The System of Crop Intensification

Agroecological Innovations for Improving Agricultural Production, Food Security, and Resilience to Climate Change

SRI-Rice

CTA

The **SRI International Network and Resources Center** (SRI-Rice) was established at Cornell University in 2010 to meet the growing demand for knowledge, advice, and technical support for the System of Rice Intensification (SRI), a climate-smart, resource-conserving, yield-increasing methodology whose benefits have been demonstrated in over 50 countries. SRI-Rice currently operates under the auspices of International Programs of Cornell's College of Agriculture and Life Sciences. The Center seeks to advance and share knowledge about SRI practices and principles, now being extended to many crops beyond rice under the rubric of System of Crop Intensification (SCI). SRI-Rice supports networking and cooperation among interested organizations and individuals around the globe.

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Suggested citation: SRI-Rice (2014). The System of Crop Intensification: Agroecological Innovations to Improve Agricultural Production, Food Security, and Resilience to Climate Change. SRI International Network and Resources Center (SRI-Rice), Cornell University, Ithaca, New York and the Technical Centre for Agricultural and Rural Cooperation, Wageningen, Netherlands.

ISBN 978-92-9081-549-5

Cover: Women of Chandrapura village in the Khageria district, Bihar, India, in one of their fields of wheat grown with SCI methods, widely referred to as SWI, the System of Wheat Intensification.

Back cover: Comparison of SWI panicles on the right and conventionally-grown wheat panicles on the left from 2019/2010 trials in the Timbuktu region of Mali.

Publication design: Devon Jenkins

Printer: XXXXXX

Available online at: ***sri.ciifad.cornell.edu/aboutsri/othercrops/SCImonograph_SRIRice2014.pdf***, and at ***http://publications.cta.int***

The System of Crop Intensification: Agroecological Innovations to Improve Agricultural Production, Food Security, and Resilience to Climate Change

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FOREWORD

This publication reports on current 'work in progress' to raise agricultural productivity in eco-friendly ways in a number of countries around the world. We think that farmers, communities and institutions in the African, Caribbean and Pacific regions would like to know about this and to benefit from it to the extent that they can.

Hundreds of thousands of households in Asia and Africa are finding that they can increase the productivity of their available resources for producing a wide variety of crops -- in the process, making these crops more resilient to the multiple stresses of climate change -- just by making changes in the ways that their plants, soil, water and nutrients are managed, as shown in this publication co-published by CTA and SRI-Rice.

The contributors to this report are listed below in alphabetical order because while most of the writing for this monograph was done by Uphoff on their behalf, it was the material, data, pictures and feedback provided by the co-authors that made this publication possible. And most importantly speaking, it was their work with farmers in their respective countries that has helped to create what is becoming widely known now as the System of Crop Intensification (SCI), reported on in this small volume.

This booklet is not presenting a new 'technology' -- to be transferred and adopted -- but a set of ideas and experiences that we hope will encourage many people to 'think outside the boxes' of their current practices and to capitalize upon certain biological processes and potentials that exist both within their present crops and within the soil systems in which these crops grow.

We hope that as more knowledge about SCI opportunities is gained through people's experimentation and experience that this will be communicated and widely shared. Both CTA and SRI-Rice welcome feedback and will try to disseminate information on further experience with SCI, both good and bad, to enable households in the ACP and beyond to have more secure and prosperous lives.

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1. The Need for Sustainable Intensification of Agriculture

Figure 1: *Biswaroop Thakur, Bihar state coordinator for the NGO ASA, during a field visit to Chandrapura village in Khagaria district, Bihar, India. The wheat field using SCI principles on the left matured earlier than the traditionally-managed field on the right, with panicles already emerged, while the traditional crop is still in its vegetative stage.*

Without clear agreement yet on what the term means, there is growing consensus that to meet our global food-security requirements throughout this 21st century, agricultural sectors around the world will need to pursue appropriate strategies for **sustainable intensification** of agricultural production (Royal Society 2009; Montpellier Panel 2013). The terminology used can vary: **sustainable agricultural intensification** (IFAD/UNEP 2013; World Bank 2006), **low-input intensification** (European Parliament 2009), **sustainable crop production intensification** (FAO 2011). But the intended redirection of thinking and practice is broadly shared.

A common denominator for these recommendations for sustainable intensification is their divergence from the kind of agricultural strategy that has prevailed over the past 50 years. Technologies for what is known as 'modern agriculture,' particularly those associated with the Green Revolution, have enabled farmers who have access to sufficient land, water, machinery and purchased inputs to cultivate ever-larger areas and produce more food and fiber.

Following the precepts of the Green Revolution, farmers have raised their production by planting (a) **improved varieties**, benefited by (b) **more water** and (c) **increased inputs** of agrochemicals, fossil-fuel energy, and capital investment. By investing more inputs to obtain greater output, they have improved upon the previously more 'extensive' strategies of production that were characterized by both low inputs per unit area and correspondingly low outputs.

This contemporary strategy for intensification that depends primarily on making genetic improvements and increasing external inputs is, however, **not the only kind of intensification that warrants consideration** -- especially given growing concerns about the **sustainability** of current agricultural practices (IAASTD 2009) and about their impacts on **climate change**. A Worldwatch Institute report in 2009 found that the land use sector was responsible for more than 30% of all greenhouse gas emissions, while another study found that the industrialized food production system as a whole is responsible for 44 to 57% of all global greenhouse gas emissions (Grain 2011).

An alternative strategy for intensification that can be broadly characterized as **agroecological** seeks to make the most productive use possible of available natural resources, including the myriad species and genetic biodiversity found in nature, and of the fields of many millions of smallholder farmers, especially women. Particularly land and water resources are becoming less abundant relative to the human populations that depend on them, with their quantity often diminishing and their quality frequently degrading. The increasing scarcity of our natural resources relative to the needs of our growing populations places an ever-greater premium upon improving the management of the soil systems, water, and biotic resources still available.

The agroecological innovations reported here can be grouped under the broad heading of **System of Crop Intensification** (SCI).[1] This approach seeks not just to get more output from a given amount of inputs, a long-standing and universal goal, but aims to achieve ***higher output with less use of or less expenditure on land, labor, capital, and water*** – all by making modifications in crop management practices.

SCI practices enable farmers to mobilize biological processes and potentials that are present and available within crop plants and within the soil systems that support them (Uphoff et al. 2006). Such agroecological innovations represent a departure from the current paradigm for 'modern agriculture.'

We do not expect that these new approaches can or will simply replace all current practices. Agricultural development does not work that way. Rather, the aim is to give farmers **more options** for meeting their own needs and those of consumers, while at the same time protecting and conserving environmental resources and services.

Farmers in quite a range of countries -- India, Nepal, Pakistan, Cambodia, Ethiopia, Mali and Cuba – have started managing the growing environments for their respective crops to bring them closer to

1 There are also other acronyms and names given for this domain for the advancement of agricultural knowledge and practice, usually including the name of the focal crop, such as System of Wheat Intensification (SWI) or System of Tef Intensification (STI). For a summary account of SCI and the material in this monograph, see Abraham et al. (2014).

an optimum, producing more food with a lighter 'footprint' on the environment. What we report here is from farmers' fields, not experiment stations, since as yet there has been limited interest in SCI from agricultural science researchers.

Two NGOs in India -- PRADAN and the People's Science Institute -- and an Ethiopian NGO -- the Institute for Sustainable Development (ISD) -- have been particularly active in applying SCI ideas across a number of crops, with results reported here. The largest-scale introduction and adaptation of SCI has been in Bihar state of India, where its rural livelihoods program JEEVIKA, supported by the state government and by World Bank IDA assistance, has enabled several hundred thousand poor households to benefit from these new approaches (Behera et al. 2013).

The contributors to this monograph are reporting as initiators or supporters of the changes being introduced, not as researchers studying them, although all have done and continue to do publishable research. By communicating observed outcomes achieved under real-world circumstances as accurately as possible, it is hoped that this information will stimulate the interest of others to undertake more systematic studies and to help establish scientific explanations for promoting the greater utilization of SCI adaptations under 21st century conditions.

No firm or final conclusions are proposed as this is a fast-moving, fast-growing domain of knowledge. The agricultural experiences reported here have become known mostly within the last five years, as part of efforts to improve food security for communities, many of them impoverished or distressed. The main concern is to assist resource-limited households that must deal with the severe and growing challenges found in degraded environments, which are now being exacerbated by the climate change that adds to their burdens and insecurity.

__Figure 2:__ Children in Gaya district of Bihar state of India admiring and playing with a simple mechanical weeder used for controlling weeds and aerating the soil when producing mustard (rapeseed or canola) with SCI methods.

The results of SCI practice -- ***producing more food outputs with fewer inputs*** -- will appear counter-intuitive to many readers, maybe even to most. But this reorientation of agriculture is what 'sustainable intensification' will require as our populations get larger and as the resources on which they depend become relatively, and in some places even absolutely, more limiting.

`2. Agroecological Management

Agroecological crop management represents a different form of 'intensification' from what is usually understood by that term, e.g., Reichardt et al. (1998). Agroecological management is exemplified by the **System of Rice Intensification** (SRI) developed in Madagascar (Stoop et al. 2002; Uphoff 2012a) as well as by ***conservation agriculture***, ***integrated pest management***, ***agroforestry***, and other combinations of practices that modify the management of crops, soil, water and nutrients. These changes achieve, among other things, enhanced soil microbial abundance and activity in the crops' rhizosphere (root zone), and even within the crops' phyllosphere (canopy) (Uphoff et al. 2013).

Such strategies can reduce, and sometimes eliminate, the need for use of the agrochemical inputs that have been a mainstay of 20th century agriculture, particularly since the Second World War. These alternative strategies can benefit from, although they do not require, improvements or modifications in crops' genetic endowments. The alternative management methods employed elicit improved **phenotypes** from most if not all existing **genotypes**, whether these are 'improved' or 'unimproved' varieties (Altieri 1995; Gliessman 2007; Uphoff 2002).

Agroecological management mostly intensifies knowledge and skills (mental inputs) rather than seeds, equipment or chemicals (material inputs). More labor input is required in some situations, but not in others, so these strategies are not necessarily more labor-intensive. Some degree of mechanization can often be introduced, utilizing capital and external energy inputs (pages 52-57); but if so, these resources are relied

Figure 3: *A mustard field in Gaya district of Bihar state of India grown from seedlings transplanted at a young age into widely spaced pits filled with loosened soil and organic matter. This field will yield triple the usual grain harvest. Standing in front of the field are Dr. O.P. Rupela, former senior microbiologist with ICRISAT in Hyderabad, India, and a young village boy who was passing by.*

upon less than in 'modern agriculture.' Dependence on agrochemicals to enhance soil nutrient supply and to protect crops from pests can be reduced or replaced by capitalizing on biological resources and dynamics that make soil systems more sustainably fertile, and that can enhance crops' inherent resistance to pests and diseases (Chaboussou 2004).

Agroecology focuses on supporting the interactions, dependencies and interdependencies among myriad organisms and especially among diverse species. By making modifications in crop management practices, we are learning, we can enhance the symbiotic relationships between plants and the communities of microorganisms that constitute the plants' microbiomes (Anas et al. 2011).[2]

Recently we have been learning that ecological interactions and interdependences exist not only ***among*** organisms and species, but also ***within*** organisms as research shows how microorganisms inhabit crop plants as symbiotic endophytes. These, when living in the tissues and cells of crops' leaves and stalks as well as in their roots and even in seeds, can beneficially affect these plants' expression of their genetic potentials (Chi et al. 2005, 2010; Rodriguez et al. 2009; Uphoff et al. 2013).

Although agroecological management may appear 'old-fashioned' to some people, scientific advances in the fields of microbiology, microbial ecology, and epigenetics in the decades ahead should make it the most modern agriculture.

Crops with larger, more effective root systems in association with more abundant and diverse life in the soil are more resilient when subjected to drought, storm damage and other climatic hazards. Buffering of such effects has been seen frequently with SRI management for rice (Uphoff 2012a). Similar effects are reported also for other crops with agroecological management, making them also less vulnerable to climate stresses including extreme weather.

Much remains to be learned about how and why agroecological management can have beneficial effects on crops' productivity and resilience, but this monograph shows that there are many advantageous relationships waiting to be explained. It is now known that certain management practices, assembled inductively to improve the performance of rice crops, can have desirable impacts on many other crops as well.

These effects will take on greater significance in a future that is affected by **climate change**. We are finding that crops grown with attention to nurturing larger, more effective root systems and more abundant, diverse soil biota show greater resilience when subjected to climate stresses and have more resistance to drought, storm damage, and other hazards.

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2 The functions and protection that beneficial microorganisms perform for crops are parallel to those that our respective human microbiomes contribute to the growth and health of members of our human species (Arnold 2013)

3. Applications of Agroecological Strategies to other Crops

Figure 4: Harouna Ibrahim, Africare technician working in the Timbuktu region of Mali who has motivated and guided farmer innovation with SWI, showing difference between wheat plants of the same variety that were grown with different management practices. SWI methods, seen on the right, promote root growth and soil organisms that contribute to more tillering, larger panicles, and more grain than with conventional practices, seen on the left.

The System of Rice Intensification (SRI) was developed in the 1980s to improve the circumstances of poor, rice-growing households in Madagascar (Laulanié 1993). Over the past decade, the SRI principles that were assembled to raise irrigated rice production have been extended first to rainfed rice, and then to improving yields of a variety of other crops (Uphoff 2012b).

This broader application, referred to as the System of Crop Intensification (SCI), extrapolates practices derived from the core principles of SRI, with appropriate modifications, to other cereals, legumes and vegetables (Araya et al. 2013; Behera et al. 2013; WOTR 2013). It is even broadened to include other kinds of agricultural production, as reported on in section 7.

Some practitioners in India who want to keep the SRI acronym intact refer to SCI and SRI together as the System of ***Root*** Intensification. This is an apt characterization, directing attention to what goes on below-ground. But its focus on roots is incomplete since much of the impact of SRI practices should be attributed to the massive, invisible multitudes of symbiotic microorganisms that inhabit soils and also plants.

The bacteria and fungi that live in, on and around plants (and animals) provide the substrate for vast and intricate soil-plant 'food webs' that range from miniscule microbes up to larger, visible creatures. These networks are composed of organisms that feed upon each other and that improve the environments of other complementary species. The soil biota channel large flows of energy (Ball 2006) that support and sustain the production of all of our crops and livestock (Coleman et al. 2004; Lowenfels and Lewis 2006; Thies and Grossman 2006).

The methodology recommended for SRI or SCI practice can be summarized under four simple ***principles*** that interact in synergistic ways:

- Establish healthy plants both early and carefully, taking care to conserve and nurture their inherent potential for root growth and associated shoot growth;
- Reduce plant populations significantly, giving each plant more room to grow both above and below ground;
- Enrich the soil with decomposed organic matter, as much as possible, also keeping the soil well-aerated to support the better growth of roots and of beneficial soil biota.
- Apply water in ways that favor plant-root and soil-microbial growth, avoiding hypoxic soil conditions that adversely affect both roots and aerobic soil organisms.

These principles translate into concrete **practices** that have proved productive for increasing yields of irrigated rice, as confirmed in large-scale factorial trials (Uphoff and Randriamiharisoa 2002). The methods which are to be adapted to local conditions such as crop, soil type and climate include:

- Planting young seedlings carefully and singly, with optimally wide spacing in a square grid or diamond pattern for better exposure to sun and air.
- Providing the crop with sufficient water to support the growth of plant roots and beneficial soil organisms, but not so much as to suffocate or inhibit them.
- Adding as much organic matter to soil systems as possible to improve soil structure and functioning, enhancing the soil's ability to support healthy plant growth.
- Breaking up the soil's surface in the process of controlling weeds, actively aerating the soil and stimulating root and microbial growth, also incorporating weeds into the soil as green manure.

The cumulative result of these practices is to induce the growth of more productive and healthier plants – phenotypes -- from any given crop variety -- genotype.

Once farmers in parts of Cambodia, Philippines, India and Myanmar who had no access to irrigation facilities saw the results of SRI practices and understood its principles, they started extending and adapting these to their rice production in ***upland areas*** that had no irrigation.[3]

Figures 5 and 6: *Applications of SCI ideas to vegetable production in Bihar state of India: at top, profuse branching of eggplant (brinjal) plants under SCI management; at bottom, SCI tomatoes ready for market.*

This was a first step beyond the use of SRI principles for irrigated rice. Subsequently, various farmers and NGOs in these and other countries began adapting SRI principles and practices to other crops beyond rice.

There has been little scientific evaluation of SCI so far, but systematic studies should begin soon. The data that follow represent a first step toward quantitative assessment, having been gathered for purposes of comparison, for farmers to know the effects of their change in practices. Often the data have been assessed through on-site visits by one or more of the contributing authors, usually with members of the local agricultural development community.

We can assure readers that the same methods were used when calculating yields from both SCI and conventional fields. This means that the **relative** yields reported, i.e., the ratios and percentages, are reasonably reliable even if there might be questions raised about the **absolute** numbers. The purpose of measurement was, as noted above, to make comparisons for farmers' sake, not to be setting any records.

That there can be increases in production without requiring greater inputs is what counts most for farming households. The standard of comparison is farmers' current practices, recognizing that what some would consider as 'best management practices' recommended by agricultural scientists have substantially higher out-of-pocket costs of production, and are beyond the means of most food-insecure farmers.

While the information on SCI given in section 4 which follows contains some limitations of precision and coverage, the impacts being observed and reported are both large and consistent. Assessments of statistical significance are more relevant when one is considering small differences that may just be measurement artifacts or chance occurrences. Such tests are less relevant for the kind of large divergences reported here.

3 Myanmar farmers' experience with rainfed SRI is documented in Kabir and Uphoff (2007).

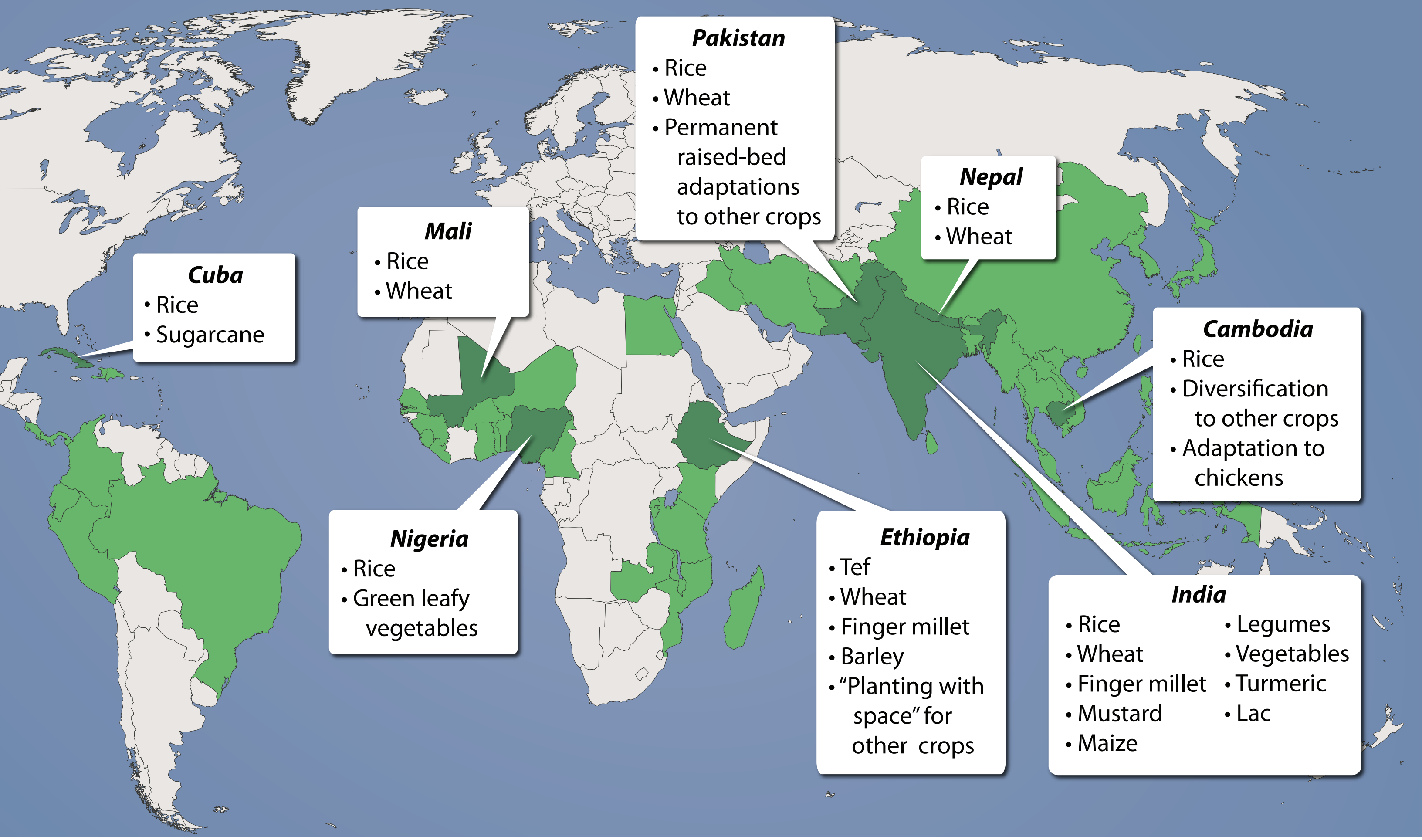


Figure 7: *Spread of SRI and SCI ideas and practices: in the light green colored countries, SRI methods have been seen to produce better phenotypes from available rice genotypes; in the dark green colored countries, in addition to this, there has been experimentation with and confirmation of SCI principles and techniques; lists for each country show which crops have to-date been shown to improve yields with SCI methods.*

The photographic evidence shown in accompanying figures reinforces the proposition that something of agricultural significance is occurring. Data from the crop-by-crop reviews that follow and from other crop performance evaluations are summarized in Annexes I and II at the end of this monograph (pages 60-63).

4. Crop Adaptations and Results from Farmers' Fields

Figure 8: A finger millet plant grown with SCI methods in Jharkhand state of India, with more tillers and larger root system, being shown by farmer and PRADAN field staff.

a. Finger millet (*Eleusine coracana*)

Finger millet is the staple food for millions of poor households in India, Sri Lanka, Nepal and parts of Eastern Africa. Its high nutritional content has made it a food traditionally fed to pregnant and lactating women and often used as a weaning food for babies.

India: Farmers in Haveri district in the southern state of Karnataka over several decades developed their own set of novel practices for growing finger millet that are remarkably close to SRI management (Green Foundation 2006).

Conventional crop management starts with broadcasting finger millet seeds on a tilled field and gives yields between 1.25 to 2 tons/ha. With good irrigation and fertilizer applications, conventional finger millet yields in Haveri district can reach 3.75 tons.

With a methodology that they call *Guli Vidhana*, farmers in Haveri, after ploughing their fields, make a square 'grid' of shallow furrows on the surface of their fields using a simple ox-drawn plow. The grooves in the soil are made in parallel and perpendicular directions with wide spacing, 45x45 cm.

Figures 9 and 10: *On left, demonstration of the* korudu *implement that Indian farmers in the Haveri district of Karnataka state use for bending over young finger millet plants to promote the growth of roots and tillers; right, farmers demonstrating the* yedekunte *implement that is used to cut weeds' roots below the soil's surface between the rows. This has the additional benefit of breaking up and aerating the top layer of soil around plants' roots.*

At each intersection of the grid, two 12-day-old seedlings are transplanted, putting a handful of compost or manure around the roots to give the young plants a good environment in which to begin growing.

While the plants are still young, between 15 and 45 days after transplanting, farmers pull a light board across the field in several directions. Bending the young plants over in different directions promotes more growth of roots and tillers from the meristematic tissue in the plants' crowns, which are at or just below the soil surface level (Figure 9).

Concurrently, farmers loosen the soil between the plants several times with another ox-drawn implement that cuts the roots of any weeds growing between the millet plants about 3-5 cm below the soil surface (Figure 10). This active soil aeration along with organic matter supplementation enables the millet plants to have 40-80 tillers and give yields of 3.75 to 5 tons/ha, even up to 6.25 tons.[4]

4 NGOs working with farmers in Karnataka have further evolved this system as seen at: **http://www.slideshare.net/SRI.CORNELL/1163-experience-of-system-of-crop-intensification-sci-in-finger-millet#btnNext**

In the eastern state of Jharkand, Indian farmers after being introduced to SRI for growing rice by the Indian NGO PRADAN (Professional Assistance for Development Action) began experimenting with SRI methods for their rainfed finger millet crop in 2005, referring to this as the **System of Finger Millet Intensification** (SFMI).

With traditional broadcast practices, usual yields in the area are around 1 ton/ha. By starting their crop with young transplanted seedlings (not broadcasted seeds), with wide spacing and modified water and nutrient management, SFMI yields rose to 3 tons/ha or more. While the intensified management increases farmers' costs by about 25%, the higher yields reduce their costs of production by 60%, from Rs. 34.00 per kg to Rs. 13.50 per kg, making SFMI very profitable. These data and information on SFMI methods are presented in a manual prepared by PRADAN (2012a).

In northern India, the People's Science Institute (PSI) undertook trials of another version of SFMI in 2008. In the Himalayan state of Uttarakhand, 43 farmers tried out these methods on a small area, just 0.8 ha. Their results showed a 60% increase in grain output, moving up from an average yield of 1.5 tons/ha to 2.4 tons/ha. By 2012, more than 1,000 farmers were using locally-adapted SFMI methods, spacing their plants 20x20 cm apart and establishing them either by direct-seeding or by transplanting young seedlings 15-20 days old. Such modified practices induce the kind of more productive plant phenotypes seen in figures 8 (page 11), 11 (below), 12-14 (following page), and 15-16 (page 15).

Figure 11: *Field day for farmers, technicians and officials to observe SCI finger millet being grown in Tigray province of Ethiopia.*

Ethiopia: Similar finger millet crop responses to SCI management have been observed in Tigray province. The first farmer to transplant finger millet seedlings there was an elderly woman who obtained a yield equivalent to 7.8 tons/ha in 2003, compared to usual finger millet yields of 1.4 tons/ha with broadcasting, or 2.8 tons/ha with generous use of compost (Araya et al. 2013).

This was considered quite fantastic, evoking curiosity and interest among farmers there and elsewhere in Ethiopia. This management strategy has come to be called 'planting with space,' and farmers are now applying its concepts and principles to many other crops as reported in section 5 below.

Figure 12: *Comparison of finger millet plants grown with different management practices. On left is a plant of an improved variety (A404) grown with farmers' SFMI practices; in center, is a plant of the same improved variety grown with farmers' conventional broadcasting; on right is a local (unimproved) variety grown also with farmers' usual methods.*

Figure 13: *Contrasting panicles of finger millet; SFMI plant is on left, and conventionally grown plant is on right.*

Figure 14: *Comparison of the root systems of SFMI plant on left and conventionally-grown finger millet plant on right.*

Transplanting methods have become standard practice among farmers in the Axum area of Tigray province. Finger millet yields now average 3.5 to 4 tons/ha, similar to the SFMI yields in Bihar, and higher than those reported from northern India. Some Tigrayan farmers have even obtained yields of >6 tons/ha when the rainy season is long enough, i.e., when it continues from July into mid-September. Farmers implementing SCI are all making and using compost which they apply to the soil when they transplant their seedlings.

Figures 15 and 16: *Evident differences in the phenotypic expression of finger millet's growth potential: on left, a farmer's son holds a single plant of broadcast finger millet; on right, a single plant grown with SCI transplanting and management, both in Kewnit village, Ethiopia.*

b. Wheat
(*Triticum spp.*)

Once farmers and researchers in India, Mali and Nepal began seeing the effects of SRI practices on rice, there was a fairly quick extension of the ideas and methods to wheat.

India: What is now called the **System of Wheat Intensification** (SWI) was first tested in northern India in 2006 by farmers working with the People's Science Institute (PSI). First-year trials near Dehradun, using several varieties, showed average increases of 18-67% in grain yield and 9-27% higher straw yields (very important for subsistence farmers as fodder) compared with the yields that farmers there usually obtained with these varieties using conventional broadcast methods for crop establishment.

Impressed with these results, PSI began promoting SWI in the states of Uttarakhand and Himachal Pradesh (Prasad 2008). Starting with 50 farmers in 2007, the number of smallholders using SWI methods expanded to more than 12,000 by the 2011-12 winter season. Average increases in grain yields from irrigated SWI reached 80-100% over usual farmers' practice, while in unirrigated rainfed fields, SWI methods increased yield by 60-80%. Despite the need for higher labor investments in sowing and weeding operations, farmers have found the ratio of benefit-to-cost with SWI to be very favorable due to the higher yields of both grain and straw.

Encouraged by good farmer response and results in these two states, PSI has been promoting SWI within a wider region of northern India since 2010 including some districts in Uttar Pradesh and Madhya Pradesh states. Households there suffer from low food productivity, having little irrigated area and frequent rainfall failures. Starting with 590 farmers in this larger area in 2010, the number of SWI farmers rose to 1,015 the next year. More details on PSI experience with SWI in northern India are given in Chopra and Sen (2013).

The most dramatic results and the most rapid growth in use of SWI have been in the state of Bihar where landholdings are very small, with an average of only 0.3 ha. At the initiative of the NGO PRADAN, 278 farmers in the Gaya and Nalanda districts, mostly women, tried out the new methods in 2008-09. Their yields averaged 3.6 tons/ha compared with 1.6 tons/ha using usual practices, which attracted farmer interest.

The next year, 15,808 farmers used SWI methods and with somewhat better weather, yields averaged 4.6 tons/ha. This led the state government's Bihar Rural Livelihood Promotion Society (BRLPS, or

JEEVIKA) to support efforts by many NGOs and the state's extension service to spread SWI use, utilizing IDA funding from the World Bank. Two years later, in 2012, the area under SWI management had expanded to 183,063 hectares, and average SWI yields were 5.1 tons/ha, according to Bihar Department of Agriculture calculations.

Intensified management for SWI does require more labor and more organic matter inputs; so farmers' costs of SWI production per hectare in Bihar are about 60% higher than with conventional practices. Still, with yields that are more than doubled, the net income per hectare soars by 150%, from Rs. 17,460 to Rs. 43,952, as farmers' costs of production per kg of wheat produced decline by 28%. The experience of Bihar farmers working with SWI methods has been summarized in a manual prepared by PRADAN (2012b).

The Aga Khan Rural Support Programme in India (AKRSP-I) has also been introducing SWI in Bihar state, with different but still favorable results. Its SWI yield increases have been 32%, with farmers averaging 3.48 tons/ha instead of 2.63 tons/ha. However, with this less-intensive version of SWI, costs of production decline by 26% per hectare, so the cost of producing wheat is only Rs. 8.17 per kg under SWI compared to Rs. 11.05 with standard practices. Standard cultivation practices for wheat have produced little net income for farmers, just Rs. 1,802 per ha, whereas with SWI practices, farmers' net income from their production of wheat is Rs. 18,265 per ha, according to an AKRSP evaluation (Raol 2012).

Mali: The international NGO Africare began introducing SRI methods for irrigated rice into the Timbuktu region in 2007. During an evaluation of SRI results the next year, with 60 farmers who had grown irrigated rice on side-by-side comparison plots evaluating SRI and conventional methods (Styger 2008-09; Styger et al. 2011), the idea was born to apply the same principles to wheat, their winter crop.

Three farmers from three villages volunteered to do SWI trials, using the same methods as SRI; but simple imitation of SRI was not very successful; mortality of transplanted seedlings was 9 to 22% in the cold winter climate, and the 25x25 cm spacing was too wide for plants to utilize all the arable area. Transplanted SWI produced 29% less grain than the control plots (1.4 tons/ha vs. 1.97 tons/ha).

Direct-seeded SWI, on the other hand, showed a 13% yield increase, producing 2.22 tons/ha. Farmers were pleased with their 94% reduction in seed requirements with SWI (10 kg/ha versus 170 kg/ha), and with a 40% reduction in labor and 30% lower irrigation water requirement (Styger and Ibrahim 2009). Thus, farmer interest in this innovation was aroused.

In the next season, 2009/2010, Africare undertook systematic SWI trials comparing different spacing and seeding techniques (Styger

Figure 17: *Comparison of SWI panicles on left and conventionally-grown wheat panicles on right, from 2009/10 trials in Timbuktu region of Mali.*

2010). While a spacing of 15x15 cm gave the highest yield (5.4 tons/ha), all of the treatments using single plants per hill gave yields above 4 tons/ha, with spacing ranging from 10x10cm to 20x20cm, as did row-planting with 20 cm distance between rows (Figure 17). These yields were all higher than the 2.22 tons/ha obtained from the broadcast control plots where farmers' usual methods were used (Styger, Ibrahim and Diaty, unpublished).

In a third season, SWI trials continued among farmers, even though Africare had no funding to support their testing; the experience of 21 farmers was monitored. Their average SWI yields were 5.45 tons/ha, compared to 1.96 tons/ha from conventional practice (Styger and Ibrahim, unpublished).

The next year, when there was drought and irrigation water was limited, Africare was able to monitor 142 farmers using SWI methods in 13 villages. Despite the adverse weather conditions, SWI yields averaged 3.2 tons/ha compared to 0.94 tons/ha from conventionally-grown plots (Styger and Ibrahim, unpublished).

Farmers indicated that their applying SWI on a larger scale was constrained by lack of good implements for direct-seeding; difficulties in soil preparation and manure transportation; and shortages of timely irrigation water. These factors limit the area of land that can be planted with SWI methods at present. Remedying these constraints could greatly enhance wheat production in Mali in the future.

Nepal: A majority of Nepalese farmers are smallholders having landholdings below 0.5 ha, and their wheat yields usually average about 1.2 tons/ha.

Figure 18: Comparison of wheat panicles from farmer field school trials in mid-Nepal.

For the last half decade, farmers have faced severe scarcity of fertilizers for their main wheat cropping season, and rainfall in the winter season has been erratic. These factors, plus very low seed replacement rates in the hill and mountain areas, have contributed to the very low productivity of wheat in Nepal.

Under an EU-funded Food Facility Program implemented in the Far Western Region by FAO and local NGOs, SWI concepts and practices were introduced to smallholding farmers in 2009, using direct-seeding (DS) rather than transplanting because DS performed better under local conditions. It was found that "sowing with proper plant density allows for sufficient aeration, moisture, sunlight and nutrient availability leading to proper root system development from the early stage of crop growth" (Khadka and Raut 2012). Such management led to more productive phenotypes of wheat.

Comparison trials in 2010-11 at 16 locations in 3 districts (Dadeldhura, Baitadi and Kailali) showed that SWI methods with seed-priming and line-sowing, using a recommended improved variety (WK-1204), and reducing the seed rate by >80%, gave smallholder farmers 91% more yield than from their local practices with this same variety (6.5 versus 3.4 tons/ha). The average number of grains per panicle was 75 vs. 44, and grain weight (grams per 1000 grains) was 29% higher with SWI (Figure 18). Although farmers' expenditures/ha were 58% higher with this more intensive crop management (Rs. 5,010 versus Rs. 3,170), farmers' net income more than doubled, rising from Rs. 4,830/ha to Rs. 9,830/ha.

In 2011-12, farmer field school experiments conducted in Sindhuli district with similarly modified SWI practices also showed better yield and economic returns. Pre-germinated seed of Bhirkuti variety sown at 20x20 cm spacing gave 54% more yield than the available 'best practices' used under similar conditions of irrigation and fertilization: 6.5 tons/ha from SWI, compared to 3.7 tons/ha with conventional broadcasting, and 5 tons/ha with row sowing (Adhikari 2012).

With SWI methods, farmers' seed requirements are reduced by >80% (20 kg/ha compared with 120 kg for usual practice). This means that the limited supply of improved seed available can be used on four times more cultivated area. Also, fertilizer is less necessary if biofertilizer can be produced or procured locally. By using improved seed with SWI crop management techniques, it has been calculated that an average household with six members in the Far West, a region known for its extreme poverty, can achieve an additional 6 months of food security each year (Khadka and Raut 2012).

Ethiopia: Experience with SWI methods has been similar in this country as well, as seen in Figures 19 and 20. We discuss Ethiopian experience with several versions of SWI (and other crops) in section 5 below on 'Planting with Space.'

That SRI methods which could enhance the productivity of rice plants would have similar effects on finger millet and wheat was not so surprising as they belong to the same large family of grasses known as Gramineae (or Poaceae) in which rice is placed. However, learning that concepts and adapted methods from SRI cultivation could be successful also for a crop as ostensibly different as sugarcane, discussed next, was unexpected. Botanically speaking, sugarcane is also a member of the Gramineae family, and its productivity is similarly enhanced by more profuse tillering and root growth.

Figures 19 and 20: *Comparison of wheat panicles from the same variety in Gembichu Woreda, Ethiopia: on left are plants grown with usual farmer methods of cultivation (39 grains per panicle on average); and on right, SWI crop management (56 grains).*

C. Sugarcane
(*Saccarum officinarum*)

India: Sugar is the world's largest crop according to FAO crop production statistics. Shortly after they began using SRI methods, some rice farmers in Andhra Pradesh state of India began adapting these ideas and practices also to their sugarcane production, as early as 2004. Some farmers were able to get much higher yields while cutting their planting materials by 80-90%, reducing their water applications, and applying fewer purchased inputs of fertilizer and chemical protectants, as with SRI-grown rice.

By 2009, there had been enough testing, demonstration and evolution of these initial practices that a joint Dialogue Project on Food, Water and Environment between the World Wide Fund for Nature (WWF) and the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad, launched a 'sustainable sugarcane initiative' publishing a detailed manual on SSI (ICRISAT/WWF 2009).

Subsequently in 2010, the director of this project, Dr. Biksham Gujja, together with other SRI and SSI colleagues, established a company called ***AgSri*** based in Hyderabad (***http://www.agsri.com/index.html***). This pro-bono enterprise is disseminating knowledge and practice of SRI, SSI and other ecologically-friendly innovations among farmers in India and beyond.

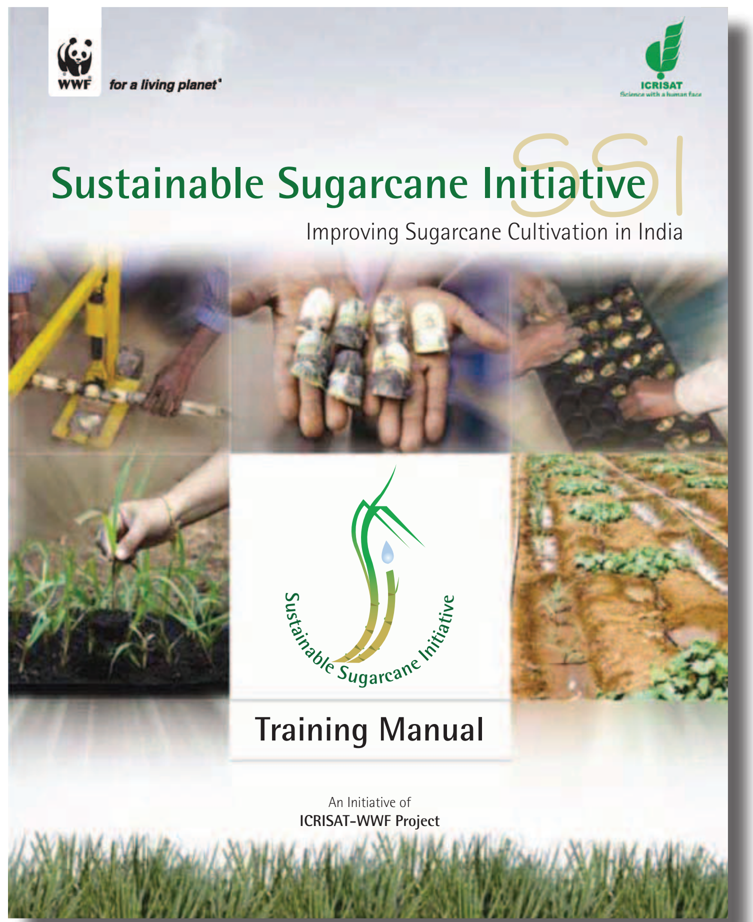


Figure 21: *The cover of a 2009 SSI training manual, published by WWF and ICRISAT.*

Large-scale field testing of SSI methods has been undertaken in all the major sugarcane-producing states of India. Currently it is estimated that at least 10,000 Indian farmers are practicing SSI, although this is still small compared to the large total numbers cultivating 5 million hectares of sugarcane. AgSri and the National Bank for Agriculture and Rural Development (NABARD) have jointly published a revised SSI manual (AgSri/NABARD 2012).

Figure 22: *Sugarcane being grown with SSI management in India.*

The Tamil Nadu state government has agreed to extend financial and technical support to farmers wanting to utilize SSI methods as it did previously in the case of SRI. The Tamil Nadu Agricultural University, having launched an SSI promotion campaign, reports that the new methods are raising average cane yields up to 225 tons per hectare, from present yields of 100 tons. This is achieved by reducing the seed rate by >90%, planting 12,500 single bud chips per acre instead of 75,000 double-budded chips as is usually done now (Anon. 2013a; Anon. 2013c).

AgSri has begun establishing high-quality nurseries to supply vigorous young seedlings to farmers. While there are still some challenges to be dealt with for meeting farmers' demand for seedlings in a timely way, good initial results have encouraged the private sector, sugar mills and agriculture development agencies to begin cooperating to scale up SSI in India and capitalize on the ability of these methods to yield phenotypes that boost both productivity and profitability in this sector (Figure 22).

Elsewhere: The first trials of SSI in Cuba using AgSri manuals posted on the web gave good results with yield estimated at 150 tons/ha (Figures 22 and 23, following page). Ministry of Sugar officials have set up a task force to establish and evaluate SSI trials/demonstrations in all provinces of the country. Farmers in Nicaragua and Tanzania are now also establishing SSI field trials.

Since sugarcane as a crop consumes about as much water as rice, requiring 1500-3000 liters of water per kg of sugar ultimately produced, management methods that can reduce water requirements similar to SRI's reductions for rice will have substantial economic and environmental benefits.

Figures 23 and 24: *First SSI trials at the CPA Camilo Cienfuegos sugar cooperative in Bahia Honda, Cuba, at 10.5 months; yield from the test plot was estimated at 150 tons/ha.*

d. Tef
(*Eragrostis tef*)

Ethiopia: Tef, the preferred cereal crop in this large food-deficit country, is grown from tiny seeds (2500 per gram) that are traditionally broadcast on repeatedly ploughed soil. Despite investment of much labor, mostly by women and children, tef yields are usually low, about 1 ton/ha.

Adaptation of SRI methods to tef cultivation was started in 2008-09 under the direction of Dr. Tareke Berhe, at the time with the Sasakawa-Global 2000 program, and now director of the Tef Value Chain Program under the government's Agricultural Transformation Agency (ATA).

By transplanting young, 20-day-old tef seedlings at 20x20 cm spacing with application of organic and inorganic soil nutrients, yields reached 3 to 5 tons/ha. Further, on plots with small soil amendments of micronutrients such as Zn, S, Mn and Mg, these improved yields were almost doubled again, responding well to the practices that Tareke christened as STI, the System of Tef Intensification.

In 2010-11, in collaboration with the Institute for Sustainable Development (ISD) which obtained some funding from Oxfam America for SCI evaluation and demonstration, Tareke conducted further controlled STI trials at two major centers for agricultural research in Ethiopia. Good results there gained acceptance for the new practices from other tef scientists and government decision-makers, and ATA began more systematic evaluations and demonstrations (Berhe et al. 2013).

In 2011-12, over 1,400 farmers who tried STI methods averaged 2.7 tons/ha. Then in 2012-13, there were 7,000 farmers using STI methods in expanded trials with transplanted seedlings, while another 160,000 farmers applied less-intensified STI methods, doing direct-seeding in rows instead of transplanting. This kind of 'STI-lite' was able to raise tef yields on a large scale by 70%, from 1.2 tons/ha to 2.1 tons/ha (ATA 2013). With such results, the government is scaling up the area under STI management to 1.6 million ha in 2013-14.

The direct-seeded method follows SRI principles including wider spacing (20 cm) between rows and enhancement of soil organic matter with compost, supplemented with some urea and DAP. 'STI-lite' practices which improve the balance of air and moisture in the soil require less labor for sowing and weeding than the full STI management.

More intensive management that starts with transplanting young tef seedlings and puts more emphasis on organic soil fertilization gives farmers better results, but the choice of methods is left to farmers, whose labor is a key factor (Figure 25).

Like other crops, the tef genome is highly responsive to management practices that do not crowd the plants together and also improve soil conditions. When individual tef plants are given ample space, their leaves are longer and wider; their darker green color indicates that the plants' photosynthetic efficiency, usually low, is enhanced by their altered growing conditions. Tef plants given wider spacing exhibit much larger and longer root systems. These in turn support larger, taller canopies that resist lodging, a major constraint with conventionally-grown tef.

For countless generations, this crop has been grown by broadcasting seed with high plant densities. STI, in contrast, reduces plant density by 90%, using 9-15 million seeds/ha instead of 90-150 million/ha. It is seen that by transplanting and making other changes in field management, tef grain and straw yields can be tripled or more (Figure 26).

Figures 25 and 26: *Top, comparison of a transplanted STI plant on left, and a broadcasted tef plant on right, both same variety; bottom, STI tef crop ready for harvest at Debre Zeit Research Station in Ethiopia.*

e. Mustard
(*Brassica nigra*)

India: Many farmers in Bihar state have begun adapting SRI methods for growing mustard -- also called ***rapeseed*** or ***canola***. Although its seeds are just 1-2 mm in diameter, when mustard is grown with more favorable management practices, the resulting plants and yields can be very impressive (see Figure 3 on page 5).

In 2009-10, 7 women farmers in Gaya district who cooperated with PRADAN and the government's Agricultural Technology Management Agency (ATMA) started adapting SRI practices to their mustard crop (SMI). Usual grain yields using broadcasting methods were 1 ton/ha; but with alternative management, their yield was tripled, to 3 tons/ha. The following year, 283 women farmers using SMI methods averaged 3.25 tons/ha. Then in 2011-12, 1,636 farmers, mostly women, got average mustard yields of 3.5 tons/ha.

Indeed, those who used all of the practices recommended for SMI averaged 4 tons/ha, while one farmer with best management reached 4.92 tons/ha as measured by government technicians. PRADAN calculated that with SMI, farmers' costs of production were reduced by about half, from Rs. 50 per kg of mustard oil seed to just Rs. 25 per kg. The SMI methods developed by farmers in Bihar are detailed in a manual produced by PRADAN based on experience there (PRADAN 2012c).

In the mountain states of Himachal Pradesh and Uttarakhand, mustard is the second most important winter crop after wheat. Accordingly, the People's Science Institute (PSI) in Dehradun ventured into applying SRI principles to mustard cropping in 2009 with the help of 68 farmers on 1.74 ha. The methods used were less intensive than those developed in Bihar: no transplanting with wide inter-plant distances; just direct-sowing in lines, 1 or 2 seeds per hill, with 15 x 20 cm spacing. Organic methods of soil fertilization are used, but only hand weeding is done, without any effort at soil aeration. Even with these less ambitious modifications of conventional practice, farmers had a 42% increase in grain yield, raising average yield from 1.4 tons/ha to 2 tons/ha. In 2010, the number of farmers increased to 227 farmers (10.34 ha), mostly doing line sowing.

A World Bank evaluation in Bihar state of India has reported an average increase in oilseed production of 50% using SCI methods, with the profitability of oilseed almost doubled, being raised by 93% (Behera et al. 2013).

f. Maize
(*Zea mays*)

India: Growing maize with SRI concepts and methods is still in its early stages. In northern India, PSI has begun working with smallholders in Uttarakhand and Himachal Pradesh states to improve their maize production with adapted SRI practices, which produce more robust phenotypes with maize as they do with rice. No transplanting is involved, and no irrigation. Farmers plant 1-2 seeds per hill with a square spacing of 30x30 cm, having added compost and other organic matter to the soil; and then they do three soil-aerating weedings. Some varieties they have found to perform best at wider spacing of 30x50 cm.

The number of farmers practicing SCI with maize in Uttarakhand went from 183 in 2009 to 582 in 2010, their area cultivated expanding from 10.34 ha to 63.61 ha in this time. The average SCI yield was 3.5 tons/ha, which was 75% more than farmers were getting with their conventional management, 2 tons/ha.

PSI has conducted on-farm trials of maize cropping in Uttarakhand to assess different spacings and plant densities. As seen from Table 1, the best results have been obtained from hills spaced 40 x 40 cm, each with just 1-2 seeds. Their yield was 6.5 tons/ha compared to 2.3 tons/ha from control plots using the usual practices. In another set of trials, where plant number was evaluated, 1 seed/hill gave an average yield of 6.1 tons/ha, compared with 5.3 tons/ha from 2-seed hills, and 2.8 tons/ha from farmers' practice (Table 1).

In Himachal Pradesh, SCI maize cultivation has also been promoted under a program supported by the Sir Ratan Tata Trust of Mumbai. The number of SCI maize farmers in two districts there, Kangra and Hamirpur, and the area cultivated under this program in 2011-12 are given in Table 2 (following page). These areas are much drier and have poorer soils compared to most areas in Uttarakhand. Nevertheless, the recorded gains in maize crop productivity through SCI methods have been 17% to 38%. Farmers' incomes were enhanced by even more because SCI reduced farmers' seed requirements.

Maize SCI in northern India has thus shown definite yield improvements from modifying management of farmers' land and seed resources. Improving soil organic matter is a critical factor given that poor households' soils are so often deficient in this material for improving the life in the soil.

Table 1: Maize yields with different plant spacings and numbers of seeds per hill, Uttarakhand, India, 2010

Plant geometry and spacing	*Ave. plant height (cm)*	*Ave. no. of grains/cob*	*Ave. cob length (cm)*	*Grain yield (t/ha)*
Square: 50 x 50 cm	185	322	25	5.7
Square: 40 x 40 cm	192	356	29	6.5
Square: 30 x 30 cm	187	297	23	5.8
Line sowing: 30 cm	193	255	20	4.8
Farmers' practice	155	191	17	2.3
No. of seeds/hill (hill spacing: 40cm row to row, and 40cm plant to plant):				
One seed	227	341	28	6.1
Two seeds	188	309	25	5.3
Farmers' practice	171	215	20	2.8

Table 2: SCI maize cultivation and yields in two districts of Himachal Pradesh, India, 2011-12

	2011		*2012*	
	Kangra	*Hamirpur*	*Kangra*	*Hamirpur*
SCI maize farmers (no.)	104	50	169	125
Area under SCI maize (ha)	4	1.1	15.12	17.86
Conventional yield (tons/ha)	-	-	2.09	0.96
SCI maize yield (tons/ha)	-	-	2.89	1.12
Yield increase (%)			38%	17%

Because maize is such an important food crop for so many millions of food-insecure households throughout Africa, Asia and Latin America, enabling them to get greater production from their limited land resources -- with their present varieties or with improved ones -- should be a priority for agricultural innovation and evaluations. This crop has already given indications that SCI adaptations can evoke genotypic potential under the wide range of ecological conditions where it is grown.

Some of the first efforts by farmers and NGOs to adapt SRI ideas and methods beyond rice were to other cereals, then to various legumes, and also to vegetables. These efforts began in a number of Indian states from 2006 onward at the initiative of PSI, PRADAN, AME, the Green Foundation, and other NGOs. In this same period, Ethiopian farmers in Tigray province working with the Institute for Sustainable Development (ISD) began experimenting with a similar range of crops. Since the most evident aspect of the new management practices was their wider spacing between plants, in Ethiopia the principles and practices have become known and communicated under the rubric of 'planting with space' discussed in section 5.

g. Legumes

India: In Figure 27 we see a farmer holding a prolific **pigeon pea** plant (*Cajanus cajan*) -- also called red gram -- grown with adapted SRI practices in Karnataka state in southern India. The Agriculture-Man-Environment Foundation (AMEF) based in Bangalore, which started promoting SRI for rice some years ago, reports that with these practices, pigeon pea yields are increased by 70%, from a usual yield of 875 kg/ha to 1.5 tons/ha (AMEF 2011).

A recent report from Karnataka describes how farmers with such methods are now getting even tripled yields from pigeon pea, as small transplanted red gram plants can grow up to have as many as 2,000 pods compared to the usual 50-100 pods per plant. Reducing the population of plants per m^2 thus has very beneficial effects on crop productivity. Although more labor is required for SCI crop management with pigeon pea, farmer incomes are reported to be greatly improved (Anon. 2013a).

Use of young seedling and wide spacing is being promoted for red gram by Department of Agriculture staff in Tamil Nadu state with a doubling of yield and with a crop cycle shortened from 160 days to 130 days, as seen in Fig. 28 (Ganesan 2013).

In central India's Madhya Pradesh state, the Aga Khan Rural Support Programme (India) began piloting, with mostly-tribal communities, the application of SCI principles to **soya beans** (*Glysine max*) in 2013. The main adaptation for this crop is wide spacing of seeds, 2 per hill at 45x45 cm distances, plus soil-aerating weeding and organic fertilization. Analysis of initial harvest results showed the yield with adapted SCI methods to be as much as 86% higher.

The phenotypical improvements in the soya plants that supported such yield increase were having: 4.2 times more branches per plant, 3.7 times more pods per plant, as many as 4.3 times more seeds per plant and 4% higher weight (grams per 100 seeds). Average dry matter per plant was 2.75 times greater. From calculations of the cost of production and revenue per acre, the increase in benefit-cost ratio with these alternative methods compared with farmers' traditional practice was 75-100% greater (AKRSP-I 2013).

The Aga Khan Rural Support Programme has worked in western India, in Dangs district of Gujarat state, with SCI **chick pea** (*Cicer arietinum*), also known as garbanzo beans or as *chana* in several Indian languages. The first and most evident change from conventional practice is to

Figures 27 and 28: *Top, visible effect of SCI practices on pigeon pea plants; bottom, red gram seedling nursery in Tiruchi, Tamil Nadu, where government technicians are now promoting SCI red gram as an intercrop with groundnut, facilitated by the one-month reduction in crop cycle for the red gram (Ganesan 2013).*

establish single plants at wide (50x50 cm) spacing, followed by 3-4 periodic weedings with a soil-aerating implement. Other new practices are regular use of a traditional organic pesticide known as *amrut pani* at 15-20 day intervals, and timely nipping (removal) of budding leaves to keep the plant from becoming too bushy. This directs the plant's nutrient supply to a limited number of branches so that these become more productive than if many branches are competing for nutrients.

Farmers observe the following effects with these changes in their practice:

- Much-reduced number of unfilled pods;
- Increase in the number of pods and number of grains per pod;
- Larger grains; and,
- Lesser attack of insect pests

Farmers report that the leaves of these better chick pea plants have a more acidic taste, which appears to discourage insect attacks. They have also observed the importance of soil health, enhanced by organic matter applications and good drainage so that the soil is aerobic. With increased soil organic matter in the soil, water is better retained so that the soil does not dry out so quickly and readily.

***Figures 29 and 30**: Top, chick-peas growing in Dangs district, Gujarat state of India – note differences seen in the size of the grains – conventionally-grown grains on the left, SCI grains on the right; bottom, an Ethiopian farmer in Gimbichu district holding up two lentil plants to show the increases possible in number of stems and number of pods per stem using SRI 'planting with space' methods. The plant on left was grown with conventional practices, the plant on the right with SCI practices.*

The programme recommends and provides farmers with an improved-variety of chick pea seed, so some of the productivity increase observed is attributable to genetic upgrading of the crop, but the expression of the variety's potential is enhanced by the management practices. Also, attention is paid to providing the plants with some micronutrient supplementation, potassium (potash) being a key element supporting pod formation.

The management changes make an evident make an evident different in crop performance, which farmers appreciate. This work is just getting started, but it indicates how different practices can enhance crop productivity. The extra labor invested in intensified management, to raise yields and improve plant health and resilience is well rewarded (Bhatt 2014).

In eastern India, the Bihar Rural Livelihoods Support Program has reported a tripling of yields from **mung bean** or green gram (*Vigna radiata*) when using SCI methods. Usual yields are about 625 kg/ha, whereas with SCI management, the average is 1.875 tons/ha on farmers' fields.

In northern India, PSI reports that with adaptation of SRI practices to the cultivation of various legumes, small farmers in Uttarakhand and Himachal Pradesh states are getting:

- 65% increase for **lentils** or black gram (*Vigna mungo*) – yields are being raised from 850 kg/ha to 1.4 tons/ha;
- 50% increase for **soya bean** (*Glysine max*) – yields go up from 2.2 tons/ha to 3.3 tons/ha;
- 67% increase for **kidney beans** (*Phaseolus vulgaris*) – yields rise from 1.8 tons/ha to 3.0 tons/ha; and
- 42% increase for **peas** (*Pisum sativum*) – yields go up from 2.13 tons/ha to 3.02 tons/ha.

No transplanting is involved with these legume crops, just sowing only 1-2 seeds per hill at much wider spacing than in conventional practice. The spacing varies by crop with the distances ranging from 15 to 30 cm between plants (hills), and 30 to 45 cm between rows. Two or more weedings are done, aerating the soil to enhance root growth and leaving the weeds on the soil surface as a mulch.

Soil fertility is enhanced with organic inputs, applying compost made from vegetative biomass and with some farmyard manure where available, augmented by a trio of indigenous organic fertilizers known locally as PAM (*panchagavya*, *amritghol* and *matkakhad*).

The first is a mixture of five products from cattle -- ghee (clarified butter), milk, curd (yoghurt), dung, and urine -- which is seen to improve plant vigor and health, possibly by stimulating the growth of beneficial soil organisms. Also, crop seeds are treated with cow urine before being planted, to make them more resistant to soil-borne pests and disease. These methods for promoting the crops' growth and giving them protection are actually rather old instead of new, having their origins in teachings and texts from the Vedic era (1200-500 BC).

These intensive production strategies for legumes as well as for vegetables require little or no cash expenditure. Poor, resource-limited households are necessarily seeking to get the maximum yield from the very small areas of land that are available to them. The resulting SCI crops they find to be more robust, more resistant to pest and disease damage, and less affected by adverse climatic conditions.

A World Bank evaluation of SCI in Bihar reported average yield increases for pulses of 56%, and profitability increases of 67% (Behera et al. 2013).

A further element of intensification has been the *intercropping* of legumes such as lentil with SWI wheat, replacing some rows of wheat with pulses. The soil benefits from nitrogen fixation done in the legumes' roots, while households can attain greater income and/or have a more diversified diet.

h. Vegetables

India: Similar SCI experimentation has been done in different states with a variety of vegetables and with similar results. In Uttarakhand, farmers working with PSI have had some good results with **tomatoes** and **French beans**, and also the oilseed crop **sesame**.

The most extensive support for farmer applications of SCI methods to vegetable crops has occurred under the aegis of the Bihar Rural Livelihoods Promotion Society (BRLPS). This agency, known as JEEVIKA, works as an arm of the Bihar state government with financial support from the World Bank's IDA. NGOs such as PRADAN lead the field operations undertaken by local NGOs that interface with women's self-help groups which need to and want to raise their households' production of vegetables (Figures 5 and 6, page 9).

Women farmers in Bihar have experimented with transplanting young vegetable seedlings widely. They place the roots of the seedlings carefully into pits that have been dug deeper than the length of the roots and are then filled with loose soil and organic soil amendments, particularly vermicompost. Water is used very precisely and carefully. While this system is indeed labor-intensive, it greatly increases yields and hence the benefits to households, especially the very poorest ones that have access to only a little land and water. These farmers need to use their limited resources with maximum productivity, making little or no cash expenditure.

BRLPS has concluded from farmer experiences with these more agroecologically-based management methods: "It is found that in SRI, SWI & SCI, the disease & pest infestations are less, use of agro chemicals are lesser, [crops] requires less water, can sustain water-stressed condition; with more application of organic matter, yields in terms of grain, fodder & firewood are higher." (BRLPS 2011; see Table 3 on following page).

These vegetable systems of crop management are each a little different from one another, in order to fit to the respective plant characteristics and needs. But all have gotten their impetus from hearing about or seeing the results of farmers working with the System of Rice Intensification (Dash and Pal 2011). A World Bank evaluation of project impact in Bihar state reported an average vegetable yield increase of 20% with SCI methods on an area basis, with profitability increased by 47% (Behera et al. 2013).

Table 3: Differences in vegetable yields between SCI and conventional practices, Bihar, 2010-11

Crop	Unit	No. of small-holders	Conventional practices	SCI practices	Increase
Chilies	kg/plant	69	1.5-2.0	4.5-5.0	170%
Tomatoes	kg/plant	168	3.0-4.0	12.0-14.0	270%
Eggplant	kg/plant	42	5.0-6.0	10.0-12.0	100%

Source: BRLPS (2011)

With upland crops, there is no reduction in the flooding of fields through SRI-type irrigation management because water supply comes from rainfall. There is little opportunity for any direct application of water during the dry season unless steps have been taken to create some supplementary supply of water. Farmers are encouraged to invest labor and possibly some cash in simple kinds of water harvesting, such as catchment ponds, thereby creating in-field capacity for water collection and storage (Box 2, page 51).

An important part of the strategy is to loosen the topsoil through weeding, thereby enabling both water and air to enter the soil, both promoting root growth and the abundance of aerobic soil organisms.

In the same village in Bihar state of India where a new world-record yield for paddy rice was set in 2011 using SRI methods (Diwakar et al. 2012), a farmer also set a new world record for potato yield that year, 72.9 tons/ha, surpassing the previous record of 45 tons/ha set in the Netherlands (Patna Daily 2012). The potatoes weighed 1 kg each (Figure 33, following page), The farmer got ideas for his innovative potato growing from his neighbors who were practicing SRI (see Box 1 on page 35).

Recently, SCI methods have been extended to improving the production of **elephant foot yam**, an important root crop in Bihar and other parts of South and Southeast Asia. Farmers' yields are usually in the range of 20 to 30 tons/ha. Following recommended practices from the state agricultural university, including inorganic fertilizer applications, this level can be pushed up to 50 to 60 tons/ha. In 2012, two farmers who adapted SCI practices to elephant foot yam were rewarded with an average yield of 102.3 tons/ha.

Huge yams, much like huge potatoes, have the liability of being less marketable than more convenient, smaller-sized tubers. But to meet some households' current needs as well as the greater general food needs in the future, these options could become important for future food security. They show what potential there is for greater output.

Figures 31 and 32: *Top, vegetable seed sowing in a farmer-participatory SCI trial with green leafy vegetables in Ibadan, Nigeria; bottom,* Corchorus olitorus *(jute mallow) with SCI management at Ajibode, Ibadan, Nigeria.*

Nigeria: Green leafy vegetables are often overlooked in considerations of how to improve vegetable production, even though these are very important parts of people's diets in much of Africa and many parts of Asia, and particularly in the Caribbean and Pacific Islands. The leaves and shoots of Celosia argentea, a member of the amaranth family, as well as the leaves of a mallow plant, Corchorus olitorus, whose fibers are used as jute, are eaten in Nigeria and other parts of the forest zone of West Africa. Poor soil fertility is known to limit the yields of these crops, but SCI experience is showing that production is constrained also by planting these crops too densely.

A research team led by Dr. Olugbenga AdeOluwa in the Department of Agronomy at the University of Ibadan, after becoming acquainted with the ideas and principles of SRI and SCI, began experimenting with SCI methods for Celosia and Corchorus. These leafy vegetables are consumed for their high content of protein and dietary fiber, as well as for high levels of vitamins and minerals, particularly iron, calcium and magnesium.

The experimental variables evaluated in initial trials on farmers' fields and with active farmer participation were seeding rate (26 kg/ha as a high rate and 13 kg/ha as a low rate) and fertilization of the soil (with or without poultry manure extract). Celosia yields usually range between 16 and 28 tons/ha. Using the lower seed rate, with wider spacing between plants, gave by far the best fresh-weight harvest, 54.7 tons/ha, almost the highest yield ever recorded.

Corchorus yields are generally not as high as with Celosia, but the same positive response was observed when plant population was reduced with organic soil amendments and active soil aeration provided, breaking up the soil with a weeder. Poultry manure extract was seen to increase both the fresh weight and dry weight of the plants. With this extract and the low seed rate, the marketable fresh leaf harvested was 12.24 tons/ha. This was 40% higher than the 8.82 tons/ha achieved with the high seed rate. The revenue resulting from the high seed rate was calculated to be $5,880 per hectare, compared to $8,160 with the low seed rate. Reduction in seed rate was thus definitely advantageous for households following SCI principles (AdeOluwa et al. 2013).

BOX 1: RECORD YIELD FOR POTATO PRODUCTION

One farmer in Darveshpura village, Nitish Kumar, with the same name as Bihar's Chief Minister, produced a world-record potato yield in 2012 of almost 73 tons/ha, surpassing a previous record yield of 45 tons/ha reported from the Netherlands (IANS 2012).

After learning of this success, Anil Verma visited the farmer to discuss his potato production methods. Kumar's practices featured:

- Extracting the 'eyes' from the seed potatoes, treating them with a chemical solution, and sprouting them before planting;
- Wider spacing between plants than usually provided;
- Good pulverisation of the soil, so that the roots could grow easily;
- Use of both organic and inorganic fertilisers--vermicompost, poultry compost, and NPK; and
- Intercultivating between rows and plants two times, to loosen the surface soil.

These practices contributed to having a well-aerated, organically-rich environment around the roots, with room for both roots and canopies to grow.

The soil we should note was relatively rich in silicon, an element often neglected. Although not considered as a nutrient, it is essential for plant growth. Like other farmers in the village, Kumar acknowledged having been influenced by the new knowledge coming into his village from SRI training, and his practices represented an adaptation of agroecological principles.

Figure 33: *Chief Minister Nitish Kumar of Bihar State, India, holding 1-kilogram potatoes grown in Darveshpura village, Nalanda district of his state.*

5. Planting with Space

Figure 34: Wide spacing of rice plants in a grid pattern -- a hallmark of SCI methods -- is clearly visible in this picture of an Indian farmer weeding her SRI rice field with a mechanical weeder.

As noted already, the Institute for Sustainable Development (ISD) in Ethiopia works with farmers who are dependent on rainfed production, having small parcels of land ranging between less than a quarter of a hectare and half a hectare. Most live and farm in drought-prone areas of northern Tigray and South Wollo provinces, although some are in better-endowed areas nearer to Addis Ababa.

Following from the farmer experimentation that started in 2003, when finger millet was first established by transplanting seedlings as discussed on pages 13-15, ISD has had little difficulty in getting support from farmers and local extension staff to adapt SRI/SCI ideas to other crops. Ethiopian farmers have found this strategy, referred to as 'planting with space,' easy to comprehend because it builds on some of their traditional experience in growing vegetables (Araya and Edwards 2011; Araya et al. 2013).

Crops whose yields have been substantially improved by such practices have included both **cereals** (tef, durum wheat, barley, maize, and sorghum) and **legumes** (faba bean and lentils – see Figure 30 on page 30).

Optimally-wider spacing between plants proves able to raise crop productivity so long as the soil is well-supplied with organic matter, enabling both rainwater and air to enter the soil more easily through pore spaces. Also, soil moisture is retained in the humus component of soil systems managed this way.

Crop establishment and fertilization: For a number of crops, Ethiopian farmers are now either transplanting young seedlings or sowing seeds directly in rows, with wide spacing between the rows and between the plants in each row.

Farmers make and use compost, which is now being promoted as part of the government's extension package for all crop-growing areas, either to be used alone or with small amounts of chemical fertilizer.

Starting in 2012, through the Agricultural Transformation Agency (ATA), all smallholder farmers are being strongly encouraged to change from their traditional broadcasting system for sowing, to planting seeds or seedlings in rows.

Figure 35: *Farmer Abbadi in Ethiopia demonstrating the use of a European-style weeder/digger that can control weeds and break up the topsoil between plants when they are being grown by 'planting with space' methods.*

Weed control: Weeds are managed by digging up the topsoil with a fork or some other implement that also aerates the soil. ISD has introduced hoes that slice through the roots of weeds and break up the surface crust (Figure 35). However, reliable local manufacturers of such hoes have not yet been established. Farmers are finding their traditional pronged forks adequate for the task, although not the most efficient tool.

The weeds uprooted by this process are collected by farmers, mostly to provide animal forage because grazing is highly restricted during the growing season. Some weedy species such as amaranth and wild-type brassicas are gathered to be cooked up as greens for the family to eat.

Intercropping strategies: Particularly farmers who have access to local urban markets are starting to use the space between their smaller cereal plants (such as finger millet and tef) to transplant and grow selected vegetables that either mature before the main crop reaches flowering stage, e.g., head cabbage, or that can continue to grow after the cereal crop has been harvested, such as chilies and tomatoes. All farmers follow the ideas of using young seedlings with wide spacing, increasing organic fertilization, and promoting soil aeration.

The yields and economic returns from these innovations in intercropping have not been systematically documented. But farmers find that they can get more income from their inter-planted chilies and tomatoes than they earn from their cereal crop because these vegetables are ready for market before the vegetables of other farmers are ready. The latter are planting their irrigated crops only after the rainfed growing season has ended. Such intercropping can be quite profitable, as well as beneficial for the soil.

Experience with specific crops: This varies across different crops but the general pattern of beneficial phenotypic responses of crops to 'planting with space' as a version of SCI is quite consistent.

- ***Tef***: Farmers who have cooperated with ISD on this crop (reported on in section 4d) quickly adapted to sowing tef seeds in rows 20 cm apart. They mix the seed, which is very small (2500 per gram), with either sand or compost in the ratio of 1 to 3 so that they can better manage sowing the seeds spaced farther apart in the 'STI-lite' management system described earlier. By the 2012 growing season, over 90 farmers in the Axum area had adopted this method for their tef cultivation.

  Near Addis Ababa, a model farmer producing high quantities of compost from bioslurry has designed a tool for tef row planting based on a funnel that has an opening the exact size to let out one seed at a time. This farmer can harvest around 4.5 tons of tef seed per hectare and can sell it at a premium price, 12% higher than the usual farm gate price, because of its evident quality. He has completely discontinued the use of chemical fertilizer, thereby reducing his costs of production.

- ***Durum wheat***: In 2009, there were initial promising results from applying SCI concepts to this crop in demonstration plots in two provinces. In Tigray, seven farmers obtained an average yield of 5.45 tons/ha, with one of them achieving the equivalent of 10 tons/ha. But SWI has not become an established practice in this area because wheat is not as important a crop in Tigray as are tef and finger millet. So farmers have preferred to invest their labor in these crops rather than in wheat.

  In Gembichu, on the other hand, where growing durum wheat is popular, 21 farmers and 5 farmer training centers have experimented with SWI on 4-m^2 plots. Their yields have ranged from 1.25 tons/ha (the national average) to 8.5 tons/ha, a huge increase, with most of the farmers (17) getting over 2.5 tons/ha, which was double their normal yield.

  On SWI plots, Gembichu farmers have counted up to 35 tillers on a plant, with each spike having between 50 and 60 seeds. Plants in broadcast-sown fields normally produce a maximum of 5 tillers per plant and between 35 and 40 seeds per spike (see Figures 19 and 20 on page 20).

Lack of funding has prevented ISD from continuing its work on wheat with Gembichu farmers. But another local NGO, Ecological Organic Seed Action (EOSA), is now working with them. It reports that farmers are making and using high quantities of compost, around 8-10 tons/ha, and have taken up row planting as a standard practice after seeing these positive initial results.

- ***Lentil***: Gembichu farmers have also experimented with SCI management for this legume, their next most important commercial crop after durum wheat. In a normal rainy season, an improved variety of lentil yields about 1.8 tons/ha. The 2009 rainy season was not a good one for lentil or other crops, as the rains started late and stopped early. Even so, 7 farmers who experimented with wider spacing and row planting got an average yield of 1.27 tons/ha in that year despite the drought, with the best farmer obtaining 2.12 tons/ha. All the farmers using the new methods observed that their lentil plants had increased numbers of branches per plant and set more pods from the bottom up to the top of each branch (Figure 31, page 31).

- ***Barley***: Barley being deeper-rooted than wheat is generally more drought-resistant. The first SCI yield recorded for barley was from Gembichu district in the very dry 2009 season, when a farmer who used SCI methods for this crop got an unprecedented yield of 13.2 tons/ha, much higher than achieved for wheat, which gave a yield as high as 8.5 tons/ha with SCI management in the same area.

  Barley is the most important crop in the drier parts of eastern Tigray where it too is being developed through 'planting with space' ideas, responding very well to this alternative management. One problem encountered was that the first barley plot established with transplanted seedlings had its yield decimated by birds because the SCI plants matured earlier than the other crops. However, it was seen that the barley plants had developed up to 20 tillers per plant, and what was left of the ears showed them to have well-developed plump grains. It is no wonder that the birds feasted on them!

  Another farmer's field of barley with direct-seeding in rows 20 cm apart produced a yield of 2.3 tons/ha, compared to one neighbor's broadcast field of only 300 kg/ha and 700 kg/ha from the field of another neighbor. A second farmer in Mai Abyi who transplanted his barley seedlings with wide spacing got a yield of 5 tons/ha, showing the potential of this methodology.

All the data reported here are from 2010, when ISD had funding from Oxfam America and was able to promote SCI with the NGO REST (Relief Society of Tigray). Unfortunately, ISD has not been able to monitor SCI impacts with barley since then.

- ***Other crops***: In the Aksum area of Tigray and in South Wollo where SCI is becoming standard practice, farmers are making their own recommendations for SCI adaptation, particularly on spacing and on direct-seeding vs. transplanting.

  For larger-seeded crops such as maize, sorghum and faba bean, they prefer direct seeding, because the larger seeds are easy to handle precisely, and they observe that the roots of these plants quickly penetrate into the soil and can get easily damaged during transplanting. For these crops, spacing of up to 75 cm between rows and 45 cm between plants in the row is recommended by the farmers.

  Direct seeding is preferred also for wheat and barley crops because their seedlings are considered to have 'soft,' easily damaged leaves compared to those of finger millet and even tef, which are more suitable for transplanting. Farmers generally establish these crops with spacing of about 20 cm between rows and 15 cm between plants in each row. This greatly reduces plant populations.

ISD now has yield data for most of these crops from 2009 to 2012. Overall, the application of SCI management in Ethiopia is resulting in both grain and straw yields doubling. And as described earlier for tef, the government's Agricultural Transformation Agency (ATA) is now strongly promoting that farmers change from broadcasting to row planting for all their field crops. Although the ATA is promoting the use of chemical fertilizer, ISD has found that most farmers are increasingly making and using compost. This enables them to greatly reduce the amount of chemical fertilizer that they need, or even to give up using fertilizer altogether.

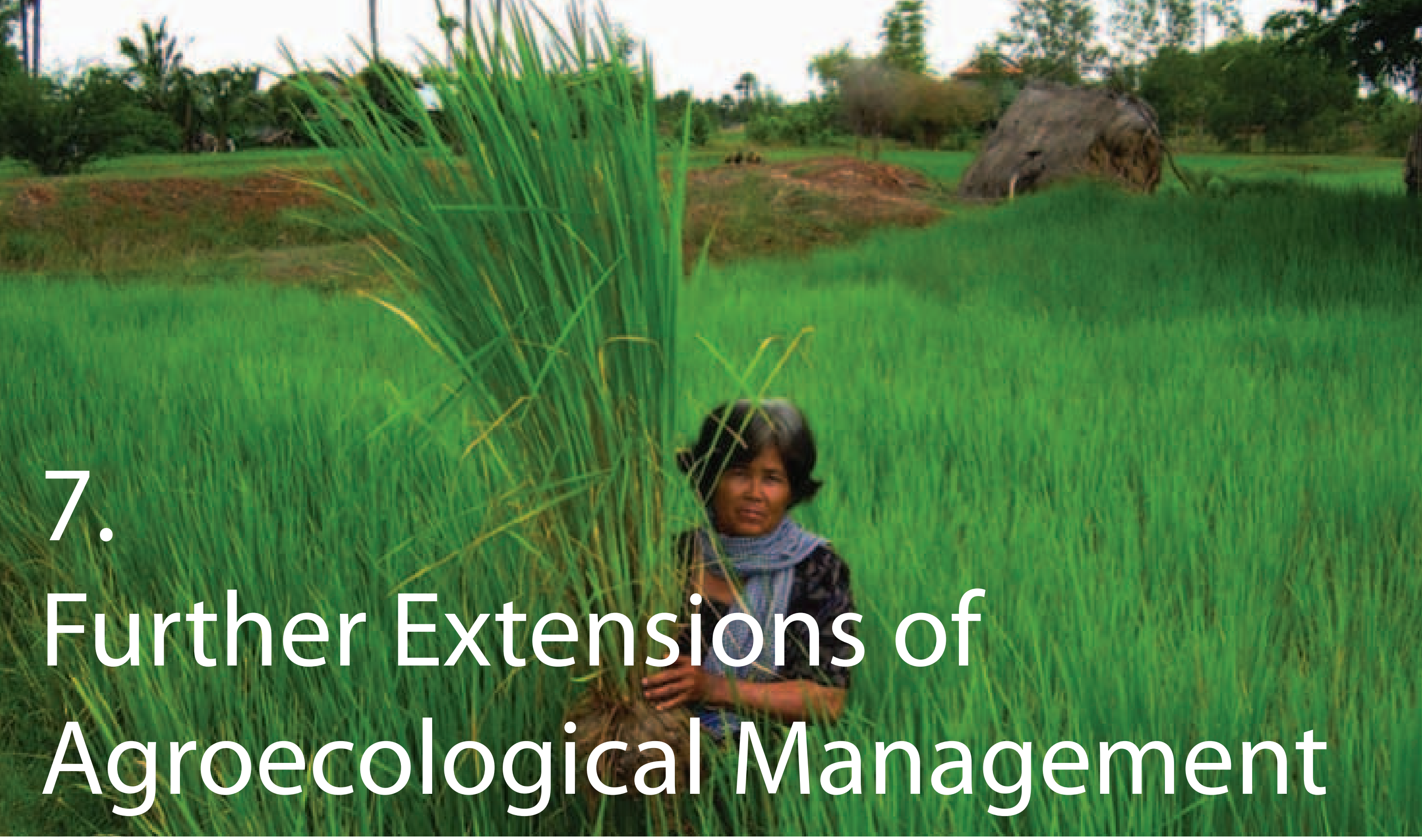
6. Wider Applications and Adaptations of SCI

Figure 36: Ethiopian farmer Nigussie and his family transplanting finger millet seedlings between their rows of head cabbage adapting SCI practices to intercropping for higher income and better nutrition.

That SRI principles and methods developed for raising the productivity of irrigated rice cultivation could be extended to wheat, finger millet, sugarcane, maize, and even tef, may not be especially surprising since these plants, like rice, are all classified botanically as grasses. These members of the *Gramineae* (or *Poaceae*) family are all characterized as **monocotyledons** (monocots) because they have just one embryonic leaf in their seeds, rather than having two. The tillers and stalks of monocots grow upward from a ground-level crown, from which the plant roots concurrently grow downward.

That mustard, legumes and various vegetables would also respond so well to SRI management practices was unexpected because they are **dicotyledons** (dicots). Such plants start with two embryonic leaves in their seed and grow differently from monocots. They have stems and leaves that branch off from a primary above-ground stem, while a primary (tap) root grows downward with secondary and tertiary roots branching off from it, similar to the observable above-ground branching. Monocots, in contrast, put out a welter of adventitious roots, all having a similar structure.

That SRI management practices can benefit both of these groups of crops, promoting the growth of legumes and vegetables as well as a great variety of cereal plants, makes SCI innovations all the more interesting scientifically. It presents an opportunity for scientists to conduct detailed experiments in order to derive agreeable explanations. In practical rather than just theoretical terms, one would like to know to what extent these proposed modifications for SCI crop management can broadly improve 21st century agriculture across a wide range of crops.



7. Further Extensions of Agroecological Management

Figure 37: *Mrs. Im Sarim of Pak Bang Oeun village in Cambodia holding up a rice plant pulled up at random in the middle of her paddy field. Before she started using SRI methods, her usual paddy yields from this field were 2 to 3 tons/ha. With SRI management, she harvested 333 kg from her 500 m2 field, a yield equivalent to 6.72 tons/ha. A crop-cutting in the best part of her field that year gave 1.1 kg from 1 m2, representing a yield of 11 tons/ha. Encouraged by these results, she and her neighbors began experimenting with SRI ideas for other aspects of their agricultural production, notably chicken raising, as discussed in c. below.*

As SRI ideas and impacts have become more widely known among farmers, we have seen some novel extensions of SRI principles and practices to very different kinds of crops than rice (or wheat, finger millet, sugarcane, etc.). Here we report on three quite unexpected extrapolations from SRI experience to a rhizome crop, an entomological (insect) product, and even to chicken rearing. The Cambodian farmer shown above reported on 'chicken SRI' to Koma and Uphoff in 2005 when they visited her village together. This sparked the realization that SRI principles could be extended well beyond rice.

a. Turmeric intensification

Where this process of innovation will end, nobody knows. But growing numbers of farmers are gaining confidence in their ability to get 'more from less,' providing more adequately for their families' food security while enhancing the quality of their soil resources and buffering their crops against the temperature and precipitation stresses of climate change. One initiative has come from the Thumbal SRI Farmers Association in Salem district of Tamil Nadu state in India. Its members have adapted SRI ideas to the production of a rhizome crop, turmeric (*Curcuma longa*).

Farmers have designated this methodology as the System of Turmeric Intensification (STI). They start by reducing their planting material by more than 80%, using much smaller rhizome portions to start their seedlings. When the seedlings are large enough to transplant, these are replanted at 30x40 cm spacing instead of the usual 30x30 cm distance.

Organic means of fertilization are applied to the soil: green manure plus vermicompost and soil inoculations of beneficial microbes such as *Trichoderma* and *Pseudomonas*. A microbe 'cocktail' patented as Effective Microorganisms (EM) is also used. The water requirements for growing turmeric are reduced by two-thirds with STI.

With this management, crop yields are increased by 25%. While this is not as much as with some other SCI production, farmers' costs of production are lowered by 21%. The net result is that their income from turmeric crop can be practically doubled. An instructional manual and a cost-benefit analysis for this innovation have been developed by the president of the Thambal SRI Farmers Association (Baskaran 2012).

Farmers in Cambodia have reportedly applied SRI ideas also to their production of ginger, another rhizome crop; but we have no detailed information on this.

Figures 38 and 39: *Top, president of the Thambal SRI Farmers' Association in Salem district, Tamil Nadu, India, P. Baskaran, showing the mixing of organic inputs with coco-peat for filling the cups in which turmeric seedlings are grown for use in STI turmeric production; bottom, STI turmeric seedlings being planted in a field in wide spacing, supported by drip irrigation, in Thambal village, Tamil Nadu.*

b. Lac intensification

Outside of producing areas in Asia and Mexico, few people know much about the source of the natural raw material known as lac, which is used for making lacquer, varnish and shellac paints and for lacquer carvings and jewelry (RCDC 2010). This is an entomological product from lac insects, which are members of the large family of scale insects *Coccoidea*. Their mouthparts pierce through the bark of trees or shrubs to feed on the sap, and they secrete a resin, which can be collected by scraping it off the bark (Abraham 2012). Once purified, this resin can be used in various products. In the traditional system of lac harvesting, the resin is collected only once during each growth cycle of the lac insect, which dies soon after it has laid its eggs.

One of the main current sources of demand for lac is to make an organic spray that can be used to thinly coat the surfaces of fruit like apples and pears, keeping them from becoming dehydrated during their shipping, storing and display in stores. At present, world demand exceeds supply, so the price is rather favorable; the farmgate price paid to peasant resin collectors is currently about $10 per kg.

Collection of lac, very labor-intensive, is done by only the poorest of the poor who have low opportunity cost for their labor. Fortunately, lac can be produced on land areas that are too poor for agricultural production, since the trees and shrubs needed to rear and harvest resin from the bark-piercing insects can grow almost anywhere, even in very dry regions.

Jharkhand state of India is the world's leading source of lac, as poor farmers and landless households there can collect lac resin from trees and shrubs scattered over that state's extensive wasteland areas. These areas are common property and not privately owned and controlled.

In Jharkhand, peasant farmers and household members working with the NGO PRADAN, most of them ethnic tribals, have begun extrapolating what they had learned from using SRI methods for their rice production to this important supplementary activity for increasing family incomes.

Since lac is produced by insects, in a process that is fundamentally different from the planting and transplanting of rice seedlings, it took considerable imagination to figure out how SRI ideas and practices could enhance their lac production. Jharkhand farmers have adapted three of the SRI concepts to raise their lac productivity (Abraham 2012).

1. ***Reduced populations***: Farmers have found that they can get as good, or even better, production of resin by reducing their bark inoculation rate by 80%, compared to the rate that they have used traditionally. Like rice farmers, lac cultivators had come to believe that by increasing the number of larvae per square meter of bark they could increase output, but concentrating many insects on a given area of bark compromises their health and their productivity.

   Tribal farmers have learned they can raise their yield of resin by reducing the number of insect larvae that they transfer to new bark areas. Coincidentally, this reduction is about as great as is recommended with SRI for reducing the number of transplanted rice seedlings per m^2. This reduction enables lac collectors to greatly expand their scale of production because under SLI management they have 4 times more inoculation material available to apply to the bark areas.

2. ***Earlier transplanting***: Normally, when lac insects are cultivated, farmers remove the bark that the insects inhabit when their larvae first begin to hatch and come out onto the bark. This bark is then grafted onto a new area of tree or shrub stem. Prompted by their SRI experience, however, farmers now know that they can boost their production by 'early transplanting' of the inhabited bark, doing this about 10 days before the larvae begin to emerge.

Figures 40 and 41: *On top, a farmer showing resin excretions of lac insects with the locally-devised System of Lac Intensification in Khunti district, Jharkhand state, India; on bottom, mature lac ready for harvest on a kusum tree.*

With 'early transplanting,' there is little or no loss of larvae during the transfer process while the eggs are still unhatched in the bark. Once larvae begin to emerge, some are lost during their movement to a new habitat.

Most important, early transfer usually permits farmers to make a second collection (scraping) of resin during the growth cycle. These two effects considerably enhance farmers' incomes.

3. ***Wider spacing***: Traditionally, lac farmers inoculated the bark of trees, until they found that inoculating the bark of shrubs instead of trees gives them better productivity per hour of labor. Shrubs can be planted much closer together than trees that grow naturally in the wild, and shrubs' multiple shoots give farmers more bark surface area that can be inoculated. This enabled collectors to reduce the time spent walking from tree to tree to monitor the condition of the lac insects and to collect the resin.

   But farmers have now realized from their SRI experience that they have been planting their shrubs too closely together, thinking that more plants would give them more bark area to exploit. With wider spacing between shrubs, as between rice plants with SRI, they find that the shrubs produce more branches on a per-square-meter basis. This enables them to 'farm' the lac insects more intensively. More widely-spaced shrubs are healthier and can better support their (parasitic) populations of insects, presumably because larger and deeper root systems enable them to produce more sap to support the insects.

   Collecting lac secretions, seen in Figures 40 and 41, requires no capital investment, just labor and skill. There is no need for land ownership as the insects' production is quick and moveable. However, having some security of land tenure could encourage better husbandry of the shrubs that support the insect populations.

Lac production is well suited for poor households living in environments with poor soil and even little rain. If the demand for 'organic' products worldwide continues to increase, there are good economic prospects for this commodity, which synthetic alternatives have not succeeded in displacing thus far. Labor productivity and returns from traditional lac production methods were always very low. SLI concepts are now making both the land and the labor involved more productive.

C. Chicken intensification

Possibly extending SRI ideas to poultry is even more unexpected than using them to improve entomological production. In Cambodia, farmers in Pak Bang Oeun village in Takeo province were among the first to begin working with CEDAC, the Center for Study and Development of Cambodian Agriculture, to introduce SRI methods with rice.

When Koma and Uphoff, respectively the directors of CEDAC and CIIFAD, visited this village in March 2005, farmers there who were using SRI methods, including Mrs. Im Sarim (Figure 37, page 42), explained how they had begun to use SRI ideas to increase their chicken production!

The farmers said that they now understand the value of making compost for their paddy fields. Households each have a compost pile near their homes to decompose food waste, kitchen scraps, plant residues, etc. Someone got the idea of putting bamboo fences around these piles and putting their free-ranging chickens inside the fences. There they can feed on insects and grubs in the decomposing organic matter, but they also then deposit their manure in the compost, which is a win-win situation for both chickens and farmers.

Most important, during hot summer months when free-ranging chickens suffer from heat stress and lack of water, getting sick and some even dying, households can easily keep their chickens well watered and healthy by giving them water within the enclosure.

Farmers told Koma and Uphoff that with this intensive system of management they do not lose any chickens to dogs or any to wild animals or to thieves. "With fewer chickens that are well-managed, we can produce more meat and more eggs. This gives us more from less, just like SRI," one farmer explained.

Chicks are kept with their mother for up to 2 weeks before separation, and water supply is changed daily, while the ground within the enclosure is regularly cleaned. Local herbs are used as medicines to prevent or cure diseases, and the chicken manure is used to grow more fodder for feeding the chickens. These are low-cost solutions to different challenges in traditional chicken rearing.

This example shows how SRI insights are contributing to a way of thinking about agriculture that rediscovers the potency of better management practices using farmers' own, locally-available genetic and other resources, so as to enable plants and also animals to give fuller expression to their genetic potentials for various products, even including meat and eggs.

Some of the specific practices evolved by Cambodian farmers have been to fence in the chicken pens, in which the compost pile is maintained and built up, by growing trees and shrubs as live fencing. This creates a more natural and healthier living environment for chicken rearing.

Achieving greater productivity from individual crops or commodities is important for farming households. But we need to keep in mind that families depend for their well-being on their ***whole farming systems***, not just on any one component of these systems.

8. Applications of Agroecological Thinking and Practice

a. Diversification of small-holder farming systems

Figure 42: View of the farm of Roas Mao in Takeo Province of Cambodia whose farming system has been diversified and intensified on the basis of SRI productivity gains. The net annual household cash income from his farm (0.48 ha) has been raised from $72 to $735, with an investment of just $112, as detailed in Lim (2007). Two of his five children now work on the farm with incomes more than they would earn from working in Phnom Penh if they migrated there.

In Cambodia, farmers working with the NGO CEDAC have very small landholdings, on average about 0.66 ha. With CEDAC encouragement, farmers have started capitalizing on productivity gains that SRI management can bring to their rice fields by reorganizing, diversifying and intensifying their rice-based farming systems. Once SRI enables them to double or triple their previous paddy yields, farmers can take 30-50% of their paddy land out of rice production and reassign it to other uses. They are now able to meet or exceed their households' staple food needs by using SRI methods on their remaining rice area (Lim 2007).

The first step for such diversification is constructing a ***farm pond***, about 10x15 m in area and 2-3 m deep. This can capture water during the rainy season and store it into the dry season. Fish, eels, frogs and other plants and animals are raised in the pond and canals, which provide water and liquid manure that can make the rest of the farmed area more productive (see Indian example on page 51).

A great variety of crops and livestock are grown on the remaining area: tomatoes, eggplants, watermelons, cucumbers, pumpkins;

mung beans and other legumes; bananas, papayas and other fruit trees; sugarcane, cassava and maize in upland areas; as well as chickens, pigs and/or rabbits.

Ponds and canals in the rice fields serve a number of functions. During the early monsoon, they help farmers to drain excess water from their rice fields, so that young seedlings will not suffer from too-high water levels. During any short dry periods within the monsoon, water from the pond can be used to irrigate the young rice plants so that they can withstand the stress of insufficient water.

Frogs and fishes living in the ponds and canals help control insects during the growing season. During the late monsoon, when the rice starts to flower with shallow flooding of the paddy, the frogs and fish move from the ponds into the rice fields, where there is plenty of food for them. During the grain-filling phase, fields are kept covered with just a few centimeters of water to ensure sufficient water supply for producing full grains. Once the crop is ripe, the fields are drained for easier harvesting of the rice; at this time, fish and frogs can also be harvested, augmenting household income and food supply.

Details on cropping, land use and investments made from the experience of five innovative but representative farmers are given in Lim (2007). These farmers' household incomes were tripled on average, with households' cash income rising from an equivalent of $200 per annum to $600. The average capital investment required for this improvement was only about $300, so it could be made incrementally over several years, with no need for credit or loans.

Apart from these monetary gains, Cambodian households appreciate the diversification and enrichment of their diets which this redesigning of their farming systems makes possible. They feel, and are, much more secure when they have multiple sources of income that bring in at least some cash income every week of the year.

Household food security no longer depends just on their seasonal rice harvests with one or two peaks of income during the year. This kind of intensification can create paid employment opportunities in rural areas that make migration to urban areas less necessary. Households can remain intact, not fragmented by economic necessity.

Farmers following agroecological management in Cambodia further report improvements in their soil and water quality, with less build-up of synthetic chemicals. Such diversification based on farming system intensification will not meet the needs of all rural households, e.g., it requires at least some access to irrigation or sufficient rainfall to fill the farm ponds. But the productivity of rather small cultivated areas can be greatly enhanced by this kind of intensified agroecological management.

BOX 2: PRODUCTIVE REDEPLOYMENT OF RESOURCES IN INDIA

A similar agroecological strategy has been developed by PRADAN working in upland areas of eastern India. Working with farmers, this NGO has developed a low-cost water-harvesting technology called 'the 5% model' that complements the innovations in crop management (SRI and SCI) that it is introducing in the region (UNEP 2012).

PRADAN encourages farmers to take 5% of their rainfed paddy land out of production in order to dig a catchment pond that can trap and store some of the water that runs over their fields during monsoon rains.

This enables farmers to provide supplementary irrigation when their crops come under water stress for lack of rainfall or low soil moisture later in the season. It also increases percolation into the soil that augments water availability downstream. The loss of cropped area is more than compensated for by the higher yields achieved.

An investment of Rs. 80,000 (1,775 USD) per hectare can increase food security for as many as 7 households by 20-30%, and can raise family incomes by 10-25%, depending on the crop mix. Farmers working with PRADAN staff, as seen for a number of crops reported on in this monograph, have been quite innovative in extrapolating their SRI experience to improving productivity of other crops.

b. Mechanization in larger-scale farming systems

Most applications of SCI ideas and methods have focused on raising the productivity of smallholder agriculture, as reported above. Accordingly, it has been mistakenly assumed by some that agroecological innovations are of limited relevance in the contemporary world with its spread of large-scale, mechanized production. Presently, much of the food supply that reaches markets for feeding urban populations and non-agricultural households comes from large and medium-scale commercial operations.

However, agroecological principles and practices being biologically based are relatively scale-neutral and can be adapted to larger-scale production, as has been shown in the Punjab province of Pakistan (Sharif 2011). There, the relatively high cost and limited availability of agricultural labor has created barriers for the adoption of any methods that seem to require much labor. Mechanization of production practices has become dominant in much of the agricultural sector in Pakistan.

Sharif, a farmer and businessman whose career had been focused on agricultural mechanization (he was the first farmer in Pakistan to laser-level his fields as a water-saving measure), became interested in SRI methods for improving rice production in his area because of its lower requirement for water. Water is the starkest constraint on farming in Punjab.

At the same time, Sharif was interested in adopting conservation agriculture (CA) because he saw the damage that was being done to his region's soil systems from continuing tillage, heavy applications of chemical fertilizer, over-irrigation of fields, and lack of ground cover that could protect the soil from erosion and from superheating by the intense sunlight. All of these stresses are complicated by the salinization of Punjab soils.

To reverse the deterioration of these soils and their declining crop yields, Sharif took steps to halt: 1) repeated plowing; 2) excessive use of water; and 3) leaving the soils bare during the summer months. These practices result in loss of organic matter from the soil, lowering its capacity for water-absorption and water-retention as well as its retention of plant nutrients that can become available over the life cycle of the crop.

Accordingly, machinery was developed as explained in Sharif (2011) that could quickly and cheaply construct permanent raised beds on laser-leveled fields, also applying small but precise amounts of fertilizer and compost (Figure 44, following page). Quick and efficient crop establishment was done by a second machine which punched holes in the raised beds at regular intervals and then filled them with water from a tank on the machine, after laborers riding on the machine had dropped 10-day-old seedlings into them (Figure 45, following page).

Figure 43: *Irrigation done by syphon tubes in furrows between permanent raised beds, saving both water and energy.*

Once the plants were growing, a third machine weeded the raised beds periodically, breaking up the soil between the precision-placed plants and thereby aerating their root zones while eliminating weeds (Figure 46, following page). The field was flooded only once, after the transplanting was completed, to 1 inch above the top of the beds. Thereafter, only furrow irrigation was done intermittently with siphons that eliminated the energy costs of pumping (Figure 43).

Sharif's initial SRI trial field was 8 hectares (20 acres), hardly a typical experiment-station plot. Its paddy yield was 12.8 tons/ha, about three times the average yield in the region. This was achieved with 70% less labor requirement than usual for paddy production, and the water use was also cut by 70%.

Because Sharif understood the principles of conservation agriculture, he introduced crop rotations along with no-till practice and ground cover, alternating many other crops in the winter season with irrigated rice in the summer season. Rice was followed by wheat, maize or cotton, or by a vegetable crop such as potato, tomato, carrots, onion, garlic or mung bean (*Vigna radiata*). The structure and fertility of the raised-bed soils is maintained with wide spacing between plants and with enhanced soil organic matter and aeration. Sharif adapted SRI ideas to all of these other crops.

Despite its productivity and profitability, the introduction of fully mechanized SRI (MSRI) production of rice has not caught on in the area, however, because of the need for specialized machines that are quite expensive for most rice or wheat growers. Even so, the principles and practices associated with MSRI are being understood and adapted for rice and other crops using manual operations once raised beds have been established.

The real test of a new crop production process is its rapid adoption by all types and sizes of farmers. From the demonstration effects of MSRI, about 80% of the farmers who grow maize, cotton, sunflower

Figure 44: *Machine making permanent raised beds on laser-leveled field, also applying fertilizer and banding compost precisely in Punjab Province of Pakistan.*

Figure 45: *Machine carrying laborers who drop 10-day-old seedlings into holes punched by the machine as it moves along the beds.*

Figure 46: *Weeder moving along raised beds, aerating the soil while uprooting weeds.*

and vegetables in the area around Sharif's farming operations have begun moving to raised-bed cultivation following SRI fundamentals.

The concepts and practices of SCI can be adapted to the production of almost any crop, according to Sharif's experience. The basic principles for such crop management are, in simple language:

- Keep the soil healthy:
    - *o* Avoid plowing as much as possible as this destroys soil structure, degrades organic matter, and sacrifices nitrogen and other nutrients.
    - *o* Avoid inundation of fields and grow crops on raised beds since standing water affects the soil adversely and suppresses most life in the soil
    - *o* Make provision for a proper drainage system if necessary to keep the soil well-drained.
    - *o* Keep the soil covered by cover crops, as much as possible, to provide it with a living mulch.

- Use enough water to keep the soil moist but also well-aerated, neither saturated nor flooded, meeting the needs of plant roots and soil organisms without any excess.

- Give more space to plants for their growth above and below ground, so that they can better harvest the sun's energy and take up the soil's nutrients.

- Leave crop plant residues on the soil so that it is protected, water is conserved, weed competition is minimized, and the biomass can become decomposed back into plant nutrients.

- Grow a variety and succession of crops, including legumes, as this minimizes plant diseases and enhances the soil's health and fertility.

With these principles, farmers can save up to 70% on their costs of purchased inputs and can expect yield increases of at least 40% compared to adjoining farmers who use conventional methods.

Appropriate management practices (timing, spacing, etc.) are developed for each crop and for yearly crop rotations according to experience and conditions. Here are some examples:

> ***Potatoes***: Yields of the best farmers in the surrounding area are 100 bags of 120 kilograms each (12 tons/ha). The SCI potato harvest in February 2013 yielded 150 bags, 50% more. With raised beds, one more row of plants can be added in the space between the two rows on a bed. Planting cover plants on the beds protects the potato plants from cold and frost in the winter season, extending their period for growth and giving larger tubers.

Carrots: Conventional farmers sow this crop by broadcasting seed on the field, and then they make ridges with a tractor to be able to irrigate along the furrows that this makes. However, making furrows this way concentrates seeds on the top of the ridge, so the plants become crowded together, lowering crop yield. Moreover, the carrots are not uniform in size and shape; only 20% qualify as 'A' grade for best market price.

In mechanized SCI production, carrot seeds are drilled on beds 42 inches wide (1.05 m), in 5 rows that are 9 inches apart (22.5 cm). One week after germination, hand-thinning is done to give the plants near-uniform spacing. Yields are increased thereby by 400%, with over 80% of these carrots classified as 'A' grade, justifying the supplemental labor.

Wheat: When an organic wheat crop was planted on raised beds, a 40% higher yield was obtained than was produced by adjacent farmers growing their wheat on flat fields. Average yield of the best farmers in the area is now about 2.5 tons/ha, while Sharif's average is around 5 tons.

Trials are underway to introduce intercropping on raised beds, e.g., rapeseed with wheat. Harvesting this presents problems for large farmers until a dual-crop harvester can be developed; however, small farmers can manage such combinations as they harvest manually.

Cotton: For the last two years, following a multi-cropping strategy, two rows of cotton are planted 30 inches (75 cm) apart, on a 42-inch (1.05 m) bed top leaving 6 inches on each side, with one row of cucurbits, melons or watermelon planted down the middle. The cotton plants provide shade to the cucurbits which yield much better than with sole-cropping, while the cotton yields the same if not more than when this crop is grown alone.

Figure 47: *This cotton crop at a Department of Agriculture research station in Punjab, Pakistan, is at flowering stage, with no fertilizer or pesticide having been used.*

There are strong financial interests in Pakistan as elsewhere promoting input-intensive modes of production and favoring new seed varieties that demand more and more purchased inputs. Now there are counter-currents, however, favoring environmental health and boosting smallholder farmer incomes currently constrained by high input costs. The On-Farm Water Management Department of the Provincial Department of Agriculture now has an SCI cotton demonstration in the 2013-14 season (Figure 47).

Sharif (2011) characterizes SCI development in Pakistan as **'paradoxical agriculture'** because it enables farmers, from large to small scales of production, to achieve more output with reduced inputs.

Where agricultural fields have been managed for years with heavy agrochemical inputs, the transition to essentially organically-managed cultivation takes some time, usually at least three crop seasons to renew chemical-dependent soil with organic amendments that make it ready for natural sustainability, giving good yields with minimum purchased inputs.

This strategy is being adopted or adapted for many crops, as a gradual process, making gradual reduction in inorganic fertilization. External nutrient amendments are applied only to meet soil deficiencies during the transition process. This work must remain both experimental and empirical.

9. Conclusions

Figure 48: A wheat field in India, grown using SCI principles, and exhibiting abundant panicles.

This is an interim report on SCI as it is an evolving phenomenon, a work in progress (ILEIA 2013). Most of the information available has not yet been published in journals, although some of the data reported are from controlled, even replicated trials, and most of the data and reports that we cite are available on-line for others' examination.

The data summarized in the tables in Annexes I and II show considerable variability; but overall, the impacts of SCI management are usually ***more than a doubling of yield***. Crop-wise, the yield increases range from 60% for sugarcane to 180% for wheat.

In economic terms, ***the costs of production per hectare*** with intensification, according to data in Annex II, ***go up on average by about 50% per hectare***. However, given the increases in yield, on average ***the costs per unit of crop produced decline by about 40%*** across the crops for which detailed cost and return data are available. This makes for more than a doubling of farmer income per hectare.

While the data presented here are not complete or standardized enough for strong scientific conclusions, the patterns of improvement in yield and profitability are dramatic and consistent enough to have attracted the attention of large numbers of farmers and also of policy makers, particularly in Bihar state of India and Ethiopia.

The results enumerated in this monograph are quite consistent with those reported from a recent evaluation of SCI in Bihar done for the World Bank (Behera et al. 2013). The study reported that as of June 2012, 348,759 farmers were using SCI methods on over 50,000 ha in Bihar with yield increases that it summarized as:

- 86% for rice
- 72% for wheat
- 56% for pulses
- 50% for oilseeds, and
- 20% for vegetables

The respective average increases in profitability for these different crop categories were calculated and reported as:

- 250% for rice
- 86% for wheat
- 67% for pulses
- 93% for oilseeds, and
- 47% for vegetables

The information in this monograph has been assembled to bring these opportunities to the attention of a wider audience that is concerned with improving agricultural production and food security -- and for those who want also to conserve environmental resources and help farmers cope with increasing climatic stresses now and in the future.

Finding explanations for the evident improvements in soil/plant interaction and farmer performance presents both challenges and opportunities to the scientific community. These experiences and observations provide unanticipated and needed opportunities to the development community, and offer even greater opportunities and security to farming communities around the world.

Annex 1 Summary of Yield Effects of SCI Management with Different Crops

Crop	Country	Location	No. of farmers	Conventional yields (t/ha)	Average yields (t/ha)	SCI increase (%)	Highest SCI yield (t/ha)	Comments
Finger Millet	India	Karnataka State	Whole villages	1.2-2.5	3.75-5.0	100-200	6.25	Farmer-developed method known as *Guli Vidhana* in Haveri district
		Uttarkhand State	43	1.5	2.4	60	–	2008 trials under People's Science Institute program
	Ethiopia	Tigray Region	Whole villages	1.4 broadcasted	3.5-4.0 transplanted	150-180	7.8	Now farmers' standard practice in very dry areas, stressing compost and wider spacing
	Range and Average			**1.2-2.5**	**2.4-5.0**	**125**	**–**	**–**
Wheat	India	Uttarakhand State	151 irrigated	2.77	5.04	82	–	Evaluations done by People's Science Institute in 2008-09 season
			317 unirrigated	1.74	3.32	91	–	
		Bihar State	2008-09: 278	1.6	3.6	125	–	Initial on-farm trials done in Gaya District by NGO; Bihar State govt. started supporting SWI in 2010; in 2011-12, SWI methods were used on 183,063 ha with average yield of 5.1 t/ha
			2009-10: 15,808	1.8	4.6	150	–	
	Mali	Timbuktu Region	2010-11: 21	1.96	5.45	178	–	On-farm trials in response to initiatives of Africare
			2011-12: 142	0.94	3.2	240	–	Drought year; results were from 13 villages
	Nepal	Kailali District	2010-11: 16 locations in 3 districts	3.4 broadcasted	6.5 line sowing + conoweeder + seed treatment	90	–	Farmer field school trials at; both broadcasting and SWI with improved variety
		Sindhuli District	2011-12: 12 FFS	3.7 broadcasted	6.5 transplanted	74	–	FFS trials, with improved variety; line sowing gave an intermediate yield of 5.0 t/ha
	Range and average			**0.94-3.7**	**3.2-6.5**	**130**	**–**	**–**

Crop	Country	Location	No. of farmers	Conventional yields (t/ha)	Average yields (t/ha)	SCI increase (%)	Highest SCI yield (t/ha)	Comments
Tef	Ethiopia	Various districts	4 years of trials	± 1.0 broadcasted	3.0-5.0 transplanted; 2.1 direct-seeded	200-400	6.2	Use by farmers in 2012 expanded under a government program to 7,000 transplanting and 160,000 with direct seeding in rows
Mustard	India	Gaya District, Bihar	2009-10: 7	±1.0 broadcasted	3.0 transplanted	200	–	Trials were initiated with 7 farmers, and within 2 years expanded to >1,600 farmers
			2010-11: 283	±1.0 broadcasted	3.25 transplanted	**225**	–	–
			2011-12: 1,636	±1.0 broadcasted	3.5 transplanted	250	4.92	4.0 t/ha yields achieved by farmers who used all SCI methods as recommended
		Himachal Pradesh State	2010: 27	1.4 broadcasted	2.0 line planting	42	–	Initiative of People's Science Institute; direct seeding, not transplanting
	Range and average			**1.0-1.4**	**2.0-3.5**	**180**	–	–
Maize	India	Himachal Pradesh State	2010: 582	2.0 farmer practice	3.5 adapted SCI	75	--	Results from farmers' on-farm trials; direct seeding, wider spacing
			Farmer participatory research	2.3 farmer practice	6.5 40x40 cm space	181	--	Spacing trials: 40x40 cm spacing of hills had highest yield
				2.8 farmer practice	6.1 1 seed/hill	118	–	Seeds/hill trials: in these trials the yield from 2 seeds/hill was 5.3 t/ha
	Range and average			**2.0-2.8**	**3.5-6.5**	**108**	**–**	**–**
Sugarcane	India	Zaheerabad, Andhra Pradesh State	30SSI and 15 conventional	115	138	20	170	Trials conducted by AgSri during 2010-11
		Latur District, Maharashtra State	33 both SSI & convetional	70	95	35	173	Trials conducted by AgSri during 2011-12 under severe drought conditions
		Tamil Nadu State	Summary of TNAU evaluations	40	90	125	Seedbud rate cut by >90%	Anon., 2013c
	Range and average			**40-115**	**90-138**	**60**	**–**	With less water and lower costs

Crop	Country	Location	No. of farmers	Conventional yields (t/ha)	Average yields (t/ha)	SCI increase (%)	Highest SCI yield (t/ha)	Comments
Legumes	India	**Pigeon pea** Karnataka	On-farm trials	0.8-0.9	1.5	76	–	Results reported by Agriculture-Man-Environment Foundation, Bangalore
		Mung bean Bihar	On-farm trials	0.625	1.875	200	–	Results from Bihar Rural Livelihood Prom. Society, Patna
		Lentils Uttarakhand	On-farm trials	0.85	1.4	65	–	Results from People's Science Institute (PSI), Dehradun
		Soya bean Uttarakhand	On-farm trials	2.2	3.3	50	–	Results reported from PSI, Dehradun
		Kidney beans Uttarakhand	On-farm trials	1.8	3.0	67	–	Results reported from PSI, Dehradun
		Peas Uttarakhand	On-farm trials	2.13	3.02	42	–	Results reported from PSI, Dehradun
	Range and average			**0.8-2.2**	**1.5-3.02**	**83**	**–**	**–**
Barley	Ethiopia	Gembichu Woreda (District)	2010	2.3 broad-casted	5.0 trans-planted	117	13.2	Drought-resistance, a big issue here, is enhanced with SCI practices

Annex 2 Summary of Economic Effects of SCI Management with Different Crops

Crop	Country	State/Province	Cost of production/ha	Cost of production/kg	Farmer net income/ha	COMMENTS
Finger Millet	India	Jharkhand State	+25%	-60%		Farmer methods showed loss of Rs 5,628/acre, while SFMI had net return of Rs 8,110/acre
Wheat	India	Bihar State	+60%	-28%	+150%	Net income/ha increased from Rs 17,460 to 43,952 reported by PRADAN
		Bihar State	-2%	-35%	+913%*	Yield increased 32%, from Rs 2,625 to 3,475 kg/ha, net revenue/ha went from Rs 1,802 to 18,265; return per man-day rose by 123%, reported by AKRSP
		Himachal Pradesh State	+58%		+494	Average profit per hectare for unirrigated SWI was Rs 4,813; for irrigated SWI it was Rs 28,603
	Mali	Timbuktu Region	Labor inputs for direct-sown SWI were reduced by 35-40%; returns to labor (kg of wheat produced/day) were increased by 74%			
	Nepal	Far Western Region	+58%	--	104%	Net income/ha increased from Rs 4,830 to 9,830
Mustard	India	Bihar State	+100%	-50%	'Made crop profitable'	Traditional methods showed a loss of Rs 4,346/acre, while SMI had net returns of Rs 23,487; gross revenue per acre increased from Rs 15,900 to Rs 64,100 as costs per acre declined from Rs 20,246 to Rs 40,613

* This percentage was not included in calculating average increase in farmer net income/ha reported in text.

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