect is associated with microbial activity in the rhizosphere and in the endosphere. While more research needs to be done on this, there is evidence that promoting SRI methods could increase the quality of the world's most widely consumed staple food, not just its quantity.

When SRI rice is milled after being harvested, the yield of polished rice for consumption is generally about 10% more than from conventionally-grown paddy rice. This is because SRI paddy rice usually has fewer unfilled grains, thus less chaff, and during the milling process fewer grains of SRI rice are broken, an effect reported to be associated with higher protein content in the grain [101]. Higher milling outturn is a bonus not accounted for in the reports of SRI's higher paddy yields. When SRI paddy rice is milled to remove husks and bran, more edible/sellable grains are turned out kg^{-1} for consumption or sale from what was brought in for milling. This has been reported from Cuba, Kenya, and India and as well as China [102]. Further, SRI rice often commands a higher market price when sold at market because of its grains' fullness and uniformity. This makes it preferable as seed rice as well for consumption, and thus worth more. The superior quality of

SRI-produced rice has also been reported from its evaluations by Tilda Ricelands Ltd., a leading exporter of basmati rice from India [103].

Table 1. Secondary and micronutrients in rice grains and straw using System of Rice Intensification (SRI) and conventional transplanting (CT) methods.

	Sulphur (%)		Zinc (ppm)		Iron (ppm)		Manganese (ppm)		Copper (ppm)
	Grain	**Straw**	**Grain**	**Straw**	**Grain**	**Straw**	**Grain**	**Straw**	**Grain**
SRI	0.075 [a]	0.127 [a]	30.4 [a]	48.4 [a]	47.8 [a]	101.0 [a]	45.2 [a]	115.6 [a]	4.6 [a]
CT	0.064 [b]	0.114 [b]	27.0 [b]	39.0 [b]	44.0 [b]	89.7 [b]	40.1 [b]	108.0 [b]	3.3 [b]
Difference	0.011	0.013	3.4	9.4	3.8	11.3	5.1	7.6	1.3
LSD	0.003	0.012	2.5	3.8	3.6	7.0	2.8	6.4	0.4

Source: Dass et al. (2017) [98]. Means followed by similar lower-case letters within a column for a particular set of treatments are not significantly different according to DMRT at 5% level of significance.

5.6. Conservation of Biodiversity

The Green Revolution is credited with conserving the biodiversity of wildlife by making arable land more productive, thereby reducing pressures to convert wildlife habitat for the production of food. The same can be said for SRI which has even greater impact on yields. There have been now a number of cases where wildlife conservation NGOs have promoted SRI as a measure for protecting natural biodiversity such as lemurs, rhinoceroses, rare ibises, and storks, respectively, in Madagascar, Indonesia, Cambodia, and Zambia [104].

Further, SRI's soil, water and nutrient management practices make the soil systems where rice is grown more hospitable for the endemic soil biota. So, SRI practice is supportive of conserving the biodiversity of microbial communities and of soil organisms in general, whereas heavy-input agriculture has adverse effects on such biodiversity.

Rice has been historically one of the most genetically-diverse crops in the world. But the promotion of 'improved' varieties has greatly shrunk the gene pool of rice. In India, the number of rice varieties grown has declined from 110,000 to less than 6000 since the advent of 'high-yielding varieties.' In Sri Lanka, the shrinkage has been from 2000 to less than 100, and in Bangladesh, from 7000 to about 400 [104].

As noted above, 'unimproved' varieties under SRI management can compete in profitability with 'new' varieties, which makes sustaining local landraces more attractive to farmers. The new genotypes have mostly been bred for quantity or for disease-resistance, rather than for factors such as taste, texture, aroma, or cooking qualities. Crop breeding as an enterprise benefits from maintaining a larger and more diverse gene pool for rice.

5.7. Soil Health

Soil degradation is becoming an increasing constraint on agricultural production in many countries, particularly with reductions in the levels of soil organic carbon. In much of India, for example, the level is below 1%, when levels much higher are more desirable. A study in Kenya found that until the level of organic carbon in farmers' soil has reached at least 3%, the application of nitrogen fertilizer does not enhance maize yields enough to cover the cost of the fertilizer [105].

Both SRI and SCI with their emphasis on growing larger root systems increase the amount of organic exudation that crop plants put out into their root zones. And the preference for organic over inorganic means of soil fertilization, using mulches, green manures or other materials, makes for demonstrable increases in soil organic matter. With enhancement of the soil biota, more nitrogen is fixed through biological processes, and unavailable phosphorus, many times more plentiful in soil systems than is the available phosphorus in the soil solution, is solubilized through microbial activity and made available for plant uptake.

Many constraints on soil fertility can be dealt with through biological means [19]. Contrary to expectations, the higher yields achieved with SRI and SCI methods more often enhance the stocks of soil nutrients than deplete them. So, these methodologies can be employed to improve soil quality where it has declined, countering soil erosion and reversing lower crop yield. When SRI methods are used for soil improvement, there would be particular concern for the promotion of root growth and enhancement of the soil biota, emphasizing the provision of organic matter and soil aeration.

5.8. Agricultural under Disrupted Conditions

Sad to say, in many parts of the world, farmers are forced to practice agriculture in conflict or post-conflict situations, or where climate crises interfere with usual agricultural practice. One feature of SRI management that makes it more functional under disrupted conditions is that it is minimally dependent on external inputs, so it can enable households to get greater food output from whatever resources they have at hand. If mechanical weeders are not available, the greatest increase in SRI yield will not be obtained, but there can be benefits from utilizing better the available resources, doing weeding by hand.

- The first report of SRI being used to assist farmers in post-conflict conditions was from Sierra Leone after the civil war there had ended in 2002. An NGO undertaking post-war reconstruction there with USAID support, World Vision, reported that SRI was well-suited for reviving agriculture because it gave farmers much higher yields than did their traditional rice cultivation methods, greatly cutting their seed requirements and not requiring them to purchase synthetic fertilizers [106].
- In Aceh province of Indonesia where communities have been battered by separatist-army conflict over several decades, and then by a tsunami in 2004, the NGO Caritas found that introducing SRI practices enabled farmers to quadruple their very low paddy yields, raising these from 2 t ha^{-1} on average to 8.5 t ha^{-1} [107].
- In Nepal during the Maoist insurrection there, a government extension officer in the Terai border area was the only person in the district administration whom the insurgent forces allowed carry out field work in the countryside. Farmers who wanted to get instruction about SRI persuaded the rebel commanders to exempt this activity from their military campaign [108].
- In Afghanistan before the Taliban takeover, both the Aga Khan Foundation and FAO conducted SRI training and extension in rural areas despite the armed conflict going on in the country [109].
- Prior to the military coup in Myanmar in 2021, a consortium of donors (EU, UK, US, Australia, and Ireland, among others) helped persecuted Muslim farmers in northern Rakhine province to double their paddy yields by introducing SRI methods there [110].

So, introducing SRI methods can strengthen relief-and-development efforts because of its quick results, within one season, and because it is not dependent on increasing external inputs or on farmers' having enough income to buy them.

6. SRI 6.0: Scientific Explanation

Research in this area, begun after SRI 1.0 was first established, has expanded with each succeeding version that followed. An initial response from some rice scientists was that SRI had nothing to offer scientifically because it was just good practice of what was already known, or because its success resulted mostly from good extension [111–113]. However, a large body of scientific research assessing SRI has accumulated since the initial dismissals [114], and there have been no published critiques of SRI in recent years.

The claim that SRI methods do not produce phenotypic improvements in rice plants has been contradicted by counter-evidence from Indian research [115] and by a meta-analysis of all of the published research by Chinese rice scientists who had compared SRI methods with what they regarded as 'best management practices' [116]. The analysis of Chinese trials showed SRI outperforming BMP by as much as had been previously claimed by [112] that BMP was superior to SRI. The question has become what can rice science learn from SRI research and experience?

That SRI practices elicit more desirable plant phenotypes from a given genotype in terms of both morphology and physiology is seen consistently [117–121]. A number of articles have undertaken to summarize what is known scientifically about SRI and to synthesize explanations [122–125]. Recently, a meta-analysis of economic evaluations has produced favorable results similar to those of agronomic analyses [126].

Addressing all of the areas in which scientific work has been done on SRI and its effects would require another whole article. Here I would like to discuss one of the most interesting lines of research that has grown out of studies initiated at the China Academy of Science's Institute of Botany in Beijing. These have converged with efforts to explain SRI effects by considering microbiological influences.

Dr. Y.X. Jing's group at the China Academy of Science started by examining the effects that symbiotic microbes (endophytes that inhabit the tissues and cells of rice plants) might have on rice plants' growth and performance. Their laboratory studies, first using standard agronomic measurements [127] and then proteomic analysis [128], assessed the influence that inoculating rice seedlings of a given variety with certain bacteria, in particular *Sinorhizobium meliloti* 1021, could have on the resulting rice plants.

Controlled trials showed a number of significant effects that seedling inoculation had on rice plants, such as greater root and shoot biomass, high levels and rates of photosynthesis, greater stomatal conductance, higher efficiency of water utilization (the ratio between photosynthesis and transpiration), and increased flag leaf area, all of which contribute to higher yield. Of relevance here is that those who had studied SRI's morphological and physiological effects saw that the effects of microbial inoculation were quite similar to the changes in rice plant phenotype that appear as a result of SRI practice.

Researchers in the Institute of Botany carried their work further by next using transcriptomic analysis to understand how inoculating rice seedlings with rhizobacteria elicits these effects on rice phenotypes. Their research showed that the presence (vs. absence) of *S. meliloti* 1021 living within rice plants as endophytes significantly affected the up-regulation and down-regulation of messenger RNA associated with specific, identifiable genes that regulate plant morphology and physiology in beneficial ways [129]. Transcriptomic analysis indicated that microbial endophytes were modifying the plants' expression of their genetic potential. This is an effect increasingly reported in the scientific literature [130,131], so it is not unique to rice plants or to *S. meliloti* 1021.

This relationship has important implications for plant breeding, for example. If the plant genotypes that plant breeders are modifying produce phenotypes determined in part by microbial endophytes, not just by their DNA and environmental factors like temperature, soil moisture, and nutrient availability in the soil, then current selection of phenotypes to use in breeding better varieties without investigating microbial concomitants will be misleading. SRI experience indicates that what is called the 'honeycomb' method for selecting plants for cross-breeding will be more useful for getting improved crop genotypes because it selects for individual plants that have superior genetic endowments which are expressed only when they are allowed to grow without constraints of space above and below ground [132]. SRI experience also calls attention to crop management as a factor affecting plant phenotype that is intermediated by the effects of certain practices on plants' microbiomes, which influence plants' expression of their genetic potential.

The research done in China prompted SRI research in Malaysia that examined the joint effects of inoculating rice seedlings with the plant-beneficial fungus *Trichoderma* and then growing the rice plants with SRI methods. The initial findings have been reported at an international conference but not yet published [133].

Controlled experiments have been conducted that undertook transcriptomic analysis of the messenger RNA in plant cells, comparing (a) plants managed with SRI methods and inoculated with *Trichoderma* to (b) *Trichoderma*-inoculated plants managed conventionally, and (c) plants managed with SRI methods but no inoculation. In the inoculated SRI plants, compared to the others, there was significant up-regulation of genes that are known to affect multiple parameters. These included, for example: crown root emergence; tillering; synthesis of the critical enzyme RuBisCo for photosynthesis and of the growth phytohormone gibberellin; phosphorus uptake; and root elongation [134]. These are all beneficial effects that are associated empirically with SRI performance.

Such research directs attention beyond the factors usually considered in crop and soil science research to focus on microbiology, both bacterial and fungal, and on plants' expression of their genetic potentials. Research on the interaction effects of SRI management and *Trichoderma* inoculation has shown some beneficial associations between microbiological influences and plant phenotype, in addition to the effects of various plant and soil management factors [135–137].

SRI practices show some effects very similar to those induced by beneficial bacteria and fungi. One cannot know how far or in what directions further research undertaken to explain SRI effects on various parameters will progress, e.g., accounting for drought-resistance, grain nutrient content, plant and root growth, or grain-filling. SRI 6.0 represents a domain for research that should have payoffs beyond rice. That similar effects are seen with other crops (SRI 3.0) should make this area of research of greater interest to scientists.

7. Conclusions: Evolving to SRI 7.0 and Beyond?

Since its inception, SRI has been presented as a work in progress, something not yet finished. No one can know when or whether it will be finished. The hope of those who have worked with this assemblage of ideas and insights is that it will contribute to a mode of agriculture that is well-suited for the conditions and constraints of the 21st century.

The current paradigm for agricultural practice was developed in the preceding century according to the needs, capabilities, and knowledge of that period. Particularly gaining a better and deeper understanding of the functions of microbes and plants' microbiomes will likely affect significantly the sciences and practices of agriculture in coming decades. The emerging understanding should capitalize upon the productive processes and potentials that exist within crop plants and within the soil systems that support them [19]. Improvements in genetics, in mechanization, etc. will make complementary contributions, it is hoped, neither resisting nor impeding agroecologically-based changes to be made in agricultural practice.

SRI and SCI will not replace current modes of production since agricultural systems change more on the basis of the demand for new technology than on its supply [138]. The emerging modes of agricultural production should give both producers and policy-makers more options to choose among. With growing per-capita scarcity of land and water, with constraints arising from global warming and climate change, and with growing concern for both soil and human health, SRI and SCI offer varied opportunities for farmers, their communities, their countries, and our biosphere.

It remains to be seen whether producers, scientists, extensionists, civil society actors, administrators, businessmen and others will be able to work together with enough mutual respect and productive curiosity to advance the knowledge and practice reported on here. This body of knowledge and practice derives its impetus from the construction of SRI 1.0 some 40 years ago in Madagascar. Since then, the phenomenon itself has grown and differentiated quite remarkably, as reviewed here.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no financial or other conflict of interest.

References

1. Laulanié, H. Le système de riziculture intensive malgache. *Tropicultura* **1993**, *11*, 110–114, Erratum in *Tropicultura* **2011**, *29*, 183–187. Available online: http://www.tropicultura.org/text/v29n3.pdf#page=57 (accessed on 7 March 2023).
2. Laulanié, H. *Le Riz à Madagascar: Un Dèveloppement en Dialogue avec les Paysans*; Karthala: Paris, France, 2003; [A posthumous publication of Laulanié's papers].

3. Uphoff, N. The development of the System of Rice Intensification. In *Participatory Research and Development for Sustainable Agriculture and Rural Development*; Gonsalves, J., Becker, T., Braun, A., Campilan, D., De Chavez, H., Fajber, E., Kapiriri, M., Rivaca-Caminade, J., Vernooy, R., Eds.; International Development Research Centre: Ottawa, Canada, 2005.
4. Uphoff, N. Farmer Innovations Improving the System of Rice Intensification (SRI). *J. Tanah Dan Lingkung.* **2007**, *9*, 45–56. Available online: https://core.ac.uk/download/pdf/230370063.pdf (accessed on 7 March 2023). [CrossRef]
5. SRI-Rice Website, Cornell University. Available online: http://sri.cals.cornell.edu/countries/index.html (accessed on 3 March 2023).
6. Abraham, B.; AdeOluwa, O.O.; Araya, H.; Berhe, T.; Bhatt, Y.; Edwards, S.; Gujja, B.; Khadka, R.B.; Koma, Y.; Sen, D.; et al. *SCI—The System of Crop Intensification: Agroecological Innovations for Improving Agricultural Production, Food Security, and Resilience to Climate Change*; SRI-Rice, Department of Global Development, Cornell University: Ithaca, NY, USA, 2014; Available online: http://sri.cals.cornell.edu/aboutsri/othercrops/SCImonograph_SRIRice2014.pdf (accessed on 7 March 2023).
7. Adhikari, P.; Araya, H.; Aruna, G.; Balamatti, A.; Banerjee, S.; Baskaran, P.; Barah, B.C.; Behera, D.; Berhe, T.; Boruah, P.; et al. System of Crop Intensification for More Productive, Resource-Conserving, Climate-Resilient, and Sustainable Agriculture: Experience with Diverse Crops in Varying Agroecologies. *Int. J. Agric. Sustain.* **2018**, *16*, 1–28. Available online: https://www.tandfonline.com/doi/full/10.1080/14735903.2017.1402504 (accessed on 7 March 2023). [CrossRef]
8. In Proceedings of the Assessments of the System of Rice Intensification (SRI), Sanya, China, 1–4 April 2002; Available online: http://sri.cals.cornell.edu/proc1/index.html (accessed on 3 March 2023).
9. Thakur, A.K.; Mandal, K.G.; Verma, O.P.; Mohanty, R.K. Do System of Rice Intensification practices produce rice plants phenotypically and physiologically superior to conventional practice? *Agronomy* **2023**, *13*, 1098. [CrossRef]
10. Obituary: Henri de Laulanié, 1920–1995: 34 ans au service de Madagascar. *Jesuit. En Mission.—Chine Madure Madag.* **2002**, *255*, 16–20. Available online: http://sri.cals.cornell.edu/aboutsri/LaulanieBiography.pdf (accessed on 7 March 2023).
11. Uphoff, N.; Randriamiharisoa, R. Reducing water use in irrigated rice production with the System of Rice Intensification. In *Water-Wise Rice Production*; Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bindraban, P.S., Tuong, T.P., Ladha, J.K., Eds.; Wageningen University Research: Wageningen, The Netherlands; International Rice Research Institute: Manila, Philippines, 2002; pp. 71–88.
12. Palanisamy, J.; Geethalakshmi, V.; Ramanathan, S.P.; Senthil, A.; Kannan, B. Unraveling the Growth Potential of Rice under Modified Rice Cultivation System in Tamil Nadu, India. *Int. J. Plant Soil Sci.* **2022**, *34*, 250–258. Available online: https://journalijpss.com/index.php/IJPSS/article/view/1873/3750 (accessed on 7 March 2023). [CrossRef]
13. Sato, S.; Uphoff, N. A Review of On-Farm Evaluations of System of Rice Intensification Methods in Eastern Indonesia. *CAB Rev.* **2007**, *2*, 54. Available online: https://www.cabidigitallibrary.org/doi/10.1079/PAVSNNR20072054 (accessed on 7 March 2023). [CrossRef]
14. Ndiiri, J.A.; Mati, B.; Home, P.; Odongo, B.; Uphoff, N. Adoption, constraints and economic returns of paddy rice under the System of Rice Intensification in Mwea, Kenya. *Agric. Water Manag.* **2013**, *129*, 44–55. [CrossRef]
15. Meyer, P. The Plant-ness of the Plant: The System of Rice/Crop Intensification Utilizes Simple Principles to Provide Plants an ideal Growing Environment: Interview with Dr. Erika Styger. *Acres USA*, February 2023. Available online: https://tinyurl.com/prebh7xw (accessed on 7 March 2023).
16. Kar, S.; Varade, S.B.; Subramanyam, T.K.; Ghildyal, B.P. Nature and growth pattern of rice root system under submerged and unsaturated conditions. *Il Riso* **1974**, *23*, 173–179.
17. Laulanié, H. Technical Presentation on the System of Rice Intensification, Based on Katayama's Tillering Model. Manuscript with Association Tefy Saina. 1993. Available online: http://journeytoforever.org/farm_library/Laulanie.pdf (accessed on 7 March 2023).
18. Uphoff, N. *The System of Rice Intensification: Memoires of an Innovation*, ch. 11, Section on Yield Enhancement from Soil-Aerating Weeding. 2022. Available online: https://www.srimemoires.com/chapter-11 (accessed on 7 March 2023).
19. Uphoff, N.; Thies, J. (Eds.) *Biological Approaches to Regenerative Soil Systems*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2023.
20. Puard, M.; Couchat, P.; Lasceve, G.G. Importance de l'oxygenation des racines du riz (*Oryza sativa*) en culture inondee. *L'Agronomie Trop.* **1986**, *44*, 119–123.
21. BIND. Growth and Yield Responses of Traditional Upland Rice on Different Distance of Planting Using *Azucena* Variety. Report for Broader Initiatives for Negros Development, Bacalod, Negros Occidental, Philippines. 2005. Available online: http://sri.cals.cornell.edu/countries/philippines/philsBIND_UplandResults2002.pdf (accessed on 7 March 2023).
22. Anthofer, J. The Potential of the System of Rice Intensification (SRI) for Poverty Reduction in Cambodia, *Deutsche Tropentag*, Berlin, October. Report of Evaluation Commissioned by GTZ. 2004. Available online: https://www.tropentag.de/2004/abstracts/full/399.pdf (accessed on 7 March 2023).
23. Kabir, H.; Uphoff, N. Results of disseminating the System of Rice Intensification (SRI) with farmer field school methods in northern Myanmar. *Exper. Agric.* **2007**, *43*, 463–476. [CrossRef]
24. Sinha, S.K.; Talati, J. Impact of System of Rice Intensification (SRI) on Rice Yield: Results of a New Sample Study in Purulia District, India, International Water Management Institute/Tata Water Policy Program, Gujarat, India. 2005. Available online: https://www.iwmi.cgiar.org/iwmi-tata/files/pdf/PM05/20_Highlight.pdf (accessed on 7 March 2023).
25. Mishra, A.; Ketelaar, J.W.; Uphoff, N.; Whitten, M. Food security and climate-smart agriculture in the lower Mekong basis of Southeast Asia: Evaluating impacts of rice intensification with special reference to rainfed agriculture. *Int. J. Agric. Sustain.* **2021**, *19*, 152–174. [CrossRef]

26. Sinha, S.K.; Talati, J. Productivity impacts of the system of rice intensification (SRI): A case study in West Bengal, India. *Agric. Water Manag.* **2007**, *87*, 55–60. [CrossRef]
27. Ramasamy, S.; Susheela, C.; Sathyamoorthi, K. 'Direct-Planting System': Energy-Saving, High-Output Rice Establishment Technique for Lowland Cultivation. In Proceedings of the 26th International Rice Research Conference, New Delhi, India, 9–13 October 2006; Available online: http://sri.cals.cornell.edu/countries/india/tamilnadu/extmats/intnramasapster06.pdf (accessed on 7 March 2023).
28. Barrett, C.B.; Moser, C.M.; McHugh, O.V.; Barison, J. Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *Amer. J. Agric. Econ.* **2004**, *86*, 869–888. [CrossRef]
29. Montero, Oscar. *Using the System of Rice Intensification at El Pedregal in Costa Rica*. 2006. Available online: http://sri.cals.cornell.edu/countries/costarica/ElPedregalEng.html (accessed on 7 March 2023).
30. Hussain Reddy, P.; Sreenivasulu, S.; Manohar, C. Report on Direct-Seeding Technology with SRI Concepts in Rice Using Drum Seeder in Chitoor District, Andhra Pradesh, India. 2012. Available online: http://sri.cals.cornell.edu/countries/india/AP/In%20AP_DST_KVK_Drumseeder_Rpt2012.pdf (accessed on 7 March 2023).
31. SNV (Netherlands Development Organization). System of Rice Intensification. 2015. Available online: https://www.youtube.com/watch?v=51uNFQL1zMw (accessed on 7 March 2023).
32. *Farm Progress Daily*. Adam Chappell Talks about Lower Seeding Rates. 2021. Available online: https://www.youtube.com/watch?v=eUd06-WwfIw (accessed on 7 March 2023).
33. Sharif, A. Technical Adaptations for Mechanized SRI Production to Achieve Water Saving and Increased Profitability in Punjab, Pakistan. *Paddy Water Environ.* **2011**, *9*, 111–119. Available online: http://link.springer.com/article/10.1007%2Fs10333-010-0223-5 (accessed on 7 March 2023). [CrossRef]
34. Sato, S.; Yamaji, E.; Kuroda, T. Strategies and engineering adaptations to disseminate SRI methods in large-scale irrigation eastern Indonesia. *Paddy Water Environ.* **2011**, *9*, 79–88.
35. Uphoff, N. Report from SRI China Visit, 22–28 February 2004. Available online: http://sri.cals.cornell.edu/countries/china/chNTUtrep0204.pdf (accessed on 7 March 2023).
36. Zheng, J.G.; Lu, X.J.; Jiang, X.L.; Tang, Y.L. The system of rice intensification (SRI) for super-high yield in the Sichuan basin. Poster presented at the 4th International Crop Science Congress, Brisbane. 2004. Available online: http://www.cropscience.org.au/icsc2004/poster/2/3/319_zhengjg.htm#TopOfPage (accessed on 7 March 2023).
37. Anas, I.; Utari, N.A.; Sukmasakti, Y.V.; Widyastuti, R. Rice Ratooning with High Yield Is Possible. In Proceedings of the 4th International Rice Research Conference, Bangkok, Thailand; 2004. Available online: http://www.slideshare.net/SRI.CORNELL/1428-irc-2014-iswandi-ratooning-with-high-yield-081014 (accessed on 7 March 2023).
38. Thakur, A.K.; Mandal, K.G.; Mohanty, R.K.; Ambast, S.K. Rice root growth, photosynthesis, yield, and water productivity improvements through modifying cultivation practices and water management. *Agric. Water Manag.* **2018**, *206*, 67–77. [CrossRef]
39. Mohammed, M.K.; Hameed, K.A.; Musa, A.J. Water Savings, Yield, and Income Benefits from Using SRI Methods with Deficit-Irrigation in Water-Scarce Southern Iraq. *Agronomy*, 2023, this issue. Available online: https://www.slideshare.net/SRI.CORNELL/2202-water-savings-yield-and-income-benefits-with-sri-in-iraqppt (accessed on 7 March 2023).
40. Rao, K.V.R.; Gangwar, S.; Keshri, K.; Chourasia, L.; Bajpai, A.; Soni, K. Effects of drip irrigation system for enhancing rice (*Oryza sativa* L.) yield under System of Rice Intensification management. *Appl. Ecol. Environ. Res.* **2017**, *15*, 487–495. [CrossRef]
41. Uphoff, N. Report on SRI Status in the Indian States of Andhra Pradesh and Karnataka, 5–8 and 14–17 October 2006. Available online: http://sri.cals.cornell.edu/countries/india/AP/inntutrep1006.pdf (accessed on 7 March 2023).
42. Araya, H.; Edwards, S. *SCI: Planting with Space*; Institute for Sustainable Development: Addis Ababa, Ethiopia, 2019; Available online: https://afsafrica.org/wp-content/uploads/2019/04/sci-planting-with-space.pdf (accessed on 7 March 2023).
43. PRADAN. *Cultivating Finger Millet with SRI Principles: A Training Manual*; 2012; Available online: http://sri.cals.cornell.edu/aboutsri/othercrops/fingermillet/In_SFMI_Pradan.pdf (accessed on 7 March 2023).
44. Adhikari, P. *Pragati, Koraput Experiences with System of Ragi Intensification*; 2014; Available online: http://sri.cals.cornell.edu/countries/india/orissa/InOdisha_Pragati_SCI%20_Ragi14.pdf (accessed on 7 March 2023).
45. Gurung, S.B.; Khadka, R.B.; Dhami, M.B. Effects of finger millet intensification on yield and disease-resistance in central hills of Nepal. *Nepal J. Agric. Sci.* **2023**, *24*, 5–21.
46. PRADAN, *Cultivating Wheat with SRI Principles: A Training Manual*; 2012; Available online: http://sri.cals.cornell.edu/aboutsri/othercrops/wheat/In_SWI_Pradan.pdf (accessed on 7 March 2023).
47. Styger, E.; Ibrahim, H. *The System of Wheat Intensification (SWI): Initial testing by farmers in Goundam and Dire, Timbuktu, Mali*; Africare and USAID: Bamako, Mali, 2009; Available online: http://sri.cals.cornell.edu/countries/mali/Mali_SWI_Africare09.pdf (accessed on 7 March 2023).
48. FAO, System of Wheat Intensification (SWI) IPM Project FAO Afghanistan—Dari. 2014. Available online: https://www.youtube.com/watch?v=aGJZoj_iWkE (accessed on 7 March 2023).
49. Rana, L.; Banerjee, H.; Ray, K.; Sarkar, S. The System of Wheat Intensification (SWI): A new approach for increasing wheat yield of smallholder farming systems. *J. Appl. Nat. Sci.* **2017**, *9*, 1453–1464. [CrossRef]
50. Dhar, S.; Bhuban, B.C.; Vyas, V.S.; Uphoff, N. Evaluation of the System of Wheat Intensification (SWI) in the northwestern plain zone of India. *Arch. Agron. Soil Sci.* **2015**, *62*, 994–1006. [CrossRef]

51. Bhushan, S.; Uphoff, N.; Suresh, K.; Sudarshan Reddy, M. Sugarcane Intensification System: An Innovative Method Developed by Farmers in Medak District. *NewsReach* **2009**, *9*, 38–42. Available online: https://www.pradan.net/images/Media/sept_09.pdf (accessed on 7 March 2023).
52. Gujja, B.; Natarajan, U.S.; Uphoff, N. The Sustainable Sugarcane Initiative. In *Achieving Sustainable Cultivation of Sugarcane*; Roth, P., Ed.; Burleigh Dodds: Oxford, UK, 2017; Volume 1, Chapter 3.
53. Gujja, B.; Loganadhan, N.; Goud, V.; Agarwal, M. Sustainable Sugarcane Initiative—SSI: Improving Sugarcane Cultivation in India. 2009. Available online: http://oar.icrisat.org/5701/1/ssi_manual_low_resolution_Sugarcane_WWF.pdf (accessed on 7 March 2023).
54. Gujja, B.; Goud, V.; Natarajan, U.S. *SSI: Sustainable Sugarcane Initiative—Producing More With Less*; AgSri and National Bank for Agriculture and Rural Development: Hyderabad, India, 2012; Available online: http://www.agsri.com/images/documents/ssi/ssi_manual_2012_full.pdf (accessed on 7 March 2023).
55. AgSri Website. Available online: https://www.agsri.com/ (accessed on 3 March 2023).
56. PRADAN. *Cultivating Rapeseed/Mustard with SRI Principles: A Training Manual*. 2012. Available online: http://sri.cals.cornell.edu/aboutsri/othercrops/otherSCI/In_SMImustard_Pradan.pdf (accessed on 7 March 2023).
57. Berhe, T.; Gebretsadik, Z.; Uphoff, N. Intensification and semi-intensification of teff production in Ethiopia: Applications of the system of crop intensification. *CAB Rev.* **2017**, *12*, 1–12. [CrossRef]
58. ATA, TIRR Package, 2015, Agricultural Transformation Agency, Addis Ababa. Available online: http://www.ata.gov.et/programs/highlighted-deliverables/tirr-package/ (accessed on 3 March 2023).
59. Behera, D.; Chaudhary, A.; Vutukuru, K.; Kumar, V.; Gupta, A.; Machiraju, S.; Shah, P. *Enhancing Agricultural Livelihoods through Community Institutions in Bihar, India*; World Bank: New Delhi, India, 2013; Available online: http://documents.worldbank.org/curated/en/467261468258525242/Enhancing-agricultural-livelihoods-through-community-institutions-in-Bihar-India (accessed on 7 March 2023).
60. Aruna, G. System of Krain Krain Intensification in Sierra Leone. 2016. Available online: http://sri.cals.cornell.edu/aboutsri/othercrops/otherSCI/SLskkiENGIM1216.pdf (accessed on 7 March 2023).
61. Baskaran, P. STI: Sustainable Turmeric Initiative: An Innovative Method for Cultivation of Turmeric (*Curcurma longa*). 2014. Available online: http://sri.cals.cornell.edu/aboutsri/othercrops/otherSCI/InTN_STI_Baskaran092712.pdf (accessed on 7 March 2023).
62. Singh, G. Beyond Apprehensions: An Experience of System of Cumin (*Cuminum cyminum*) Intensification in India. Aga Khan Rural Support Program-India, 27 March 2015. Available online: http://sri.cals.cornell.edu/aboutsri/othercrops/otherSCI/InGujaratSCIcumin.pdf (accessed on 7 March 2023).
63. Singh, G. Making Lemonade from Thinning: An experience from the System of Coriander (*Coriandrum sativum*) Intensification in India. Aga Khan Rural Support Program-India, 30 March 2015. Available online: http://beingdgreen.blogspot.in/2015/03/making-lemonades-fromthinning.html (accessed on 7 March 2023).
64. Uphoff, N. *The System of Rice Intensification: Memoires of an Innovation*, 2022, ch. 14. Available online: https://www.srimemoires.com/chapter-14 (accessed on 7 March 2023).
65. Kassam, A.; Friedrich, T.; Derpsch, R. Successful experiences and lessons from Conservation Agriculture worldwide. *Agronomy* **2022**, *12*, 769. [CrossRef]
66. UN Food and Agriculture Organization Website on Conservation Agriculture. Available online: http://www.fao.org/conservation-agriculture (accessed on 7 March 2023).
67. Carnavale Zampaolo, F.; Kassam, A.H.; Friedrich, T. Converging the System of Rice Intensification and Conservation Agriculture for more sustainable agriculture. *Agronomy*, 2023, in press.
68. PQNK stands for Paedar Qudratti Nizam Kashatquari, Meaning Sustainable Natural Farming System. Available online: https://m.facebook.com/Pedaver/videos/four-easy-steps-to-move-from-conventional-farming-system-to-sustainable-farming-/3042010099424671/ (accessed on 3 March 2023).
69. Lv, S.H.; Dong, Y.J.; Jiang, Y.; Padilla, H.; Li, J.; Uphoff, N. An opportunity for regenerative rice production: Combining plastic film cover and plant biomass mulch with no-till soil management to build carbon, curb nitrogen pollution, and maintain high-stable yield. *Agronomy* **2019**, *9*, 600. [CrossRef]
70. CEDAC. Experiences with Multi-Purpose Farming: Raising Household Incomes in Cambodia by Utilizing Productivity Gains from the System of Rice Intensification (SRI), 2007, Prepared by Lim S., Center for the Study and Development of Cambodian Agriculture, Phnom Penh. Available online: http://sri.cals.cornell.edu/countries/cambodia/cambSidMPREng.pdf (accessed on 7 March 2023).
71. Uphoff, N. *The System of Rice Intensification: Memoires of an Innovation*, 2022, ch. 20. Available online: www.srimemoires.com (accessed on 7 March 2023).
72. A Model Farmer for Agroecology: Multi-Purpose Farming, 2018. Agroecology Learning Alliance for Southeast Asia. Available online: https://ali-sea.org/item/a-model-farmer-for-agro-ecology/ (accessed on 7 March 2023).
73. Thakur, A.K.; Mohanty, R.K.; Singh, R.; Patil, D.U. Enhancing water and cropping productivity through Integrated System of Rice Intensification (ISRI) with aquaculture and horticulture under rainfed conditions. *Agric. Water Manag.* **2015**, *161*, 65–76. [CrossRef]

74. Khumairoh, U.; Khumairoh, U.; Groot, J.C.; Lantinga, E.A. Complex agroecosystems for food security in a changing climate. *Ecol. Evol.* **2012**, *2*, 1696–1704. [CrossRef]
75. Khumairoh, U.; Lantinga, E.A.; Handriyadi, I.; Schulte, R.P.; Groot, J.C. Agro-ecological mechanisms for weed and pest suppression and nutrient recycling in high-yielding complex rice systems. *Agric. Ecosyst. Environ.* **2021**, *313*, 107385. [CrossRef]
76. Hoang, V.P.; Ha, X.L.; Dang, H.H. Adaptive research on rice/potato rotation model (SRI for rice and minimum tillage method for potato) in paddy land of Phu Binh District, Thai Nguyen Province. *Thai Nguyen Univ. J. Sci. Technol.* **2021**, *226*, 240–249. Available online: https://vjol.info.vn/index.php/tnu/article/download/58254/48612/ (accessed on 3 March 2023).
77. Shah, T.M.; Tasawwar, S.; Bhat, M.A.; Otterpohl, R. Intercropping in rice farming under the System of Rice Intensification: An agroecological strategy for weed control, better yield, increased returns, and social-ecological sustainability. *Agronomy* **2021**, *11*, 1010. [CrossRef]
78. Adaptation Fund, 9 December 2022. Available online: https://www.adaptation-fund.org/project/scaling-up-climate-resilient-rice-production-in-west-africa-benin-burkina-faso-co%CC%82te-divoire-the-gambia-ghana-guinea-liberia-mali-niger-nigeria-senegal-sierra-leone-and-togo/ (accessed on 3 March 2023).
79. Available online: https://www.climateresilientfarmingsystems.org/ (accessed on 3 March 2023).
80. Styger, E.; Traoré, G. *50,000 Farmers in 13 Countries: Results from Scaling Up the System of Rice Intensification in West Africa*; CORAF/WECARD: Dakar, Senegal, 2018; Available online: https://sriwestafrica.files.wordpress.com/2018/04/sri-waapp-book-double-p-8mb.pdf (accessed on 7 March 2023).
81. Thakur, A.K.; Mandal, K.G.; Mohanty, R.K.; Uphoff, N. How agroecological rice intensification can assist in reaching the Sustainable Development Goals. *Int. J. Agric. Sustain.* **2021**, *20*, 216–230. [CrossRef]
82. Falkenmark, M.; Rockström, J. The new blue and green water paradigm: Breaking new ground for water resources planning and management. *J. Water Res. Plann. Manag.* **2006**, *132*, 129–132. Available online: https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%290733-9496%282006%29132%3A3%28129%29 (accessed on 7 March 2023). [CrossRef]
83. Jagannath, P.; Pullabhotla, H.; Uphoff, N. Meta-analysis evaluating water use, water saving, and water productivity in irrigated production of rice with SRI vs. standard management methods. *Taiwan Water Conserv.* **2013**, *61*, 14–49.
84. Carrijo, D.R.; Lundy, M.E.; Lindquist, B.A. Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. *Field Crops Res.* **2017**, *203*, 73–180. [CrossRef]
85. Park, W.D.; Seo, J.; Choi, Y.; Kim, G.; Yun, D.; Jeong, W.; Lee, S. Effects of System of Rice Intensification on water productivity and NPS pollution discharge. *Irrig. Drain.* **2016**, *65*, 143–149. [CrossRef]
86. Chang, Y.C.; Uphoff, N.; Yamaji, E. A conceptual framework for ecofriendly paddy farming in Taiwan, based on experimentation with System of Rice Intensification (SRI) methodology. *Paddy Water Environ.* **2015**, *14*, 169–183. [CrossRef]
87. Styger, E.; Uphoff, N. *The System of Rice Intensification: Revisiting Agronomy for a Changing Climate*; Global Alliance for Climate-Smart Agriculture, FAO: Rome, Italy, 2016.
88. Thakur, A.K.; Uphoff, N. How the System of Rice Intensification can contribute to climate-smart agriculture. *Agron. J.* **2017**, *109*, 1163–1182. [CrossRef]
89. Earth Security Group. *Financing Sustainable Rice for a Secure Future: Innovative Financial Partnerships for Climate Mitigation and Adaptation*; Earth Security Group: London, UK, 2019; p. 4.
90. Hawken, P. (Ed.) *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*; Penguin Books: New York, NY, USA, 2017; Available online: https://drawdown.org/solutions/system-of-rice-intensification (accessed on 7 March 2023).
91. Gathorne-Hardy, A.; Narasimha Reddy, D.; Venkatanarayana, M.; Harriss-White, B. System of rice intensification provides environmental and economic gains but at the expense of social sustainability. *Agric. Syst.* **2016**, *143*, 159–168. [CrossRef]
92. Gathorne-Hardy, A. A Life Cycle Analysis (LCA) of greenhouse gas emissions from SRI and flooded rice in SE India. *Taiwan Water Conserv.* **2013**, *61*, 110–125.
93. International Energy Agency, Report on Methane and Climate Change, Paris. 2021. Available online: https://www.iea.org/reports/methane-tracker-2021/methane-and-climate-change (accessed on 28 February 2023).
94. SRI-2030 Website. Available online: https://www.sri-2030.org/ (accessed on 28 February 2023).
95. Vent, O.; Sabarmatee; Uphoff, N. The System of Rice Intensification and its impacts on women: Reducing pain, discomfort and labour in rice farming while enhancing households' food security. In *Women in World Agriculture*; Fletcher, A.J., Kubik, W., Eds.; Routledge: Abingdon, UK, 2016; pp. 55–68.
96. SRI4Women. Available online: https://sri4women.org/phumani/ (accessed on 28 February 2023).
97. Mrunalini, A.; Ganesh, M. Work load of women using cono weeder in SRI method of paddy cultivation. *Oryza* **2008**, *45*, 58–61. Available online: http://arrworyza.com/AdminPanel/download/Work%20load%20on%20women%20using%20cono%20weeder%20in%20SRI%20method%20of%20paddy.pdf (accessed on 7 March 2023).
98. Adak, A.; Prasanna, R.; Babu, S.; Devi, N.B.; Verma, S.; Singh, M.P.; Shivay, Y.S.; Nain, L. Micronutrient enrichment mediated by plant-microbe interactions and rice cultivation practices. *J. Plant Nutr.* **2016**, *39*, 1216–1232. [CrossRef]
99. Dass, A.; Chandra, S.; Uphoff, N.; Anil, K. Agronomic fortification of rice grains with secondary and micronutrients under differing crop management and soil moisture regimes in the north Indian plains. *Paddy Water Environ.* **2017**, *15*, 745–760. [CrossRef]
100. Thakur, A.K.; Mandal, K.G.; Raychaudhuri, S. Impact of crop and nutrient management on crop growth and yield, nutrient uptake and content in rice. *Paddy Water Environ.* **2019**, *18*, 139–151. [CrossRef]

101. Leesawatwong, M.; Jamjod, S.; Kuo, J.; Rerkasem, B. Nitrogen fertilizer increases seed production and milling quality. *Cereal Chem.* **2005**, *82*, 588–593. [CrossRef]
102. Xu, F.Y.; Jun, M.; He-Zheng, W.; Hui-Yuan, L.; Qing-Long, H.; Wen-Bo, M.; Dong-Feng, M. Rice quality under the System of Rice Intensification. *Acta Agron. Sinica* **2005**, *31*, 577–582.
103. Tilda Ricelands Ltd. Promotion of SRI with Basmati Rice. *Presented at 3rd National SRI Symposium, Coimbatore, India*. 2008. Available online: https://www.slideshare.net/SRI.CORNELL/0854-welcome-to-the-world-of-tilda-promotion-of-sri-with-basmati-rice-in-haryana (accessed on 7 March 2023).
104. Uphoff, N. The System of Rice Intensification: Memoires of an Innovation, ch. 18. 2022. Available online: https://www.srimemoires.com/chapter-18 (accessed on 7 March 2023).
105. Marenya, P.P.; Barrett, C.B. Soil quality and fertilizer use among smallholder farmers in western Kenya. *Amer. J. Agric. Econ.* **2009**, *40*, 561–572. [CrossRef]
106. Lartigue, L. New Techniques Improve Rice Harvest in Rural Sierra Leone. *Reconstruct. Reintegr.* 6 February 2004. USAID Mission, Freetown. Available online: https://sl.usembassy.gov/embassy/freetown/sections-offices/usaid/ (accessed on 7 March 2023).
107. Cook, G.; O'Connor, T. Rice Aplenty in Aceh. In *Caritas News*; Spring: Berlin/Heidelberg, Germany, 2009; pp. 9–11. Available online: https://www.caritas.org.au/docs/publications-and-reports/caritas-news---2009-spring.pdf (accessed on 7 March 2023).
108. Uprety, R. Extension under a Political Insurgency: Gaining Approval from Maoist Rebels. In Proceedings of the International Conference of Australasia Pacific Extension Network, Beechworth, Adelaide, Australia, 6–8 March 2006; Available online: http://www.regional.org.au/au/apen/2006/refereed/1/3058_upretyr.htm?print=1 (accessed on 7 March 2023).
109. Ramzi, A.M.; Kabir, H. Rice production under water management constraints with SRI methods in Northeastern Afghanistan. *Taiwan Water Conserv.* **2013**, *61*, 76–85.
110. Thaw, M.M. It Is Impossible to Keep Going with the Traditional Ways. Tat Lan Programme Website, 2018, Closed after Military Coup in 2021; Reported on SRI-Rice Website. Available online: http://sri.cals.cornell.edu/countries/myanmar/index.html (accessed on 30 March 2023).
111. Dobermann, A. A critical assessment of the system of rice intensification (SRI). *Agric. Syst.* **2004**, *79*, 261–281. [CrossRef]
112. Sheehy, J.; Peng, S.; Dobermann, A.; Mitchell, P.L.; Ferrer, A.; Yang, J.; Zou, Y.; Zhong, X.; Huang, J. Fantastic yields in the system of rice intensification: Fact or fallacy? *Field Crops Res.* **2004**, *88*, 1–8. [CrossRef]
113. McDonald, A.; Hobbs, P.R.; Riha, S.J. Does the System of Rice Intensification outperform conventional best management? A synopsis of the empirical record. *Field Crops Res.* **2006**, *96*, 31–36. [CrossRef]
114. SRI-Rice Website. Available online: http://sri.cals.cornell.edu/research/JournalArticles.html (accessed on 3 March 2023).
115. Thakur, A.K.; Uphoff, N.; Antony, E. An assessment of physiological effects of System of Rice Intensification (SRI) practices compared with recommended rice cultivation practices in India. *Exper. Agric.* **2010**, *46*, 77–98. [CrossRef]
116. Wu, W.; Uphoff, N. A review of the system of rice intensification in China. *Plant Soil* **2015**, *393*, 361–381. [CrossRef]
117. Wang, S.H.; Wang, S.; Cao, W.; Jiang, D.; Dai, T.; Zhu, Y. Physiological Characteristics and High-Yielding Techniques with SRI Rice. In Assessments of the System of Rice Intensification (SRI). In Proceedings of the International Conference on SRI, Sanya, China, 1–4 April 2002; pp. 116–124. Available online: http://sri.cals.cornell.edu/proc1/sri_27.pdf (accessed on 7 March 2023).
118. Tao, L.X.; Wang, X.; Min, S.K. Physiological Effects of SRI Methods on the Rice Plant. In Assessments of the System of Rice Intensification (SRI). In Proceedings of the International Conference on SRI, Sanya, China, 1–4 April 2002; pp. 132–136. Available online: http://sri.cals.cornell.edu/proc1/sri_29.pdf (accessed on 7 March 2023).
119. Zhu, D.F.; Chang, S.H.; Zhang, Y.P.; Lin, X.Q. Tillering Patterns and the Contribution of Tillers to Grain Yield with Hybrid Rice and Wide Spacing. In Assessments of the System of Rice Intensification (SRI). In Proceedings of the International Conference on SRI, Sanya, China, 1–4 April 2002; pp. 125–131. Available online: http://sri.cals.cornell.edu/proc1/sri_28.pdf (accessed on 7 March 2023).
120. Mishra, A.; Uphoff, N. Morphological and physiological response of rice roots and shoots to varying water regimes and soil microbial densities. *Arch. Agron. Soil Sci.* **2013**, *59*, 705–731. [CrossRef]
121. Uphoff, N.; Fasoula, V.; Iswandi, A.; Kassam, A.; Thakur, A.K. Improving the phenotypic expression of rice genotypes: Rethinking 'intensification' for production systems and the selection practices for rice breeding. *Crop J.* **2015**, *46*, 77–98. [CrossRef]
122. Mishra, A.; Whitten, M.; Ketelaar, J.W.; Salokhe, V.M. The System of Rice Intensification (SRI): A challenge for science, and an opportunity for farmer empowerment towards sustainable agriculture. *Int. J. Agric. Sustain.* **2006**, *4*, 193–212. [CrossRef]
123. Stoop, W.A. The scientific case for the System of Rice Intensification and its relevance to sustainable crop intensification. *Int. J. Agric. Sustain.* **2011**, *9*, 443–455. [CrossRef]
124. Toriyama, K.; Ando, H. Towards an understanding of the high productivity of System of Rice Intensification (SRI) management from the perspectives of soil and plant physiological processes. *Soil Sci. Plant Nutr.* **2010**, *57*, 636–649. [CrossRef]
125. Thakur, A.K.; Uphoff, N.T.; Stoop, W.A. Scientific underpinnings of the System of Rice Intensification (SRI): What is known so far? *Adv. Agron.* **2016**, *135*, 147–179.
126. Takahashi, K. A UFO? Assessment of Systen of Rice Intensification from the agricultural economics perspective. In *Agricultural Development in Asia and Africa*; Estudilllo, J., Ed.; Springer: Singapore, 2023; pp. 87–97.
127. Chi, F.; Shi-Hua, S.; Hai-Ping, C.; Yu-Xiang, J.; Yanni, Y.G.; Dazzo, F.B. Ascending migration of endophytic rhizobia, from roots to leaves, inside rice plants, and assessment of benefits to rice growth physiology. *Appl. Environ. Microbiol.* **2005**, *71*, 7271–7278. [CrossRef]

128. Chi, F.; Yang, P.; Han, F.; Jing, Y.; Shen, S. Proteomic analysis of rice seedlings infected by *Sinorhizobium meliloti* 1021. *Proteomics* **2010**, *10*, 1861–1874. [CrossRef]
129. Wu, Q.Q.; Peng, X.; Yang, M.; Zhang, W.; Dazzo, F.B.; Uphoff, N.; Jing, Y.; Shen, S. Rhizobia promote the growth of rice shoots by targeting cell signaling, division and expansion. *Plant Molec. Biol.* **2018**, *97*, 507–523. [CrossRef] [PubMed]
130. Ren, X.; Shan, Y.; Li, X.; Fan, J.; Li, Y.; Ma, L.; Wang, L. Application of RNA sequencing to understand the benefits of endophytes in the salt-alkaline resistance of rice seedlings. *Environ. Exper. Botany* **2020**, *196*, 104820. [CrossRef]
131. Cook, J.; Degon, Z.; Ruiz, D.; Pope, J.; Rahmatallah, Y. The plant growth-promoting bacteria *Azospirillum brasiliensis* induce an array of genes in rice shoots and promote growth. *Plant Growth Regul.* **2022**, *97*, 143–155. [CrossRef]
132. Fasoula, V.A.; Fasoula, D.A. Honeycomb breeding: Principles and applications. *Plant Breed. Rev.* **2000**, *18*, 177–250.
133. Doni, F. Physiological Effects and Transcriptomic Profiling of Rice Plant-Microbe Interactions in System of Rice Intensification (SRI) Management. In Proceedings of the 5th International Rice Congress, Singapore, 14–17 October 2018; Available online: https://www.slideshare.net/SRI.CORNELL/1809-physiological-effects-and-transcriptomic-profiling-of-rice-plant-microbe-interatctions-in-system-of-rice-intensification-sri-management-slide8 (accessed on 28 February 2023).
134. Doni, F.; Zain, C.R.C.M.; Isahak, A. Relationships observed between *Trichoderma* inoculation and characteristics of rice grown under System of Rice Intensification (SRI) vs. conventional methods of cultivation. *Symbiosis* **2017**, *72*, 45–59. [CrossRef]
135. Doni, F.; Zain, C.R.C.M.; Isahak, A. A simple, efficient and farmer-friendly *Trichoderma*-based biofertilizer for application with SRI management. *Organic Agric.* **2018**, *8*, 207–232. [CrossRef]
136. Khadka, R.B.; Uphoff, N. Effects of *Trichoderma* treatment with System of Rice Intensification management and with conventional management of transplanted rice. *Peer J.* **2019**, *7*, e5877. [CrossRef]
137. Doni, F.; Isahak, A.; Fathurrahman, F.; Yusoff, W.M.W. Rice plants' resistance to sheath blight infection is increased by synergistic effects of *Trichoderma* inoculation with SRI management. *Agronomy* **2023**, *13*, 711. [CrossRef]
138. Hayami, Y. *; Ruttan. V.W. Agricultural Development: An International Perspective*; Johns Hopkins Press: Baltimore, MD, USA, 1985.