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Editorial

Introduction to Special Issue on "The System of Rice Intensification (SRI)—Contributions to Agricultural Sustainability"

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The ideas and methods that constitute the System of Rice Intensification (SRI) were first synthesized in Madagascar by Henri de Laulanié in the early 1980s [1]. Within two decades, in 2002, researchers and practitioners from 15 countries could report on SRI's effectiveness at an international conference in China, hosted by the now-departed Prof. Yuan Long-ping, widely regarded as 'the father of hybrid rice' [2]. Now, another 20 years later, the principles and practices of SRI have been validated in more than 60 countries in Asia, Africa, Latin America, and North America [3]. Yet, many individuals still know little or possibly nothing about this methodology for raising the productivity of the land, labor, capital, seeds, and water employed in rice cultivation.

SRI's methodology changes, often quite counter-intuitively, how most rice farmers in the world manage their seeds (plants), soil, water, and soil nutrient amendments when producing rice. First, it drastically reduces plant density (plants m^{-2})—by as much as 90%—so that each plant has more access to the sunlight, water, and nutrients that it needs. Then, by eliciting more vigorous growth of rice plant roots, SRI practices reduce irrigation requirements by 30–50%. SRI plants, by being more robust and having more leaves and tillers, can better tolerate biotic and abiotic stresses, many associated with climate change, so that agrochemical protection is less needed or even unnecessary. Furthermore, SRI's enhancement of the abundance and diversity of soil biota means that crop yields can be increased with less or possibly no reliance on inorganic fertilizer.

SRI is a paradoxical cropping strategy where more is produced with lessening of external inputs. Even labor inputs, although initially higher during the learning phase, can usually be cut back because of the reduction in plant populations. Although SRI was originally developed for irrigated rice cultivation, once farmers understood its logic, they adapted the changes in management practices to growing unirrigated (upland) rice as well. An unexpected bonus has been that SRI's agroecological methods, with appropriate adaptations, improve the production of other crops, such as wheat, sugarcane, finger millet, pulses, and vegetables [4,5].

SRI operates differently from most contemporary agricultural technology in that it capitalizes on biological processes and potentials that already exist in crop plants and in their soil environments. This diverges markedly from the currently predominant strategy that seeks to improve plants' growth and health through genetic modification and by relying heavily on exogenous inputs such as inorganic fertilizer and agrochemical protectants.

SRI was somewhat controversial when it first became known within the scientific community in the early 2000s, e.g., Refs. [6–8]. However, there have been few attempts since then to dismiss or discredit SRI methodology because SRI's merits have become better documented and are being used by approximately 20–30 million farmers. The literature evaluating SRI has grown quite large [9]. Scientific explanations for SRI effects have been published in the literature, e.g., [10–13]. Furthermore, the effectiveness of SRI methods has been confirmed in a wide variety of agroecosystems, ranging from tropical Indonesia [14] to sub-tropical and temperate regions of China [15], even to the edge of the Sahara Desert in West Africa [16].

Still, SRI is not, and never should be, regarded as a 'silver bullet' or as a panacea. A criticism that has not been committed to paper—that 'SRI is just good agronomy'—is, in fact, an apt characterization. From the outset, proponents of this innovation have insisted that there is nothing magical or mystical about SRI, agreeing with skeptics that its methods and explanations should be subjected to and informed by scientific examination.

This Special Issue of *Agronomy* will introduce readers not acquainted with SRI to this protean phenomenon by highlighting different facets of this innovation. Concurrently, it aims to offer readers who are already knowledgeable about SRI some syntheses of what has been learned through recent studies and evaluation.

SRI is still a work in progress, as there are still many things to be learned and understood about it, e.g., Ref. [17]. There are too many different aspects of SRI to be able to address them all in a single Special Issue. For example, SRI's resilience to the stresses of climate change, its implications for gender equity, and its consequences for soil health are not considered here. However, the articles assembled here address major aspects of SRI, such as water saving, lowering the costs of production and thus raising income by more than the increase in yield, the reduction of greenhouse gas emissions, and the conservation of rice biodiversity.

The invitation to guest-edit this Special Issue pressed me to clarify how various manifestations of SRI ideas and methods relate to one another. Therefore, the issue opens with an historical perspective [18], characterizing the original version as 'SRI 1.0' and laying out an evolutionary framework for understanding how this innovation has expanded and diversified over the past 25 years. It has been a strength of SRI rather than a defect that it has proceeded inductively, shaped by needs and opportunities rather than by a priori assumptions or assertions, e.g., the widespread idea that rice plants perform better when grown in standing water [19].

This opening overview of SRI is followed by a review of experimental results from India and elsewhere that compare how rice plants grown according to SRI precepts have more desirable morphological and physiological characteristics than are observed in plants of the same variety when cultivated with either farmer practices or research recommendations [20]. This review article shows that previous assertions that SRI methods of crop management do not elicit phenotypical improvement in rice crops, e.g., Refs. [7,8], were quite incorrect. There is much evidence now that SRI practices, by creating more conducive environments for plant growth, produce superior rice phenotypes from given genotypes, both improved and 'unimproved' varieties.

The Special Issue then presents evaluations of SRI performance in three quite diverse agroecological rice-growing regions of the world: Nigeria, India, and Iraq. These papers [21–23] report on various aspects of SRI impact: agronomic results; gains in productivity; economic, environmental, and other benefits; and water saving in rice production (which is an increasing concern in many countries).

These three papers are followed by two studies that focus on the effects of SRI for reducing rice crop losses due to pests or disease. The first is a multi-year, multi-location evaluation from India of SRI impacts on crop losses due to insect pests [24]. The second, from Indonesia, examines beneficial interactions under SRI management between the biocontrol fungus, *Trichoderma*, and *Rhizoctonia solani*, a pathogenic fungus that causes sheath blight, one of the most ruinous diseases for rice [25]. SRI methods are shown to have synergistic effects for the biocontrol of this scourge in the rice sector.

The Special Issue concludes with three papers that address some broader issues:

- *The integration of SRI with broader agroecological methods of crop and soil management:* How elements of SRI and Conservation Agriculture, a rapidly spreading cropping system that eliminates soil tillage, can each benefit the other, by making certain modifications in their respective practices. This is made feasible by their congruent grounding in agroecological principles [26].

- *Climate change:* This article reviews all of the studies found in the published literature that assess how much the emission of greenhouse gases from rice paddies is reduced by alternate-wetting-and-drying irrigation (AWD) and/or by SRI crop management, which includes AWD [27]. This effect is particularly important for reducing the generation of methane (CH_4), the greenhouse gas that contributes most quickly and most potently to global warming.
- *Rice biodiversity:* SRI management can make traditional rice varieties (also referred to as local, unimproved, native, indigenous, or heirloom varieties) that are being displaced by newer varieties considerably more successful agronomically and more competitive economically with modern, improved, or hybrid varieties. SRI's enhancement of the yield from 'unimproved' cultivars can make endangered varieties better able to persist and preserve the rice species' gene pool with market forces sustaining them [28].

There were some other issues that we had hoped to address, such as how SRI methods can be adapted to *rainfed or unirrigated cultivation*; how *mechanization* of SRI practices can reduce SRI labor requirements and facilitate larger-scale use of its methods; and how SRI can contribute to improving *human nutrition*. For example, three studies in India have shown that SRI methods can increase rice plants' uptake of micronutrients from the soil and then elevate their concentration in grain, as well as in the plants' straw (an effect that can be enhanced through the inoculation of rice plants with certain beneficial microbes) [29–31]. However, such reviews could not be completed for this issue and remain to be done.

Those who have worked with SRI have come to understand it as a paradigm shift rather than an alternative or new technology. Probably the two most significant comprehensions that have emerged from SRI practice and research to date are as follow:

- *The importance and functioning of* ***plant roots*** *for crops' success*. Roots have long been a stepchild within the disciplines of soil and plant science, although they are finally starting to gain the prominence that they deserve [32,33].
- *The ubiquitous contributions that the* ***soil biota*** *make to the growth, health, and achievements of crop plants* [34–36]. The life in the soil, and particularly the plant-soil microbiome, an unseen assemblage, are beginning to get overdue attention [37–40].

It is unfortunate that these two fundamental components of the biological realm were largely left out of the planning and pursuit of the Green Revolution. That omission has had regrettable consequences for the field of agronomy far beyond rice production. The practice and study of SRI should help to correct for this oversight.

Under present and foreseeable conditions for the practice of agriculture around the world—with the deterioration and degradation of soil systems, significant changes in climate patterns, and water constraints and unreliability becoming more widespread—agricultural researchers and practitioners should greatly increase the attention paid to plants' roots and to the soil biota. These need to become prominent concerns within both plant science and soil science (and not just concerning rice), as well as for microbiology and the hybrid field of soil ecology. As noted in Ref. [18], some of the evolved versions of SRI (SRI 6.0) focus on what the practice and study of SRI can contribute to the agricultural sciences in general, more than just to greater crop production and to the sustainability of crop and soil systems.

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