AGROECOLOGICALLY-SOUND AGRICULTURAL SYSTEMS: CAN THEY PROVIDE FOR THE WORLD'S GROWING POPULATIONS?

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Keynote for *DEUTSCHER TROPENTAG 2005*, Hohenheim, Oct. 11-13, 2005

I. Considerations Affecting Current Agricultural Systems

Global food prospects, especially for the tropical regions, are not necessarily optimistic for this new century, despite various current technological advances. Although population growth is now slowing down, overall growth will continue at least through the middle of this century. This means that the land and water available per capita for agricultural production will thus keep declining. To feed the growing populations, the productivity of all factors of production -- not just of land or of labor -- will need to increase considerably in the coming decades.

Unfortunately, further progress with what is called 'modern agriculture' -- relying particularly on genetic improvements and increased inputs of purchased inputs -- has become somewhat problematic. Cereal production is not the only measure of progress, however, it is a widely and highly regarded indicator. According to this measure, there has been little improvement in absolute terms over the past decade, while in relative terms, the world's per capita production of cereals has been stagnant and even declining since the mid-1980s.

What is referred to as 'modern agriculture' is facing many challenges:

(a) **Costs of production** are increasing, with many farmers starting to experience 'diminishing returns' to external inputs. The widening market competition resulting from globalization is putting downward pressure on agricultural prices, so that farmers are caught in an unenviable price squeeze.

(b) **Government subsidies** that have in recent decades sustained agricultural producers in the U.S., Europe and Japan are now contracting, which means that the economics of input-dependent production need to be reconsidered in those regions; such subsidies are not even being considered any more in the less-developed countries.

(c) **Relying on inputs derived from petroleum** – many fertilizers, insecticides, fungicides, etc. – is becoming more uncertain and costly as world petroleum markets become more volatile. The crude oil prices of the last 50 years are unlikely to be seen in this century.

(d) **Adverse environmental impacts** from the application of agrochemical inputs are cumulating, and they are becoming greater and more contested, with increasing government regulation.

(e) **Global climate change** is going to force some fundamental reorientations in agricultural production strategies. *Global warming* is likely to be less of a challenge, since it can be adapted to gradually over time, than *increased variability* of climate – extreme events of rain, heat, cold and drought that take a heavy toll on crop and animal production.

Modes of production that could be successful in the preceding century are thus now less likely to succeed in this one. Already we see a stalling in the expansion of chemical fertilizer and agrochemical use worldwide, as a convergence of increased input prices and lower output prices, with often declining effectiveness or diminishing returns, is curbing global demand.

II. Different Strategies to Deal with These Constraints and Trends

Biotechnology offers some prospects for dealing with various constraints and creating new opportunities. But its timeframe for creating the expected benefits is uncertain, while the costs of biotech development are very considerable, and regulatory issues associated with biotech present many difficulties, most still unresolved. Also, the use of biotechnology remains controversial due to varying assessments of environmental risks and hazards. While biotechnology appears to be new and innovative, it is really an extension of the 'modern agriculture' paradigm that developed and prevailed during the last half of the 20^{th} century.

Agroecology is not necessarily a competitor with biotechnology as there are possibilities for complementarity (Uphoff, 2006). Agroecology has the advantage of being already available, not something on the horizon -- even though it has received only a tiny fraction of the research resources that have been made available for biotech. The costs of developing and extending agroecological practices are much less than those for biotechnology, and regulatory issues are minimal, as there are few foreseeable environmental hazards. As will be shown, agroecological methods can match or outperform the results of biotechnology, making them more cost-effective.

Agroecology offers a paradigm that can be characterized as 'post-modern agriculture' in that it represents a step beyond current agricultural theory and practice. It is different from 'post-modernism' in the humanities and social scientists, however, in that it is not hostile either to 'modernity' or to science. In moving beyond the precepts and practices that are now thought of as 'modern,' it builds upon the ***most modern*** science being produced in the contemporary biological and ecological domains. It capitalizes particularly on what is becoming known in the realms of soil biology, soil ecology and microbiology.

The 'Green Revolution' is the apotheosis of modern agriculture and could turn out to be its culmination. It was premised on two main strategies for raising agricultural productivity:

(a) Changing the **genetic potentials** of plants (and animals), and

(b) Increasing the **use of external inputs** – more water, fertilizer, insecticides, etc.

Agroecology does little or none of either. Certainly, genetic factors are important. One should always select those cultivars that have the best genetic potential for functioning within any given agroecosystem, considering not just their own potentials but also those of other associated species as well as the constraints and opportunities presented by the biophysical environment (Uphoff, 2002). But agroecology is less 'genocentric' than modern agriculture has become.

Core principles of agroecological strategies, as summarized by Altieri (2002) include:

(1) **Enhance the recycling of biomass**, with a view to optimizing nutrient availability and balancing nutrient flows over time.

(2 **Provide the most favorable soil conditions** for plant growth, particularly by managing organic matter and by enhancing soil biotic activity.

(3) **Minimize losses of energy and other growth factors** within plants' microenvironments above and below ground. Losses resulting from unfavorable flows of solar radiation, air and water can be mitigated through microclimate management, water harvesting, and better soil management and protection through increased soil cover.

(4) **Diversify species and genetic resources** in the agroecosystem over time and space.

(5) **Enhance beneficial biological interactions and synergies** among the components of agrobiodiversity, thereby promoting key ecological processes and services.

Agroecological approaches minimize the use of exogenous inputs, preferring to mobilize the endogenous capabilities of the cropping system and its relevant soil and above-ground environment through optimizing management of plants, soil, water and nutrients. They operate without relying on synthetic fertilizers and agrochemical biocides, instead adjusting management practices to alter the 'E' factor in the GxE interaction (genetic potential x environment) as this determines the phenotypical development of each and every organism.

The significance of 'E' can be seen from the rice plant shown in Figure 1, grown from a single seed of traditional variety, and from the rice field in Madagascar shown in Figure 2, also planted with a traditional rice variety. In these situations, the 'G' had been giving rather inferior results before the introduction of the System of Rice Intensification (SRI), discussed below, changed the 'E' dramatically and productively.

SRI experience underscores the second of the agroecology principles listed above. In particular, it illuminates the importance of managing plants, soil, water and nutrients to:

(a) Promote the **growth and functioning of root systems**, which are the interface between plants and their soil environment (a good SRI example is shown in Figure 3), and

(b) Increase the **abundance, diversity and activity of soil organisms**, which provide many benefits and services to plants. The two rice plants shown in Figure 4 are the same genotype (cultivar VN 2084) and the same age (52 days). Yet their root growth and tillering are phenotypically very different.

No analysis could be done of the soils in which these two plants were growing (on a farm in Cuba). But from what is known in the literature, the marked difference was probably contributed to by the production of phytohormones by soil biota that stimulate root growth. Microbes benefit from increases in the carbohydrates, amino acids, etc. that are exuded by plant roots into the rhizosphere, the soil surrounding the roots which is inhabited by millions of microorganisms (Pinton et al., 2001). This plant-microbial symbiosis is a fundamental component of agroecological thinking and practice, which seeks to promote such synergies so that positive-sum outcomes become possible.

III. The System of Rice Intensification as an Agroecological Strategy

The System of Rice Intensification (SRI) is discussed at some length here because it represents an agroecological strategy that enhances food production and contributes to food security at the same time that it helps to improve the natural resource base on which agriculture and other human activities, as well as life itself, depend. It was developed 20 years ago in Madagascar by Fr. Henri de Laulanié, SJ. The synthesis of the innovative, mostly counterintuitive practices that constitute SRI followed 20 years of working with farmers, making observations and doing experiments, topped off with some serendipity (Laulanié, 1993).

In 1990, Laulanié established, together with some dedicated Malagasy colleagues, the NGO known as Association Tefy Saina to promote rural development in Madagascar, with SRI as an 'entry point' for getting rural people oriented toward changing behavior and thinking. In 1994, Tefy Saina began working with the Cornell International Institute for Food, Agriculture and Development (CIIFAD) in the region around Ranomafana National Park under a USAID project that sought to halt slash-and-burn cultivation encroaching on the park's rain forest ecosystems by giving farmers better, more productive alternatives. Average rice yields around the park were only 2 tons per hectare (t/ha), and the soils were quite 'poor' in chemical terms (Johnson, 1994). CIIFAD was initially skeptical that SRI could deliver what Tefy Saina said it could – yields of 5, 10, even 15 tons/hectare (t/ha), without changing rice varieties or using chemical fertilizers and agrochemicals, and using less water. But after farmers using the methods taught by Tefy Saina had averaged 8 t/ha for three years -- and some had reached almost twice this – CIIFAD began trying to get SRI methods tried in other countries.

It was not until 1999 that any researchers outside of Madagascar could be persuaded to try out SRI methods, which contradicted widespread beliefs and practices regarding irrigated rice production. That year, scientists at Nanjing Agricultural University in China and at the Sukamandi rice research center of the Agency for Agricultural Research and Development in Indonesia gave SRI a try. Their positive results were soon repeated by farmers working with NGOs in Cambodia, Philippines, Bangladesh, Sri Lanka, Sierra Leone and other countries. Within three years, SRI had reached 15 countries (Uphoff et al., 2002), and today 'the SRI effect' has been demonstrated in at least 22 countries around the world. As of May 31, it has been officially endorsed by the Govt. of India (http://pib.nic.in/release/release.asp?relid=9545).

A. SRI Practices

SRI is best viewed as a methodology rather than as a technology, because its core is a set of insights and principles formulated by Fr. de Laulanié based on systematic empiricism. Explanation of SRI, however, usually focuses on specific practices that present the innovation in concrete terms. It is recommended that these practices be presented with the advice to try them out first on a part of the rice field, not the whole field. This is to test whether the methods 'work' under the particular biophysical conditions, and for farmers to gain skill and confidence in the methods. Farmers are encouraged to adjust and adapt the practices to their own conditions and needs, taking responsibility for experimentation and evaluation rather than just 'adopting' the new system.

The basic SRI practices can be summarized as follow:

(1) Start with **young seedlings**, preferably only 8-12 days old, with just two leaves, and usually less than 15 days old (which is likely to the start of the fourth phyllochron – transplanting should be done during the second or third phyllochron of growth to minimize setback to young plant growth). Transplanting young seedlings rather than older ones, as is usually done, preserves potential for profuse growth of roots and tillers. Seedlings should have been grown in a garden-like nursery rather than in a flooded one.

(2) Plant the **seedlings singly**, rather than in clumps of 4-6 seedlings as is usually done, and widely space in a square pattern, starting at 25x25 cm, transferring the seedlings quickly and carefully from the nursery to the field and planting them gently so that the roots have minimum trauma and the seed sac is kept attached to the young root. Such plants will

have little or no delay in resuming growth, compared to the 7-14 days seen with conventional (traumatizing) methods of transplanting.[1]

(3) Apply **reduced water**, just the minimum needed by the plant, so that the soil remains as aerobic as possible. Rice fields are usually kept continuously submerged in the mistaken belief that rice plants grow better under such conditions (DeDatta, 1981). However, rice paddy soil only needs to be kept moist and should be allowed to dry out periodically. If soil is maintained under anaerobic conditions, the rice roots die back (Kar et al., 1974), and soil flora are mostly anaerobic, the aerobic bacteria and fungi that support plant growth symbiotically being suppressed.

(4) When rice fields are not kept continuously flooded, weeds are likely to become more of a problem. Thus, farmers are advised to **weed with a 'rotating hoe,'** a simple, inexpensive mechanical implement that aerates the soil a the same time it controls weeds, by churning them back into the soil where they decompose and their nutrients are conserved.

(5) Provide **organic matter**, as much as possible, for the soil organisms and the plant. SRI was initially developed by Laulanié using chemical fertilizer, which does boost yield in conjunction with these above practices. However, when government subsidies were removed and few Malagasy farmers could any longer afford to use fertilizer, compost was used instead (made simply from any kinds of biomass, as manure was scarce), with better results (Uphoff, 2003)

These are the basic practices. Each offers some advantage separately, but together their synergy promotes root growth through wider spacing, aerobic soil and organic nutrient supply. Root growth in turn, by mobilizing water and nutrients in the soil, supports more growth of the canopy. This through greater leaf area and photosynthesis concurrently supports more root growth. Indeed, phytohormones produced in the root (cytokinins) promote growth of the shoot at the same time that others produced in the shoot (auxins) enhance root growth (Oborny, 2004). There are also other many ways in which soil biota contribute to plant growth and performance (Dobbelaere et al., 2003). Not been much detailed research has been done yet on the effects of SRI practices on soil biota, but the following increases (Table 1) were reported in a presentation by Dr. T. M. Thiyagarajan of the Tamil Nadu Agricultural University in India at the World Rice Research Conference in November, 2004.

Table 1: Microbial populations in the rice rhizosphere with different practices

Microorganisms	Conventional Practices	SRI Practices
Total bacteria	$88x10^6$	$105x10^6$
Azospirillum	$8x10^5$	$31x10^5$
Azotobacter	$39x10^3$	$66x10^3$
Phosphobacter	$33x10^3$	$59x10^3$

Source: Thigayarajan (2004), Slide 21, TNAU on-station trials.

[1] Note that transplanting is not a necessary part of SRI. Direct-seeding is being experimented with by some farmers to save labor time. The SRI principle is that if one transplants, young seedlings (ones not yet into their fourth phyllochron of growth) should be used, and they should be transplanted very carefully (Stoop et al., 2002).

B. SRI Results

SRI has been producing some remarkable results. While most attention has been focused on increases in yield, this is only one consideration among many when assessing production systems:

(1) **Immediate benefits** from utilizing these practices. There is no 'transition' period needed as is necessary with many conversions to 'organic agriculture.'Soil ecosystems after prolonged exposure to synthetic chemicals (particularly nitrogenous and chlorinated forms) often require some time to become fully restored. SRI yields often improve over time, but there is no initial period of loss as first-season yields are usually already higher.

(2) **Yield increases of generally 50-100%, and often more**, without changing rice varieties. There is no need to buy new seed since all varieties have been responding to these new methods, although some varieties respond better than others.

(3) **No need for mineral fertilizers**, which are a major cost in modern agriculture and are having some adverse environmental impacts; compost gives better yields.

(4) **Little or no need for agrochemicals**, since SRI plants are more resistant to damage by pests and diseases, as discussed more below.

(5) **Less water is needed** -- a reduction of usually 25-50% -- and also **seed saving** as this requirement is reduced by 80-90% thanks to a dramatic reduction in plant population.

(6) While more labor is required initially -- the main limitation on SRI, along with the need for good and reliable water control to get best results -- it is now being documented that **SRI can even become labor-saving** once farmers have mastered its methods.

This all sounds 'too good to be true,' and SRI has come under some attack in the agronomic literature in recent years (Dobermann, 2002; Sheehy et al., 2004; Cassman and Sinclair, 2004; Sinclair, 2004). However, SRI should be put to empirical tests, rather than being dismissed or ignored on grounds of *a priori* reasoning, preconceptions or prejudice.

An evaluation of SRI in Cambodia was commissioned by GTZ and conducted by an independent team in early 2004. It covered 500 farmers in five provinces, 400 of them randomly-chosen SRI farmers and 100 non-SRI farmers for comparison. The very positive findings of this study, reported at the ***Deutscher Tropentag 2004*** (Anthofer, 2004) confirmed what had been learned about SRI and reported from other countries.

Recent evaluations by China Agricultural University (Li et al., 2004) and the India program of the International Water Management Institute (IWMI) (Singh and Talati, 2005) have found similar net benefits in very different agroecosystems. In the CAU study of a village in Sichuan province, SRI adoption had expanded from 7 farmers to 398 in just one season. Farmers there regarded labor-saving as SRI's greatest advantage. In the IWMI study, SRI use had risen from 4 to 150 farmers over three seasons. These farmers lived in two very poor tribal communities that had only rainfed opportunities, i.e., no irrigation. Farmers had successfully adapted the principles and practices of SRI to their own conditions.

Since SRI represents a methodology rather than a fixed technology, its concepts of promoting greater root growth and more soil biotic activity are fairly widely adaptable. The interactions among soil biota and with plant root systems that SRI promotes have produced different *phenotypes* from the various genotypes (varieties) of rice with which it has been used so far.

The results are empirically demonstrable, even if not all of the mechanisms are yet well-established. Chinese researchers have done the most work on the scientific basis of SRI, e.g., Wang et al., 2002; Tao et al., 2002; Zheng et al., 2004; Lin et al., 2005. Some of these findings are shown in Figures 5, 6 and 7. Genetic differences were controlled by using the same variety for each comparison (two comparisons in Figure 6). So the measured differences are attributable to the changes made in the way plants, soil, water and nutrients were managed.

More general benefits resulting from SRI management include:

(1) **Accessibility for the poor:** The lower capital costs involved in using SRI means that its economic and other benefits are not limited by access to capital, nor does it require loans and indebtedness. It thus can contribute rapidly to greater food security for the poor. There was some initial evidence that SRI's labor requirements made it less accessible to the poor (Moser and Barrett, 2003); but a larger study by IWMI in Sri Lanka found poorer farmers as likely to adopt SRI as richer ones, and were less likely to disadopt (Namara et al., 2004). The GTZ evaluation (Anthofer, 2004) also found no such barrier.

(2) **Greater profitability:** The costs of production with SRI averaged about 20% less per hectare in seven evaluations from five countries (Bangladesh, Cambodia, China, India and Sri Lanka). Then this is accompanied by higher yield, farmers can increase their incomes from rice production by more than their increase in yield.

(3) **Reduction in economic risk:** This has been documented in the evaluations done in Cambodia and Sri Lanka for GTZ and IWMI, respectively (Anthofer, 2004; Namara et al., 2004). This benefit complements the reduction in agronomic risk discussed below.

(4) **Environmental benefits:** Reduction in water requirements and reduced reliance on agrochemicals for high yield takes pressure off water-stressed ecosystems and enhances soil and water quality.

(5) **Human resource development:** The recommended strategy for dissemination of SRI emphasizes farmer experimentation and encourages farmer innovation in ways that conventional agricultural technology development and extension strategies do not. Fr. de Laulanié intended that SRI should enhance the human condition, not just meet people's material needs (Laulanié, 2003).

In specific agronomic terms, SRI farmers report the following advantages that go along with their higher yield and profitability from the new methods:

(1) **Drought resistance:** Because SRI rice plants develop larger and healthier root systems, once these have gotten established at an early age, the plants themselves are more resistant to drought and less severe periods of water stress (see Figure 8).

(2) **Resistance to lodging:** With stronger root systems and tillers, in part due to the greater uptake of silicon when soil is not kept saturated, SRI plants show remarkable resistance to wind, rain and storm damage (e.g., Figures 9 and 10). This is a very important effect.

(3) **Reduced time to maturity:** Contrary to the claim made by some critics that SRI has a longer growth cycle (Surridge, 2004), when SRI methods are used properly the time for maturation can be shortened by as much as 15 days, even while yield is being doubled (Uprety, 2004). This reduces farmers' risk of agronomic or economic losses due to extreme weather events, pests or disease and/or frees up the land for other production.

(4) **Resistance to pests and diseases:** This has been frequently commented on by farmers and is now being documented by researchers, e.g., a 70% reduction in sheath blight in Zhejiang province, reported by the China National Rice Research Institute. An explanation for this observation can be found in the theory of *trophobiosis* proposed by the French plant pathologist Francis Chaboussou (2004). This attributes the incidence, spread and severity of pest and disease attacks to *nutrient imbalances and deficiencies* that lead to an excess in plants' sap and cells of (a) free amino acids, not synthesized into proteins, and (b) reducing sugars, not incorporated into polysaccharides. These excesses make plants more attractive and vulnerable to insect, bacteria, fungal and viral parasites.[2]

(5) **Conservation of rice biodiversity:** While high-yielding varieties and hybrids have given the very highest yields with SRI methods (all SRI yields over 15 t/ha have been achieved with improved cultivars), very respectable yields can be obtained with traditional varieties as SRI plants resist lodging despite their larger panicles. In Sri Lanka, farmers using SRI methods have obtained yields between 6 and 12 t/ha with 'old' varieties. These are more profitable to grow because consumers are willing to pay a higher price for them, preferring their taste, texture, aroma, etc.[3] Rice is an immensely varied crop, with very diverse species and cultivars. We anticipate that rice consumption in the 21st century could become as differentiated as people's tastes for different coffees and teas have become in recent years, thanks to good marketing. This could enhance farmers' incomes.

C. Extension to Other Crops

Perhaps the most interesting development with SRI is the range of extrapolations that farmers have made of its concepts and methods to other crops besides irrigated rice.

(1) In the Philippines, an NGO has adapted SRI concepts to growing unirrigated, **upland rice** in Negros, getting an average yield of 7.2 t/ha, much more than most rice farmers get with irrigation (Gasparillo, 2003). This is particularly important for poverty reduction because so many of the world's poor households have no access to irrigation.

(2) An NGO in Karnataka state of India is disseminating an innovative farmer-developed method for growing **finger millet** (*ragi*) that has much in common with SRI and triples yield without purchased inputs (Green Foundation, 2004). This is important because *ragi* is a main crop for the poor.

(3) Some farmers in Andhra Pradesh state have adapted SRI concepts to growing **sugar cane** and tripling yield with a reduction in water and herbicide application (Uphoff, 2005).

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[2] The use of synthetic fertilizers (particularly nitrogenous ones) and of agrochemicals (particularly chlorinated and nitrogenous ones) can unbalance or interfere with plants' metabolism, making them more vulnerable to infestation by pests and pathogens. SRI practitioners find these kinds of external inputs to be unnecessary and uneconomic. The vigorous growth that SRI practices promote supports the incorporation of amino acids and simple sugars into proteins and polysaccharides so that the rice plants become less attractive and less accessible to pests. Chaboussou supports his theory with evidence from decades of research published in 'mainstream' journals. Because his findings and predictions correspond with many observations of plant-pest-chemical application relationships over the past 75 years, his theory deserves more attention and empirical evaluation than it has received. Note that Chaboussou's analysis does not support an approach to agriculture with no external inputs. His focus on plant nutrition justifies making some soil amendments with inorganic materials when that is the best way to remedy deficiencies. His critique is of 'force-feeding' plants with extra nutrients to promote growth; this becomes self-defeating.

[3] In April 2005, CIIFAD with partners in Cambodia, Madagascar and Sri Lanka received one of the five SEED Awards given by UNEP, UNDP and IUCN to recognize and support entrepreneurial efforts that support biodiversity conservation. This partnership promotes the production, sale and export of indigenous rice varieties grown organically with SRI methods. This will make the preservation of local varieties more profitable.

(4) A farmer in Poland has begun using SRI concepts and practices with his **winter wheat** crop, getting increased tillering and plant vigor (Thadeusz Niesiobedzki, pers. comm.).
(5) In the Cambodian village where the picture in Figure 1 was taken, farmers have been prompted by SRI experience to improve their **chicken** production. They now produce compost in large piles that are fenced in. Chickens reared and maintained on these piles feed on worms and insects (high in protein) and add manure to the compost. Farmers, who can get more yield from raising fewer chickens this way, now prefer intensive management to their previous extensive, free-range methods, where disease, thirst, predators, thieves and other hazards reduced their supply of meat and eggs.

IV. DISCUSSION

These Cambodian farmers have seen with their chickens, as from their growing rice with SRI methods, that if biological processes are understood and capitalized upon, '***less can produce more.***' In the case of rice, it can be clearly shown that:

(1) **Smaller, younger rice seedlings become larger, more productive mature plants** with practices for managing plants, soil, water and nutrients that are conducive to synergistic biological processes, not only within the plant but also surrounding it in the soil.
(2) **Fewer rice plants per hill and per m^2 give higher yield** when used with the other SRI practices.
(3) **Half as much water can produce more rice** because aerobic soil conditions are more supportive of root health and plant growth than are anaerobic (hypoxic) conditions.
(4) **Greater output is possible with fewer or no external (chemical) inputs** because these increase plants' susceptibility to pests and diseases (Chauboussou, 2004). They also inhibit endogenous soil processes that mobilize nutrients and sustain crop health.

There are thus scientifically-respectable reasons for the performance of SRI. There is nothing magical, mysterious or miraculous about it; it is not 'voodoo science' as alleged by Cassman and Sinclair (2004). However, most of the factors contributing to SRI productivity at present remain hypotheses, derived from well-established knowledge in the agronomic and microbiological literature, because they still undocumented and not systematically tested. Only a few scientists have become engaged with the research issues and opportunities that SRI raises; but this work has begun, as seen from the references at the top of page 7.

There should be many investigations, in relation to SRI phenomena, of such well-documented processes as biological N fixation with non-leguminous plants (Döbereiner, 1987); mobilization and cycling of N by protozoa and nematodes (Bonkowski, 2004); solubilization of P by aerobic bacteria (Turner and Haygarth, 2001); increased uptake of water, P and other nutrients by mycorrhizal fungi (Kapulnik and Douds, 2000); microbially-induced systemic resistance to pests and diseases (Heil, 2001); and bacterial and fungal production of phytohormones to stimulate root growth (Frankenberger and Arshad, 1995). These and other processes and mechanisms are considered in a forthcoming book that I have edited with the support of a large number of scientists having more knowledge and better credentials on these subjects than I have (Uphoff et al., 2005). Over 100 researchers and practitioners from 28 countries contributed to this effort.

There are many ways in which biological processes could be contributing to the remarkable SRI results reported above. Not all need to be operative for us to be able to construct an adequate accounting for the overall effects of SRI practices. Standard reductionist approaches that study only separate effects *ceteris paribus* are likely to be inadequate for constructing a full explanation, although they will surely be helpful in putting together different parts of the SRI 'puzzle.' Evaluations should explore the possibility that SRI effects result at least in part from synergies among the practices, since we know there are positive feedback loops between root system and canopy growth, with both contributing in turn to grain filling.

SRI is still a rather recent innovation. Six years ago, its methods and effects were known only in the country of its origin. Today, they have been demonstrated in almost two dozen countries. Proponents of SRI have not urged that the methods be *adopted* everywhere, but only that they be *tried out* wherever there is a desire by individual farmers, by NGO or government agencies, or by national governments to raise yields, lower costs, save water, enhance environmental quality, etc. One always needs to check out whether the new methods can reproduce under specific local conditions what has been achieved elsewhere.

Because SRI methods fit into a larger body of theory and practice known as agroecology, most of its proponents are not concerned only with rice, but also with how the agricultural sector as a whole can be made more productive and sustainable. The challenge is to learn how to capitalize upon the possibilities that SRI demonstrates: that more outputs can be produced with fewer external inputs by capitalizing better upon endogenous biological potentials and processes within agroecosystems. This does not mean that research and experimentation on other methods should not proceed. There are some problems that may best be solved with genetic modifications, by conventional or other means (Uphoff, 2006). But certainly more attention and investment are due to agroecological approaches than they now receive if we are to meet world food needs in this century.

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Figure 1: Ms. Im Sarim in Pak Bang Oeun village, Takeo province, Cambodia, holding up a single rice plant, grown with SRI methods, September 2004. Harvested yield was 6.72 t/ha, with crop cuttings in some portions of the field reaching 11 t/ha. Plant was selected randomly. (Photo courtesy of Dr. Koma Yang Saing, CEDAC)

Figure 2: SRI rice field at _______________ near Moramanga in Madagascar. The yield at harvest time was calculated by a Department of Agriculture staff member as __ t/ha. Note that this traditional variety with long panicles is not lodging despite the weight of the heads of grain. (Photo courtesy of George Rakotondrabe, LDI.)

Figure 3: Root system of an SRI rice plant (improved variety MTU 1071) grown
at Maruteru agricultural research station, Andhra Pradesh, India, 2004.
Note the healthy (white) color of the roots as well as the density of root mass.
(Photo courtesy of Dr. P. V. Satyanarayana, the rice breeder responsible for this variety.)

Figure 4. Two rice plants of same variety (VN 2084) and same age (52 days), both started in same nursery on farm of Luis Romero, San Antonio de los Baños, Cuba. Plant on right was transplanted at 9 days into an SRI environment, with wide spacing, aerated soil, and good supply of organic matter; plant on left was kept in conventional nursery (flooded, close spacing) and removed at the usual time for transplanting in Cuba (50-55 days). Plants were randomly chosen for comparison. (Photo courtesy of Dr. Rena Perez, Ministry of Sugar.)

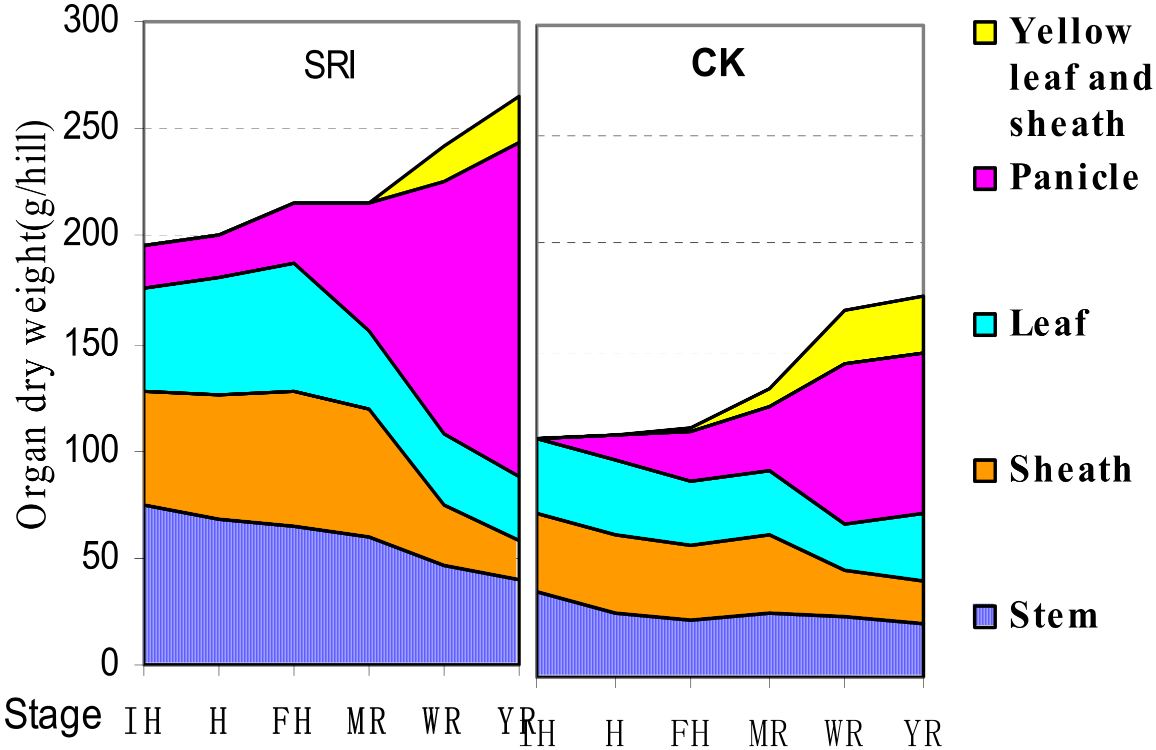

Figure 5: Differences in the dry weight of organs of rice plants at different stages of growth under System of Rice Intensification (SRI) or control (CK) practices (Tao, 2004). ('Yellow' refers to senescent leaves and panicles.)

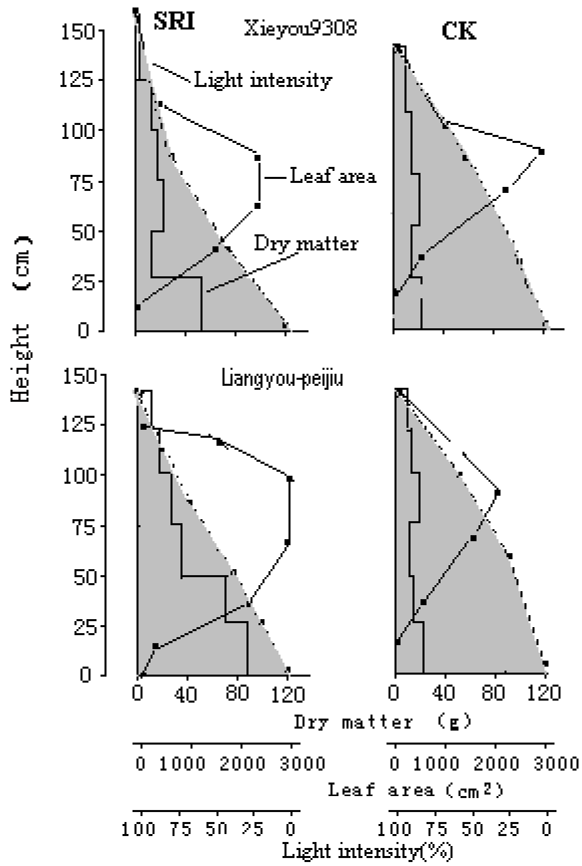

Figure 6: Plant physical structure (measured in terms of leaf area and dry matter at different plant heights) associated with light intensity distribution at heading stage for two rice varieties under System of Rice Intensification (SRI) or control (CK) practices (Tao et al., 2002).

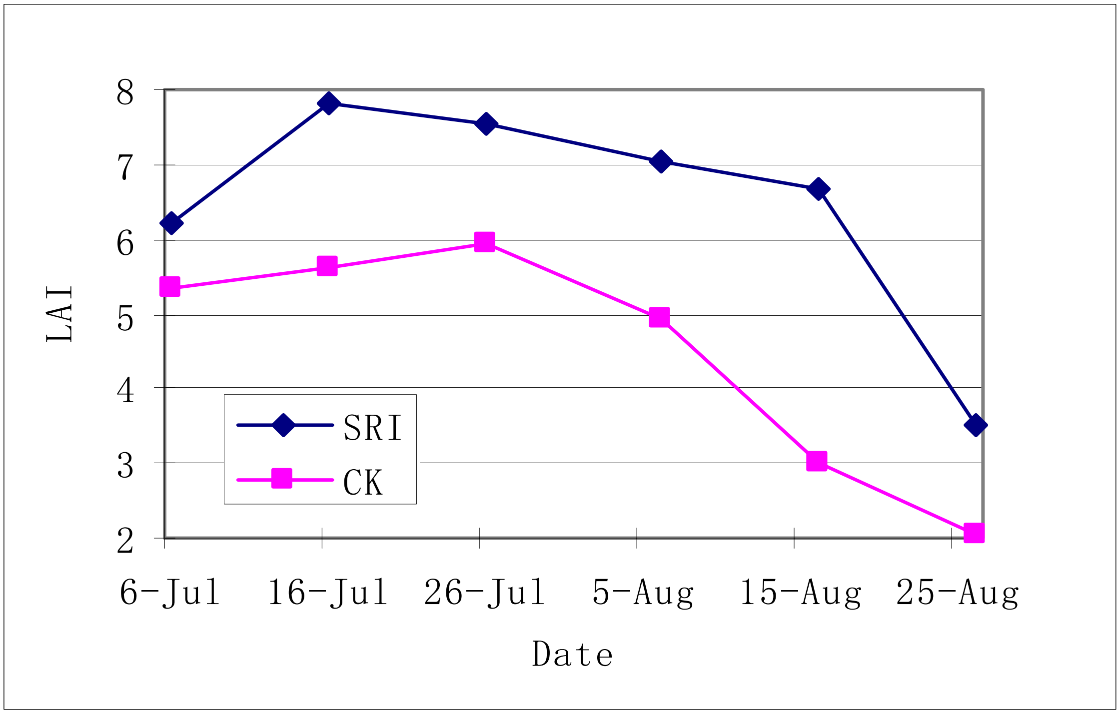

Figure 7: Changes in leaf area index (LAI) during the growth cycle of rice plants grown with System of Rice Intensification (SRI) or control (CK) practices (Zheng et al., 2004).

Figure 8: Adjacent rice fields in Sri Lanka with same rice variety, same soil, same irrigation system, and same drought. Plants on left were grown conventionally, with continuous flooding until water supply was interrupted; plants on right were grown with limited, intermittent water supply, which led to deeper root systems that can withstand surface water shortage. (Photo courtesy of Dr. Gamini Batuwitage, Ministry of Agriculture.)

Figure 9: Adjacent rice fields in Vietnam after heavy rain. Field on right was grown with conventional methods, while field on left and strip in center were grown with SRI methods. The center strip was planted with closer spacing, and the plot on right with wider spacing. (Photo courtesy of Dr. Max Whitten, retired from ACIAR.)

Figure 10. Rice plots in Tamil Nadu, India. Conventionally-grown crop is in the foreground, battered by a rainstorm; the SRI crop growing behind it resisted lodging (Thiyagarajan, 2004).