OPPORTUNITIES FOR WATER SAVING WITH HIGHER YIELD USING THE SYSTEM OF RICE INTENSIFICATION

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ABSTRACT

The System of Rice Intensification (SRI) developed in Madagascar is showing that by changing the management of rice plants, soil, water and nutrients, water requirements for growing irrigated rice can be reduced by 25-50%, with yield increased by 25-100%. Since SRI methods also reduce costs of production concurrently, they can increase farmers' net incomes by even more than yield. This gives rice farmers, who face a growing scarcity of irrigation water, incentive to reduce their water use. While these results may sound too good to be credible, the validity of SRI concepts and practices has been demonstrated in more than 20 countries. Here we briefly review the methods that make these improvements possible and discuss how they are achieved. We then consider experience with SRI in Andhra Pradesh and Tamil Nadu, two of India's main rice-growing states, where water availability is becoming more problematic and where SRI use is spreading. The implications of SRI for saving irrigation water where its supply for agricultural production is getting shorter are considered in conclusion.

I. INTRODUCTION

Scarcity of water for agricultural production is becoming a major problem in many countries, particularly the world's leading rice-producing countries, China and India, where competing and growing demands for freshwater are coming from other sectors. Also, climate change in some areas may be reducing rainfall, thereby creating short-term problems even if only a cyclical rather than a permanent change. In many areas, rainfall patterns are becoming more and more unreliable, with extremes of drought and flooding occurring at unexpected times.

Government fiscal problems have put greater budgetary pressure on irrigation departments so that their operation and maintenance expenditures are curtailed, and new investments to create more irrigation capacity have declined. To alleviate fiscal burdens, efforts are being made to turn the ownership and operation of irrigation facilities over to the private sector, but this move, although having some policy logic, is likely to leave smaller and poorer producers less able to ensure themselves of water for their crops.

All of these trends make water-saving a high priority for the agricultural sector in the years ahead. Because irrigated rice production is the leading consumer of water in the agricultural sector, and rice is the world's most widely consumed staple crop, finding ways to reduce the demand for water to grow irrigated rice should benefit both producers and consumers. If rice production can be increased while water consumption is reduced, this will make changes in agricultural practice more attractive.

It has long been believed that rice is an aquatic plant, or at least a hydrophilic one. However, this belief is being challenged by both scientific studies and field experience. Research done at Tamil Nadu Agricultural University in cooperation with Wageningen University has showed, e.g., that water applications can be reduced without sacrificing yield, and indeed a small increase in yield can be attained with less water application on well-drained soils (Ramasamy et al., 1997). The International Water Management Institute (IWMI) has published a monograph bringing together evidence on this relationship (Guerra et al., 1998). Still, it continues to be widely assumed that rice needs or grows better in standing water. The most widely-known text on rice says that rice "thrives on land that is water saturated, or even submerged, during part of all of its growth cycle…most rice varieties maintain better growth and produce higher grain yields when grown in a flooded soil than when grown in nonflooded soil" (De Datta, 1981: 41, 297-298). This, we contend based on considerable evidence, is incorrect.

Getting farmers to adopt water-saving methods in rice production is impeded by the fact that, so far, there has been little or no associated increase in yield and profitability that would compensate farmers for their greater labor and management effort. Small increases in the range of 5-10% may not suffice to justify the added cost and inconvenience. As long as water has been freely available, farmers have used water in ways that reduce their labor requirements.

Private decision-making need not take account of externalities such as the losses to society from excessive use of water, which has opportunity costs, or of the direct costs to downstream farmers who are deprived of water that they need for growing crops. As it becomes better recognized that rice does not need to be kept continuously submerged for best results, farmers and researchers are acknowledging that the main benefit from continuous flooding of rice paddies is weed control. This is a labor-saving strategy known and used for many centuries. To change production systems, especially age-old ones, there need to be attractive options.

II. THE SYSTEM OF RICE INTENSIFICATION

At a time when rice farmers in many countries must begin finding ways to achieve their production goals with less use of water, an innovation in rice-farming methods has become available that can (a) increase yields and production, so that economic and food-security goals are met, (b) reduce costs of production, so that profitability is enhanced, and (c) decrease the amounts of irrigation water required. This innovation is called the System of Rice Intensification (SRI), developed 20 years ago in Madagascar (Stoop et al., 2002; Uphoff, 2003).

A. SRI Origins

The SRI methodology was developed by Fr. Henri de Laulanié, a French Jesuit who spent >3 decades in Madagascar trying to devise improvements in rice production that would improve the lives of Malagasy households, impoverished and heavily dependent on rice. By 1984 he had assembled the set of simple, but synergistic practices that now constitute SRI (Laulanié, 1993). By relying as little as possible on external inputs, he sought a methodology that would be accessible to poor and marginal farmers and environmentally-friendly.

The changes introduced in the management of the rice crop, discussed below, elicit different, more productive *phenotypes* from rice genomes, including larger root systems (see Figures 1a and 1b). That this growth and performance are achieved with substantial reductions in water application, usually between 25 and 50%, should make it of interest to irrigation specialists and policy-makers.

Figure 1a: An individual rice plant grown under SRI conditions. Normally this variety (MTU 7029, known as Swarna), widely grown in Andhra Pradesh and other Indian states, is considered 'shy-tillering.' With SRI methods, the phenotype is quite different with greatly increased tillering and grain formation. Average Swarna yield in Andhra Pradesh has been 6.55 t ha^{-1}; with SRI, it is 10.2 t ha^{-1}, an increase of 55% (photograph courtesy of Dr. A. Satyanarayana, ANGRAU).

Figure 1b: The root system of a single rice plant (MTU 1071 variety) grown with SRI methods at the Maruteru Agricultural Research Station in Andhra Pradesh (photograph courtesy of Dr. P. V. Satyanarayana, Maruteru ARS).

B. SRI Methods

How is 'more crop per drop' achieved? SRI changes the management of rice plants and of the soil, water and nutrients that support them in simple but specific ways. The aim is to create an optimal growing environment for the rice plant so that its genetic potential is better expressed. Plant and other phenotypes are the product of GxE, i.e., the interaction of genetic endowment with environmental conditions. Instead of accepting E as given and trying to raise production primarily by manipulating G, SRI seeks to improve the E for any G. SRI is not a set technology but rather derives from certain insights about how rice plants can be induced to become more productive, particularly by eliciting greater root growth. The methods recommended based on SRI principles should always be tested and adapted to local conditions when utilizing the system, e.g., age of seedlings, spacing, and the amount and timing of water deliveries should be evaluated and adjusted in the field for best results.

1. SRI methods give highest yield when very young seedlings (<15 days and preferably 8-12 days old) are transplanted, preferably before the start of the 4th phyllochron (Stoop et al., 2002). This preserves potential for tillering and root growth that is compromised by later transplanting, as seen from factorial trials (Randriamiharisoa and Uphoff, 2002). Transplanting is not a necessary part of SRI, however, because its concepts and methods are now being adapted for direct seeding, using pre-germinated seed, to save labor. Eventually

much or even most SRI rice may be established this way. But for now, transplanting is the most reliable method.

2. Transplanting should be done carefully to avoid trauma to the plants' roots, and also quickly to avoid their becoming desiccated. Seedlings are raised in a garden-like, unflooded nursery and then moved into the field within 15-30 minutes. Seedlings are planted only 1-2 cm deep, with their roots kept as horizontal as possible. Plunging them into the soil vertically inverts the tips of seedling roots upward and slows plants' recovery from the shock of transplantation.
3. Plant density is greatly reduced compared with conventional rice cultivation. Rather than transplant seedlings in clumps of 4-6 plants, seedlings are transplanted singly and in a square pattern. To begin, 25x25 cm spacing is recommended. But as SRI practices improve the soil over time, wider spacing can give even higher yields. Sparse planting avoids the inhibition of root growth that results from crowding. It also gives plants more exposure to light and air, creating 'the edge effect' (also known as 'the border effect') throughout the whole field.
4. Seedlings are transplanted into a muddy field, not a flooded one. During the vegetative growth phase, paddy soil is kept moist but never continuously saturated. Flooding creates hypoxic soil conditions that cause rice roots to degenerate. Under continuous flooding, up to three-fourths of roots are degraded by time of flowering (Kar et al., 1974). After panicle initiation, irrigating paddies with only 1-3 cm of standing water is recommended. However, even this may be more than necessary. Some SRI farmers are doing alternate wetting and drying (AWD) throughout the crop cycle, with no continuous flooding and good results.
5. To control weeds, use of a mechanical weeder is recommended, starting ~10 days after transplanting, with additional weedings done every 10-12 days until the canopy closes. One or two weedings is usually sufficient to control most weeds. However, additional weedings boost yield, by 0.5-2 t weeding^{-1}. This aeration appears to stimulate the growth of aerobic bacteria and fungi and associated organisms in the soil food web. The square planting pattern allows farmers to weed in perpendicular directions, which achieves more and better soil aeration.
6. SRI was originally developed using chemical fertilizer to augment soil nutrient supplies. When government subsidies were withdrawn in the late 1980s, Laulanié switched to applying compost, and got even better results when this was used with other SRI practices, something advantageous for cash-poor farmers. The benefits from using compost are seen from factorial trials (Uphoff, 2003), but SRI practices can be used with fertilizer if organic matter is scarce.

These six practices, even when used imperfectly, usually confer some benefit on the rice crop. With precision and care, yields in the range of 10-15 t ha^{-2}, or even higher, can be achieved.

III. WATER-SAVING POSSIBILITIES ASSOCIATED WITH ECONOMIC BENEFITS

Evidence on increases in water-saving and income with SRI is beginning to accumulate from a number of countries. Here are results from independent assessments in five countries where SRI has been introduced.

A. China: When the China National Hybrid Rice Research and Development Center began evaluating SRI methods in 2000, it found that with careful management, water applications could be reduced by as much as 65% on its SRI plots compared with conventional irrigated ones, while still getting 1-2 t ha^{-1} more production on top of the record-high yields it was obtaining with the its hybrid varieties (Yuan L-P., pers. comm.). In 2001, an on-station record of 12.9 t ha^{-1} was set at the Center with SRI methods. That year, a Super-1 hybrid variety grown with SRI methods in Sichuan province gave a yield of 16 t ha^{-1} in trials, verified by the Sichuan Provincial Department of Agriculture, 35.6% higher than the 11.8 t ha^{-1} achieved with the same hybrid and conventional, water-intensive methods (Yuan, 2002). In 2004, two yields of 18 t ha^{-1} were achieved with SRI methods and hybrid varieties in Yunnan Province, and one even higher, all with reduced rather than continuous water applications (Uphoff, 2004).

An evaluation done in 2004 for China Agricultural University (CAU) on the use of SRI methods in a village in Sichuan province found that the number of SRI users there had gone from 7 in 2003, to 398 the next year (65% of village farmers). Water reduction for farmers using SRI in the 2004 season was calculated to be 43.2% (Li et al., 2005). Water costs mu^{-1} were reduced from 72.43 yuan with conventional cultivation in 2002 to 39.76 yuan using SRI methods in 2004 (15 mu = 1 ha).

The rapid switch to SRI was partly due to the robustness of SRI yield under water-stress conditions. 2003 was a drought year, when yield with conventional methods declined by one-quarter (from 6,055 kg ha^{-1} in 2002 under normal conditions to 4,468 kg ha^{-1}); however, the yield of farmers who used SRI methods *went up* by 10% (to 6,598 kg ha^{-1}). In 2004, a season with more typical water supply, conventional methods yielded 5,637 kg ha^{-1} while SRI produced 7,606 kg ha^{-1} (Li et al., 2005).

Another incentive for adoption was increased profitability. Gross farmer income mu^{-1}, not counting family labor which farmers do not normally consider as a cost of production, doubled with SRI methods, reaching 377.03 yuan mu^{-1} in 2004 compared with 188.81 yuan mu^{-1} using conventional methods in 2002 (both were average rainfall years). This is a comparison calculated at constant prices. When CAU researchers calculated net income considering an imputed cost for family labor, they found that farmers' net income mu^{-1} had increased by 48% with SRI. In both the survey of SRI users and in focus group discussions, farmers in Xinsheng village identified water-saving as a major advantage of SRI, although labor-saving was rated in both questionnaires and focus groups as SRI's greatest benefit. This was surprising since SRI has been regarded as a more labor-intensive method for growing rice, which we are finding now is not necessarily true.

B. Cambodia: An evaluation of experience with SRI commissioned by GTZ, the German development agency, surveyed 400 SRI users and 100 non-SRI users, randomly selected in 5 provinces of this country (Anthofer et al., 2004). As in the Sri Lanka evaluation, not all 'SRI users' were using all of the recommended practices; yet their average yield was 41% higher than that of non-SRI users, and their economic returns ha^{-1} were 74% higher (note that all SRI plots <0.3 ha were excluded from the analysis to avoid any 'small plot' effect).

No volumetric assessment was made of water use, however, among SRI farmers, flooding during transplanting fell from 96.3% before the adoption of SRI, to 2.5% after, and 'keeping soil just moist' went from 3.5% to 92.3%. During vegetative growth, permanent flooding was reduced from 64.3% to 22.4% while alternating wetting and drying went from 35.7% to 77.6%. This means that water savings were substantial, although given the topography, climate and lack of control structures, careful water management was reported to be the most difficult SRI practice for these Cambodian farmers to adopt. According to the GTZ report, three of the conclusions that farmers drew from their experience with SRI were: 'Less water required,' 'Rice grows well even when the field is dry,' and 'More drought resistance.'

The NGO that introduced SRI into Cambodia, CEDAC, did its own evaluation of 120 farmers who practiced the new methods for three years (2001-2003) to assess changes over time and to consider SRI's sustainability (Tech, 2004). This study found a doubling of yield (with incomplete use of the methods, as in the GTZ study) from 1.34 t ha^{-1} to 2.75 t ha^{-1}. Farmers' rice income ha^{-1} was almost doubled with SRI; they had earned 460,700 riels ha^{-1} before using SRI, and were earning 869,800 riels ha^{-1} three years after adoption.

The volume of water used could not be measured retrospectively, but SRI farmers' cost of water ha^{-1} went from 19,100 riels before adoption to 9,600 riels in their second and third years of SRI use. Specifically, their pumping costs ha^{-1} went from 13,700 riels before, to 7,000 riels in the third year, suggesting that water use was reduced by about half while production and income roughly doubled.

C. Indonesia: In 2003, the Nippon Koei technical assistance team managing the JIBC-funded Small-Scale Irrigation Management Project in Eastern Indonesia began SRI trials with farmers on 1.6 ha. By the end of 2005, 1,849 on-farm comparison trials had been conducted on 1,363 ha, with an average SRI yield of 7.23 t ha^{-1} compared with 3.92 t ha^{-1} with standard methods, an 84% increase. Water saving with SRI was calculated as 40%, while costs of production were reduced by >25% because of reductions in fertilizer application. Calculations of net profitability showed net income ha^{-1} rising from 1.2 million rupiahs with standard methods to 6.2 million rupiahs with SRI. This five-fold increase in part reflected how unprofitable conventional methods are, given high cost of purchased inputs. In the Batu Bulan dam irrigatoin scheme, the benefit-cost ratio increased by 7.2 times (Sato, 2006).

D. Philippines: An evaluation of SRI done in 2003 by farmer field schools supported by the National Irrigation Administration in three communities in Negros Occidental province calculated that they were able to reduce their water use by 67% (Lazaro et al., 2004). Their SRI yield of 7.33 t ha^{-1} was more than double the 3.66 t ha^{-1} produced with TQPM, a 'modern' system of rice production that requires the use of fertilizers and more water. It was almost triple the 2.65 t ha^{-1} obtained from standard farmer practice. Net income ha^{-1} from SRI production was 25,054 pesos, more than double the 11,130 pesos with TQPM and more than triple the 7,592 pesos from farmer practice. So SRI in Negros Occidental made substantial changes both in the water needed for rice production and in farmers' returns from using less water.

E. Sri Lanka: Water-saving potential can been seen also from an evaluation of SRI methods carried out in this country by the International Water Management Institute (IWMI). In 2002, a team of IWMI researchers surveyed 60 farmer using SRI methods and 60 not using them, randomly sampled in two districts (Namara et al., 2004). Most of the 'SRI users' were not using all of the recommended practices, or using all as recommended. But even so, there was a 44% increase in yield with SRI, and more than a doubling of net income ha^{-1} compared to conventional methods.

The average number of paddy irrigations for SRI farmers was 24 in the dry season (yala) and 22 in the wet season (maha), compared with 32 and 29 for non-SRI farmers, a 25% reduction (Namara et al., 2004: Table 10). Given the higher yields obtained with SRI methods, this gave a 90% increase in water productivity in terms of the number of tons of rice produced $irrigation^{-1}$. SRI farmers reported investing 30% fewer hours in irrigation activity. The evaluators noted that the water reduction with SRI would probably have been even greater if groundwater providers had charged farmers on a volumetric basis rather than simply by the number of uses.

These evaluations of SRI experience done for CAU, GTZ, NIA, Nippon Koei, and IWMI in five countries -- Cambodia, China, Indonesia, Philippines and Sri Lanka – all point to substantial water savings being accompanied by significant gains in rice production and profitability.

IV. OTHER INCENTIVES FOR USING LESS WATER WITH SRI

SRI results reported from these and other countries indicate additional benefits from adopting SRI methods that can make the use of less water in irrigated rice production more attractive.

A. Lower Costs of Production and Reduced Agrochemical Use: Because SRI plants develop larger root systems, they can utilize better otherwise-unavailable nutrients in the soil, and their functioning appears to confer greater resistance to pests and diseases, so chemical protection becomes unnecessary or uneconomic. While fertilizer can raise yields when used with the other SRI practices, the highest yields have usually come with the application of compost. Farmers can thus avoid or reduce the cost of chemical fertilizers if they have time and opportunity to collect, compost and apply organic materials, rice straw, manure or any other biomass that can be gleaned from their surroundings. Almost all farmers who have tried SRI methods report that their rice plants are enough healthier and resistant that they no longer need chemical biocides or can greatly reduce their use, consistent with the theory of trophobiosis (Chaboussou, 2004).

When the third author visited Tian Tai country in Zhejiang provice, China, in September 2004, seeing SRI fields that set a provincial yield record of 12.5 t ha^{-1}, farmers and local officials informed him that sheath blight, the major hazard for rice farmers in the area, was reduced by 70% with SRI methods. In Cambodia, where about 20,000 farmers used SRI methods in 2004 (compared with 28 in 2000), the survey reported by Tech (2003) found that compost use had gone up on average from 942 kg ha^{-1} to 2,100 kg ha^{-1} among SRI users, with a doubling of yield, while applications of chemical fertilizer had fallen from 116 kg ha^{-1} to 67 kg ha^{-1}, and use of chemical pesticides went from 35 kg ha^{-1} to 7 kg ha^{-1}. Farmers' cost of production had declined by more than half, from 231,000 riels ha^{-1} before SRI to 113,140 riels ha^{-1} with SRI. (The GTZ evaluation of SRI in Cambodia documented a \$23 $ha^{-}1$ reduction in costs of production, which together with \$66 ha^{-1} from higher yield, raised farmers' net profit ha^{-1} to \$209 ha^{-1}, compared to \$120 ha^{-1} with standard methods). A qualitative benefit that Khmer farmers reported was that SRI reduced the need to make cash expenditures at the start of the season, when farmers have least money on hand.

B. Reduction in Seed Requirements: With SRI, seeding rates are drastically reduced, to 5-10 kg ha^{-1}, about 5-10 times less than conventional rates. Especially for poor farmers, this is a real benefit. Farmers in Madagascar have reduced their need for seed by as much as 100 kg ha^{-1}. Recently, a farmer informed that Chief Minister of Andhra Pradesh that from 2 kg of seed he had produced 92 bags of rice, or 4,600 kg (*The Hindu*, November 16, 2005).

Another important feature of SRI is that farmers do not need to change their variety to get higher yields with less water, since most varieties respond to its practices. To be sure, some respond more than others to the new practices. All SRI yields >15 t ha^{-1} have come from high-yielding varieties (HYVs) or hybrids, so genetic potential is important. Because SRI cuts farmers' seed requirements by 80-90%, those who want to use improved varieties find that the higher cost of seed is no deterrent to planting HYVs or hybrids. While this may not be a huge incentive, if this occurs with less requirement for water, it is a boon to farmers.

At the same time, however, traditional varieties also respond well to SRI practices, showing previously unrealized potential that is inhibited by modern practices such as heavy application of N fertilizer. Some Sri Lankan local varieties have produced >12 t ha^{-1} (Dissanayake, 2002). Since the price received for such varieties is usually often 2-3 times more than for modern ones, SRI is making these 'old' varieties profitable and able to compete with 'new' ones, thereby helping to conserve rice biodiversity.

C. Resistance to Abiotic Stresses: In addition to reduced losses to pests and diseases, it has been observed that SRI plants, given their larger, healthier roots systems, are better able to resist damage from the effects of hurricane (Meishan, Sichuan Province, September 2002); cyclone (Andhra Pradesh Province, December 2003); cold snaps (Andhra Pradesh Province, February, 2004); and drought (Sri Lanka, last three years; also Andhra Pradesh and Cambodia in recent years). SRI rice plants can, of course, be damaged by extreme winds, rain, cold or desiccation; but farmers find that these have observably more resilience and capacity to withstand various climate-induced losses (see Figure 3).

D. Less Economic Risk: Farmers using SRI methods are less subject to economic failures, even though SRI practices initially appear to entail greater risk. Two evaluations based on random samples of SRI users and non-users have found SRI methods to be less risky overall. The IWMI evaluation team in Sri Lanka calculated that SRI rice farmers were >7 times less likely than were conventional farmers to experience a net economic loss in any particular season because of SRI's higher yield and lower cost of production (Namara et al., 2004: Table 15). The GTZ evaluation of Cambodian farmers' experience with SRI, assessing their risk of falling short of some target net income, concluded that for a \$100 ha^{-1} target net income, the risk for an SRI farmer was 17% whereas that of a conventional farmer was 41%. Anthofer et al. (2004: 37) concluded: "SRI is an economically attractive methodology for rice cultivation with a lower economic risk compared to other cultivation practices."

Moreover, SRI farmers in Cambodia saw their risk reduced by the fact that with less need to purchase inputs, they had less cash expenditure exposed to loss if flooding or drought occurred. On the other hand, when there is inadequate capacity to control water applications, the risks with SRI can increase at the start of the season because young seedlings are more vulnerable to damage from continuous submergence. Once their root systems get established, the risks with SRI are generally reduced.

E. Higher Milling Outturn: A bonus with SRI is that in addition to getting a higher yield ha^{-1} of paddy rice, when this unmilled rice is processed there is usually a higher percentage of saleable rice resulting. SRI paddy rice has usually fewer unfilled grains (therefore less chaff) and fewer broken grains after milling (due to less shattering). Andhra Pradesh millers have estimated that their outturn with SRI goes up from ~67% to ~75%, justifying payments to farmers of 10% more bushel^{-1} for SRI paddy. This is also reported from the Mahaweli System 'H' in Sri Lanka (U. G. Abeygunawardena, Ministry of Agriculture, pers. comm.) The first sugar cooperative in Cuba to take up SRI has seen its milling rate with SRI paddy go up by ~15%, from 60% to 68-71% (personal communication, CPA Camilo Cienfuegos, Bahia Honda, Cuba, July, 2004). In China, the milling rate with SRI paddy has been measured to be 16.1% above that of conventionally-grown rice of the same variety, and head milled rice by 17.5% (Jun, 2004). Such increases add to the value of higher SRI paddy yield.

F. Reduction in Crop Cycle: In Nepal, farmers using SRI methods have found that their crops mature 10-20 days sooner compared with the same variety grown conventionally. Dates of planting and harvesting are the least disputable agronomic data. In 2004, 22 farmers harvested their SRI rice on average 15.1 days sooner, with 114% higher yield (7.85 vs. 3.37 t ha^{-1}); in 2005, with less favorable conditions, 54 farmers reduced their time to harvest on average by 19.5 days, with 91% higher yield (5.51 vs. 2.88 t ha^{-1}) (data provided by Rajendra Uprety, district agricultural extension officer, Morang district, Nepal). Harvesting sooner reduces crops' exposure to storm or other damage; it also reduces total amount of irrigation water needed.

V. POSSIBLE LIMITATIONS OR DISADVANTAGES OF SRI

A. Weeding: The most obvious drawback of SRI for most farmers is that when fields are not kept continuously flooded, weed control presents a problem. Use of herbicides is effective, but these do not have the positive effect of aerating the soil that is achieved when rotary hoes or cono-weeders, are used. Such implements not only remove weeds but create more favorable growing conditions for rice plant roots and for the majority of soil biota which are aerobic. This operation can be quite labor-demanding, but its timing is more flexible than for transplanting, and farmers are inventing weeding tools that reduce the labor time required.

B. Labor-Intensity: SRI has been considered too labor-intensive for many farmers. This was given as a reason for disadoption of SRI by up to 40% of farmers, particularly poor ones, surveyed in one study done in Madagascar (Moser and Barrett, 2003). However, as farmers become more comfortable and skilled with the new methods, SRI is becoming *labor-saving*. In the Chinese study reported above, labor-saving was regarded by farmers as the main attraction of SRI, more than its water saving, and more than its yield and profitability increases (Li et al., 2005). In Cambodia, 55% of 120 farmers who have used SRI for three years evaluated it as 'easier' to practice, whereas only 18% considered it 'more difficult'; 27% said there was 'no difference' (Tech, 2004). The GTZ evaluation reported above, analyzing detailed labor input data collected from the 500 Khmer farmers interviewed, concluded that there was on average no significant difference in labor requirements: 305 hrs/ha for SRI vs. 302 $hrs.ha^{-1}$ for conventional methods (Anthofer et al., 2004).[1] When the SRI average is disaggregated, it is seen that beginners require more time than the average but experienced SRI users expend less time ha^{-1}.

An evaluation done of 108 farmers in Madagascar who were using both SRI and conventional methods determined that while first-year users required 20-30% more labor ha^{-1}, by the fourth year, SRI required 4% less labor and by the fifth year, 10% less (Barrett et al., 2004). A study of an adaptation of SRI methods to rainfed rice production in West Bengal carried out by IWMI's India program found both higher yield and net income from SRI accompanied by a reduction in labor requirements ha^{-1} of 8% (Singh and Talati, 2005). Similar results are reported from Tamil Nadu in Section VIII.

Although it previously appeared that the labor-intensity of SRI could be a barrier to its adoption, this seems now to be a transient constraint. Some previous studies, e.g., Namara et al. (2004), regarded SRI as a static technology rather than an evolving methodology modified by farmer learning. Farmers continue to find ways to reduce SRI's labor requirements, such as the roller-marker designed to speed up transplanting and the improved weeders devised by farmers in Andhra Pradesh. Once farmers see SRI as saving labor as well as water and costs of production, it should become widely adoptable.

C. Biomass Limitations: One common constraint identified by farmers is that many do not have access to as much biomass as is recommended for enriching the soil for SRI practices. As noted already, the other SRI methods can be used beneficially with chemical fertilizer, while saving water, if organic sources of nutrients are insufficient. Once farmers come to appreciate the merits of organic soil fertilization, and see the returns they can get from SRI, they begin making more use of available biomass sources and start harvesting and even growing biomass on non-arable areas. Little research and experimentation has been done on how to maximize/optimize biomass production for greater soil fertility. Presently-available tools, implements and transportation equipment are not very adequate for large-scale production, but improvements will probably be made, and surely there is scope for relying more, if not totally, on organic nutrients.

D. Water Control: This is the main objective constraint on SRI adoption, since the methodology hinge on the application of small but reliably available water to the rice crop. In their first few weeks, tiny transplanted seedlings are vulnerable to inundation. This limits their use in monsoon climates where little effort has been made to promote drainage, thinking that maintaining flooded fields is beneficial for the rice crop. Investments in drainage facilities, innovations like raised beds, and better organization among farmers to manage excess water are more profitable with, so they are likely to increase. While water control is important for success with SRI, most of the other methods -- wider spacing, more organic nutrients, reduced water application after flooding subsides -- can be beneficial even without such control.

The various benefits noted in sections III and IV should give farmers considerable incentives to change their production practices for irrigated rice, adopting SRI or some version of it that can reduce water requirements by as much as 25-50%. For such savings to scale up to

[1] Farmers liked the fact that SRI reduced their labor requirements for transplanting by about 10 days ha^{-1}. This operation has to be completed during a time of peak labor demand. While SRI requires 9 days ha^{-1} more labor for weeding, this operation is more flexible in terms of its timing, so it presents less of a problem. Threshing and harvesting the larger SRI crop takes 2 days less labor ha^{-1}. SRI was appreciated because it reduces farmers' need to purchase new seeds, fertilizer, sprays, etc. at the beginning of the planting season when cash reserves are lowest.

system level, of course, all farmers need to change their practices however, so this represents a next-stage challenge.

VI. CRITIQUES OF SRI AND EMPIRICAL EVALUATIONS

SRI remains somewhat controversial as some rice scientists dispute the reports and claims regarding SRI (Surridge, 2004). Recent critiques of SRI (Cassman and Sinclair, 2004; Dobermann, 2004; Sheehy et al., 2004; Sinclair, 2004; McDonald et al., 2006) have not based on direct work with SRI methods in the field or with farmers. The three small trials in China reported by Sheehy et al. (2004), for example, did not follow a protocol that SRI proponents would regard as a real test of the methods as there was no active soil aeration, excessive N fertilizer (180-240 kg ha^{-1}) was applied; some of the SRI trials lodged, which almost never occurs when SRI is done as recommended. For an assessment of the critiques, see Stoop and Kassam (2004).

The conclusion of Sheehy et al. (2004) dismissing SRI as having "no major role in improving rice production generally" based on a single set of contestable trials is contradicted by 5 years of research by rice scientists at major Chinese institutions. These include the China National Rice Research Institute (Zhu, 2002; Tao, 2002; Zhu et al., 2004; Lin et al., 2005), the China National Hybrid Rice Research and Development Center (Wang and Peng, 2003), Nanjing Agricultural University (Wang et al., 2002), and the Sichuan Academy of Agricultural Sciences (Zheng et al., 2004).

These researchers have demonstrated that SRI methods offer some important new opportunities for improving rice production, particularly with reduced use of water, which is becoming a major issue in China. They have repeatedly documented phenotypic differences between rice plants of the same variety grown under SRI conditions vs. plants raised with conventional practices including continuous flooding. In September 2004, the Chinese Ministry of Agriculture put SRI on a short list of technologies to be promoted in the major rice-growing regions of China in its effort to restore growth to that country's rice sector, which has stagnated since 1998.

For the same reason, the Indonesian Agency for Agricultural Research and Development already in 2002 included SRI practices in its new strategy for integrated crop and resource management to restore momentum to its rice sector (Gani et al., 2002). In 2004, the Indian Council for Agricultural Research began supporting SRI demonstrations in all rice-growing parts of that country after reviewing SRI results summarized in sections VII and VIII. On May 31, 2005, the Ministry of Agriculture issued a press release advising Indian rice farmers to use SRI practices "wherever feasible" to increase their yield (and save water). Thus, researchers and policy-makers in the world's three largest rice-producing countries are satisfied that SRI has an important role to play in improving rice production, not least because of its water-saving possibilities.[2]

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[2] Also, there are results from two years of evaluations done in Bangladesh with funding from the International Rice Research Institute (IRRI) program there. The evaluations were done by three NGOs (BRAC, CARE, and POSD), the Bangladesh Rice Research Institute (two sets of trials), and Syngenta Bangladesh Ltd. Five of the six sets of trials clearly demonstrated the advantages of SRI methods in terms of both yield and profitability. Yield was increased by 6-50%, and net farmer income by 4-82% (Husain, 2004). Reductions in water use were reported from most of the on-farm trials, but without measurement of amounts. The only negative findings, based on <2% of the on-farm trials, were reported by Latif et al. (2005).

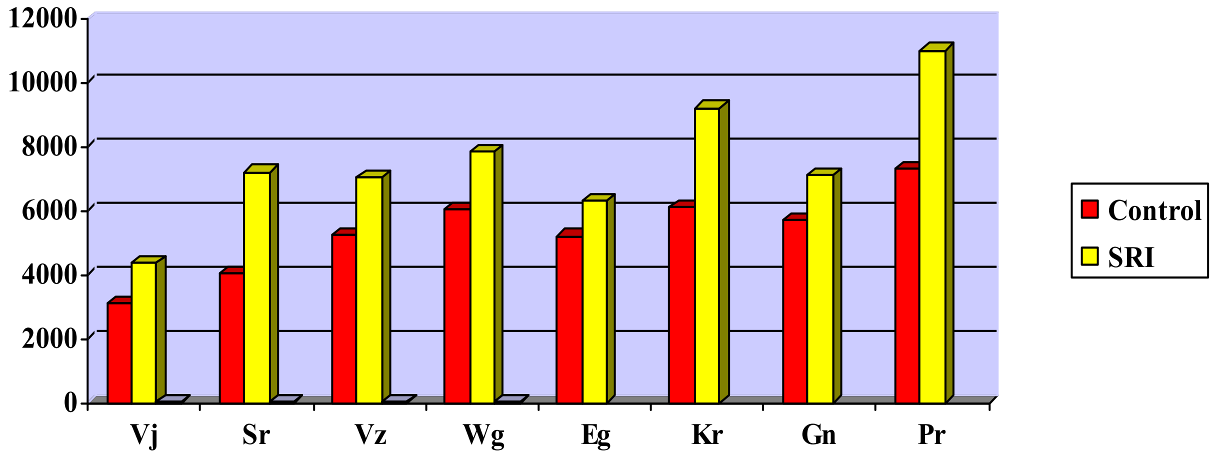
VII. SRI RESULTS IN ANDHRA PRADESH, INDIA

The agricultural sector in the state of Andhra Pradesh (AP) has been affected by ongoing water crises in recent years. Recurrent monsoon failures have been worsened by inter-state disputes over river-water allocations so that crises have political as well as agronomic and economic repercussions. Farmers in the state who depend on irrigation feel insecure, especially as their costs of production keep rising. Production from the state's 45 m ha of land devoted to rice, about 60% of which is irrigated, had previously reached 90 m t. In 2002-03, however, production was only 75.72 m t, the lowest level in 10 years, due mostly to water shortages, as well as diminishing returns from agrochemical inputs. This created a situation where SRI was attractive.

The first author, at the time Director of Extension for AP, visited Sri Lanka in early 2003 to learn about SRI directly from Sri Lankan farmers who were using the new methods. He then established 200 on-farm trials in the 2003 kharif (summer) season, 150 of them supervised by the State's extension service and 50 by his university (ANGRAU). They were spread across all 22 districts of the state to assess the effects of SRI methods with all kinds of soils and irrigation methods. Nineteen varieties were used. The trial areas were each 0.4 ha, 0.2 ha under SRI and 0.2 ha under the farmer's present practice. The data reported in this section were thus controlled for farmer and soil differences. The farmers' practices included mostly modern methods since the resulting yield was well above the average rice yield in AP, 3.87 t ha^{-1}.

Results from the first season's trials are shown in Figures 3a, 3b and 3c for districts in the coastal area, the central Telangana area, and the dryer interior Rayalseema area, respectively.[3] The average regional increases in yield achieved with SRI methods are shown in Table 1, all with reduced water use. SRI's yield advantage was consistent, although it varied by region, reflecting differences in soil characteristics and water management capacity. Results from trials conducted by the Department of Agriculture in 16 districts are shown in Figure 3d. SRI average was 8.34 t ha^{-1} compared to 4.89 t ha^{-1} from the control plots, a 70% increase.

Figure 3a. Paddy yields in on-farm comparison trials supervised by ANGRAU research staff, SRI vs. control, in the coastal region of Andhra Pradesh, by district, kharif season, 2003



[3] Districts in coastal region: Vj=Vizianagaram, Sr=Srikakulam, Vz=Visakhapatnam, Wg=West Godavary, Eg=East Godavari, Kr=Krishna, Gn=Guntur, Pr=Prakasam; districts in Telangana region: Ma=Mahabubnagar, Ra=Rangareddy, Me=Medak, Na=Nalgonda, Wa=Warangal, Kh=Khannam, Ka=Karimnagar, Ni=Nizamabad, Ad=Adilabad; districts in Rayalseema region: Ku=Kurnool, Ka=Kadapa, An=Anantapur, Ch=Chittoor.

Figure 3b. Paddy yields in on-farm comparison trials supervised by ANGRAU research staff, SRI vs. control, in Telangana region, by district, kharif season, 2003

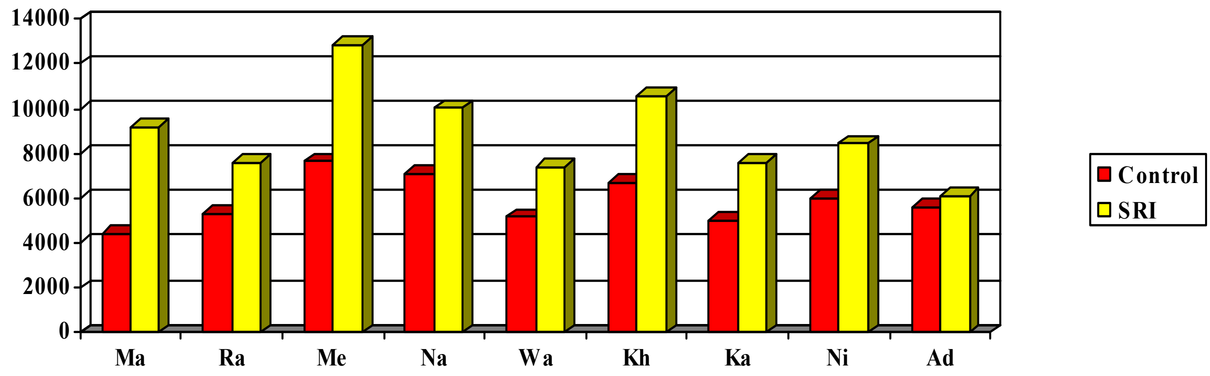


Figure 3c. Paddy yields in on-farm comparison trials supervised by ANGRAU research staff, SRI vs. control, in Rayalseema region, by district, kharif season, 2003

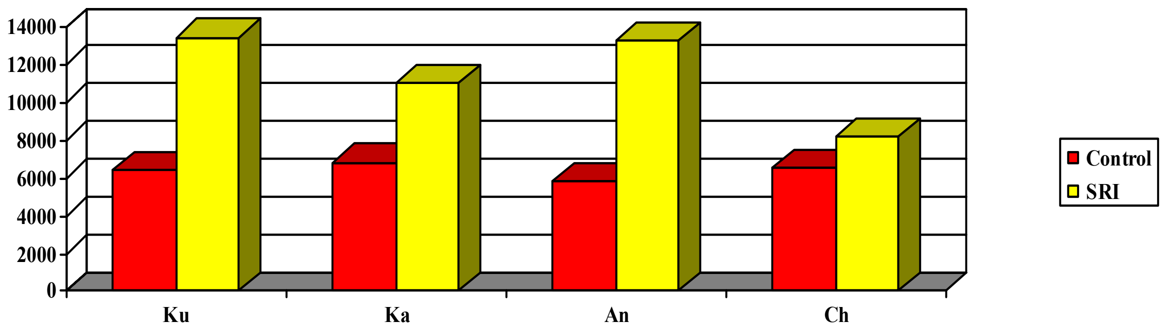


Figure 3d. Paddy yields in on-farm comparison trials supervised by MOA extension staff, SRI vs. control, across whole state, by district, kharif season, 2003

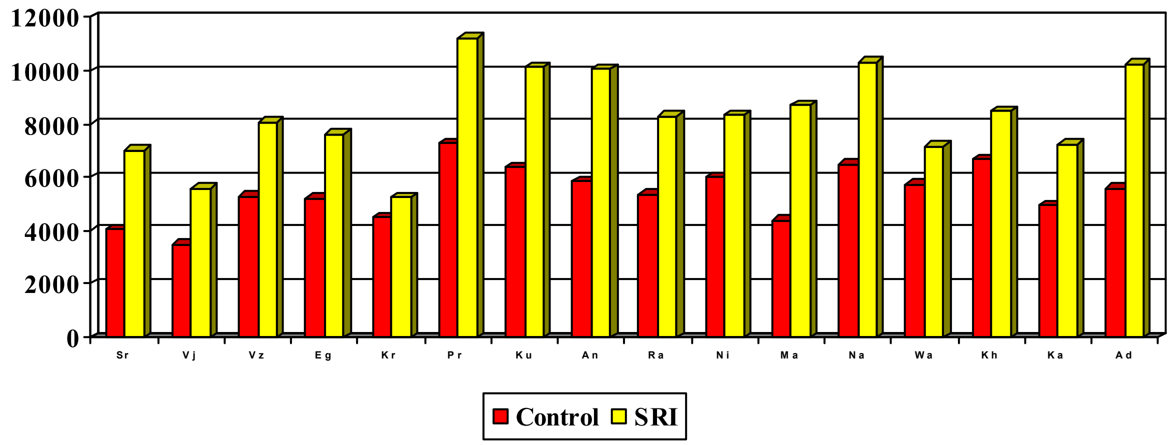


Table 1. Summary of results of on-farm comparison trials, supervised by ANGRAU extension staff, by region, kharif season, 2003

Region	No. of comparison trials	Ave. yield for farmer practice ($t\ ha^{-1}$)	Ave. yield for SRI practices ($t\ ha^{-1}$)	No. of SRI trial yields >10 $t\ ha^{-1}$	Range of SRI yields ($t\ ha^{-1}$)	Ave. SRI yield advantage ($t\ ha^{-1}$)
Rayalseema	10	6.499	11.230	6 (60%)	7.8-15.5	4.731
Telangana	40	6.311	8.815	10 (25%)	4.2-16.2	2.504
Coastal	84	6.539	7.684	17 (20%)	3.2-14.3	1.145

Such results from the kharif season encouraged larger numbers of farmer in rabi season 2003-04 to use SRI methods in Andhra Pradesh. The university and extension service oversaw >2,000 on-farm trials, but many more farmer evaluations were done independently. No complete data collection was possible for all trials, so we can report results only where extension staff supervised the operations and measurement. For 94 comparisons where farms and farmers were the same, the average SRI yield using less water was 9,669 kg ha^{-1} compared with an average of 7,125 kg ha^{-1} with those farmers' current practices.

This average yield increase of 2,554 kg ha^{-1} was a 37.5% increase over an already high yield level. Note that the average control yield in these trials was >80% above the AP average rice yield, 3,870 kg ha^{-1}. One commercial farmer (N. V. R. K. Raju, Kurelagudem, West Godavari district) cultivated a contiguous area of 40 ha with SRI methods using five different varieties. He had an average harvested yield (not based on sampling) of 11.13 t ha^{-1}, adjusted for grain moisture (AP Department of Extension report). As a standard of comparison, note that the average yield increase reported from a series of 'site-specific nutrient management trials' across six Asian countries was only 360 kg ha^{-1} when compared with farmer practice (Dobermann et al., 2002), only 16% as much as was achieved in AP with less water and other costs.

Unfortunately, there were no facilities on farmers' fields to measure their water use, so no exact figures on water saving in Andhra Pradesh can be given here; but all farmers reported using less water with SRI than with conventional practice. The range of reductions reported was 40-50%. Field-level water savings demonstrated thus far only show the *potential* of SRI to reduce water use in irrigated rice production. Full benefits will only be actualized when there is widespread adoption.

The general observations made by AP farmers about their SRI crop were the following:

- Root systems of SRI rice plants are larger, healthier and more functional; their white color shows that they are not dying back as happens with continuous irrigation.
- Tillering is profuse and robust with SRI methods, and SRI rice plants have larger panicles. Contrary to expectations, ripening is observed to be synchronous.
- SRI plants are more resistant to brown plant hopper, blast and sheath blight, reducing the need for chemical applications.
- The period of maturation is shorter, usually by 7-10 d, reducing farmers' risks since typhoons often come at the end of the rice-growing season. This contradicts the claim against SRI reported in Surridge (2004) that SRI rice takes two weeks *longer* to reach maturity.
- During a typhoon in December 2003, SRI fields resisted lodging from the wind and rain; during a cold spell in February 2004, SRI plants were little-affected by the chill.

With such results, interest in SRI is growing rapidly among both farmers and researchers. In the 2004 kharif season, >10,000 farmers used SRI methods, up from just 300 a year before. One of the main incentives that farmers cite for taking up the new system is its water-saving potential. Water shortage is becoming a fact of life for Andhra Pradesh farmers, threatening the continuation of their livelihoods and way of life. In the summer season 2005, the AP Department of Irrigation recruited 1,000 experienced SRI farmers, logistically supported by 25 NGOs, to lead a campaign to spread SRI use to 100,000 ha in major irrigation schemes of the state. The main purpose is to reduce offtakes of increasingly scarce irrigation water. Enhancement of yield and profitability adds to farmers' reasons for adopting SRI's water-saving methods.

VIII. SRI RESULTS IN TAMIL NADU, INDIA

Rice occupies 70% of the total irrigated area in the state of Tamil Nadu (TN) and is grown on 2.0 m ha in different seasons throughout the year, depending upon water availability. This availability is declining, with a projected gap in water supply vs. demand for irrigated crops of about 21 billion m^{-3} by 2025 (Palanisamy and Paramasivam, 2000). Water shortage has already resulted in some reduction of the irrigated rice area in TN with a shift toward less water-demanding crops. During the past two decades, net area sown for rice has declined at an average rate of 84,600 ha yr^{-1}. An offsetting increase in productivity of 82 kg $ha^{-1}yr^{-1}$ has made up about one-third of the impact on rice production from declining area (Thiyagarajan et al., 2000).

The recommended water application for irrigated rice cultivation is 5 cm depth one day after disappearance of flooded water. However, many farmers are unable to follow this recommended practice due to difficulties in controlling water flow and uncertain water availability, so they take even more whenever possible. Consecutive failure of the monsoon rains during the past three years has affected rice production severely through reduced water availability in rivers, tanks and ground water. Given the confluence of (a) water scarcity, (b) declining area under rice, and (c) continuing increase in population, raising rice productivity has become a serious concern to the government and rice scientists.

The advent of SRI is thus timely in Tamil Nadu. Its evaluation by the Crop and Soil Management Center of the Tamil Nadu Agricultural University (TNAU) at Coimbatore started in 2000 with carefully conducted field experiments and then adaptive research trials in farmers' fields with the support from the state government. SRI has now become a prime extension focus for the Department of Agriculture which is promoting it throughout the state. SRI is being recommended for rice production areas in one of the World Bank-supported projects seeking to increase the efficiency of water use in agriculture. Initial experimental results with SRI are reported in an annex to this paper.

Based on TNAU's experimental evaluations that showed increased yield with decreased water use, as well as labor saving in weeding operations and a lower seed rate, the state government accepted a proposal to promote this modified method of rice cultivation in Tamil Nadu beginning in 2003. The Government sanctioned US$50,000 to evaluate SRI in two major rice-growing areas of the State, one of which was the Tamiraparani basin in southern TN.

In Tamiraparani, 100 Adaptive Research Trials (ARTs) were laid out in farmers' fields in different parts of the basin during the rabi (wet) season, October 2003-March 2004. Farmers were exposed to SRI through field demonstrations and were given theoretical explanations so they understood the purpose of the modifications in practice. The trials compared SRI with conventional cultivation on areas of 1,000 m^2 each, two on each farm, without replication. As in Andhra Pradesh, farmer and farm differences were minimized for the sake of comparison.

The recommended SRI components were:

(i) 14-15 d old seedlings from special and simple nursery beds,

(ii) planting single seedlings per hill spaced at 20 x 20 cm to enable the

(iii) use of rotary weeder at 10 d intervals, up to 40-45 days after planting, and

(iv) up to panicle initiation, irrigating to 2.5 cm depth after small cracks developed on the soil surface; after panicle initiation, immediate irrigation was given after ponded water had disappeared.

Seedbed preparation and planting were done under the supervision of TNAU research staff. Rotary weeders were supplied to the farmers, and the trials were continuously monitored.

The utilization of SRI components varied according to local constraints, so not all of the new practices were applied as recommended. Only 36 farmers managed all of the components as expected, with the rest (64) missing some of the components. However, all farmers used 14 d seedlings (conventional practice is around 25 d) and adopted 20 x 20 cm spacing (conventional spacing is 20x10 or 15x10 cm). Ten different varieties were used.

Grain yields were recorded carefully by collecting all the panicles from 5 randomly selected 1 m^{-2} areas from both the SRI and conventional plots and recording the grain weight after threshing and cleaning. The yields, reported at 14% moisture, ranged from 4,214 kg ha^{-1} to 10,655 kg ha^{-1} for SRI and from 3,887 kg ha^{-1} to 8,730 kg ha^{-1} for conventional cultivation (Table 8). The respective mean grain yields of 7,227 kg ha^{-1} and 5,657 kg ha^{-1} showed an overall yield advantage for SRI, even with incomplete utilization, of 1,570 kg ha^{-1} (27.8%).

Thirty-one farmers recorded grain yields of more than 8 t ha^{-1} on their SRI lots, while only 3 conventional plots surpassed this target. The maximum yield advantage recorded for SRI was 4,036 kg ha^{-1}, a 70% increase. Yield increase was due to increased numbers of panicles m^{-2} and increased numbers of grains $panicle^{-1}$. Of the 10 varieties used by farmers, three were found to perform very well under SRI. One of these had been previously regarded as 'shy tillering,' but under SRI, it produced many more tillers, like MTU 7029 variety in AP (Figure 1a).

As seen from the bottom line of Table 3, with SRI methods there was a doubling of farmers' net returns ha^{-1} with also a 8% reduction in overall labor requirements. Men had to work harder at some activities, but women saved a lot of time in transplanting and other operations. Usually SRI methods have been thought to *add* to farmers' total labor requirement. The lower labor requirement together with higher yield meant that SRI increased labor productivity (rice kg d^{-1}) by almost 40%. The 40-50% reduction in water use reported meant that water productivity (rice kg m^{-3} water) was raised by >130%.

Planting in a square pattern was the only constraint that farmers singled out, noting that the traditional method of random planting is quicker.

The results of SRI evaluations conducted through this large set of ARTs paved the way for getting support from extension staff and leadership of the state's Department of Agriculture. Demonstration trials have now been laid out in all rice areas of the state, which should speed the adoption of SRI by still more farmers. From conversations with farmers, one of the reasons making them more receptive to SRI is the opportunity they see to reduce their water requirements. Not only will this reduce labor and costs, but it can also lessen conflict with neighbors when water is scarce.

Table 3. Comparison of yield, labor requirement, costs of cultivation, and net returns from conventional and SRI in farmers' fields (N=100)

	Conventional cultivation		SRI cultivation		% difference	
	Low	High	Low	High	Low	High
Grain yield (kg ha^{-1})	3,887	8,730	4,214	10,655	+8.4	+22.1
Average grain yield (kg ha^{-1})	5,657		7,227		+ 27.8	
Male labor requirement ha^{-1}	50		83		+ 66.0	
Female labor requirement ha^{-1}	222		167		- 24.8	
Total labor requirement ha^{-1}	272		250		- 8.1	
Costs of cultivation ha^{-1}	21,424		19,060		- 10.0	
Net economic return (Rs ha^{-1})	11,149		23,868		+ 114.1	

The benefits reported by TN farmers from using SRI practices were the following:

(i) Drastic reduction in seed rate, from 60-75 kg ha^{-1} to 7.5 kg ha^{-1}.
(ii) No need to use herbicides.
(iii) Multiple advantages from using the rotary weeder: weed control, less time required for weeding, incorporation of top-dressed fertilizer, aeration of the soil, incorporation of weeds and their nutrients back into the soil, and increased tillering.
(iv) Water savings of 40-50%.
(v) Increased number of panicles m^{-2}, grains $panicle^{-1}$, grain yield, and straw yield.
(vi) Higher net profit for farmers.

VI. DISCUSSION

Because SRI is still a new methodology, developed purely inductively, further improvements will probably be made as its theoretical and empirical foundations are strengthened. SRI is an unusual agricultural innovation in that its results are often better on farmers’ fields than those that researchers obtain on-station. This observation has directed our attention to consideration of factors of soil biology. These can be highly variable and can be adversely affected by sustained applications of chemical fertilizer and agrochemical biocides. There is some hard evidence to support this proposition (Chaboussou, 2004), but until more systematic research has been conducted on this question, it will remain formally a hypothesis.

The data reported in sections VII and VIII confirm observations and measured results from other countries that SRI offers multiple advantages and raises factor productivity, not just for water or for land, but across the full range of production inputs. That these benefits can be accomplished with less use of water is counterintuitive, given that rice has been considered to be hydrophilic if not exactly aquatic. However, maintaining aerobic soil conditions benefits both plant roots and soil organisms. The latter mobilize soil nutrients for plants and provide other services, starting with N-fixation and P solubilization by bacteria and nutrient and water access through mycorrhizal fungi (see, e.g., Doebbelaere et al., 2003). Such processes which could be producing SRI effects have been discussed in Randriamiharisoa et al. (2005).

An understanding of soil ecology reinforces the idea that water applications for irrigated rice production should be optimized – not maximized. While rice plants need water, their roots need oxygen as well. So do the aerobic microbes (rhizobia, mycorrhizal fungi, etc.) and other soil flora and fauna that are beneficial for rice plant nutrition and health (Yanni et al., 2001; Martin et al., 2001). The results that SRI methods can attain of more yield with less water must, of course, have demonstrable scientific explanations. There is, however, enough understanding and repetition of these results that practitioners can begin to utilize these practices while scientists from multiple disciplines work to establish more complete and rigorous explanations for them.

REFERENCES

Anthofer, Jürgen et al. 2004. Evaluation of the System of Rice Intensification (SRI) in Cambodia, February-April 2004. Report to GTZ, Phnom Penh.

Barrett, C. B., C. M. Moser, O. V. McHugh, and J. Barison, 2004. Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *American Journal of Agricultural Economics*, 86, 869-888.

Cassman, K. G., and T. R. Sinclair. 2004. Agronomic UFOs. *ACSSA: Agronomy, Crop and Soil Science Alert*, March.

Chaboussou, Francis. 2004. *Healthy Crops: A New Agricultural Revolution*. Jon Anderson, Charnley, UK.

DeDatta, S. K. 1981. *Principles and Practices of Rice Production*. New York: John Wiley.

Dissanayake, Salinda. 2002. A policy-maker's perspective on SRI in Sri Lanka. In: N. Uphoff et al., eds., *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*, pp. 26-28. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development

Dobermann, Achim, et al. 2002. Site-specific nutrient management for intensive rice cropping systems in Asia. *Field Crops Research* 74: 37-66

Dobermann, Achim. 2004. A critical assessment of the system of rice intensification (SRI). 2003. *Agricultural Systems* 79: 261-281.

Doebbelaere, S., J. Vanderleyden, and Y. Okon. 2003. Plant growth-promoting effects of diazotrophs in the rhizosphere. *Critical Review in Plant Science* 22: 107-149.

Gani, A., et al. 2002. The System of Rice Intensification in Indonesia. In: N. Uphoff et al., eds., *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*, pp. 58-63. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development.

Guerra, L. C., S. I. Bhuiyan, T. P. Thuong, and R. Barker. 1998. *Producing More Rice with Less Water in Irrigated Systems.* SWIM Paper No. 5. Colombo: International Water Management Institute.

Husain, A. M. Muazzan. 2004. Evaluation of System of Rice Intensification (SRI) trials in Bangladesh: Results from PETRRA sub-projects. Paper presented at World Rice Research Conference, Tsukuba, Japan, Nov. 7.

Kar, S., S. B. Varade, T. K. Subramanyam, and B. P. Ghildyal. 1974. Nature and growth pattern of rice root system under submerged and unsaturated conditions. *Riso* (Italy), 23: 173-179.

Latif, M. A., M. R. Islam, M.Y. Ali and M. A. Saleque. 2005. Validation of the system of rice intensification (SRI) in Bangladesh. *Field Crops Research* 93, 281-292.

Laulanié, H. 1993. Le système de riziculture intensive malgache. *Tropicultura* (Brussels) 11: 110-114.

Lazaro, R. C. et al. 2004. Water-saving high-yielding TQPM and SRI trial runs and demonstrations in the Magballo-Balicotoc-Canlamay Integrated Irrigation Sub-Project. Report to National Irrigation Administration, Quezon City, from the Southern Philippines Irrigation Support Project.

Li, Xiaoyun, Xu Xiuli, and Li He. 2005. A socio-economic assessment of the System of Rice Intensification (SRI): A case study from Xiushang village, Jianyang county, Sichuan province. Report for the Center for Integrated Agricultural Development, China Agricultural University, Beijing.

Lin Xianqing, Weijun Zhou, Defeng Zhu, and Yubin Zhang. 2005. Effect of SWD irrigation on photosynthesis and grain yield of rice (*Oryza sativa* L.). *Field Crops Research*, forthcoming.

Martin, F. M., S. Perotto, and P. Bonfante. 2001. Mycorrhizal fungi: A fungal community at the interface between soil and roots. In: R. Pinton, Z. Varanini, and P. Nannipieri, eds., *The Rhizosphere: Biochemistry and Organic Substances at the Soil-Plant Interface*, 263-296. New York: Marcel Dekker.

McDonald, A.J., P.R. Hobbs, and S.J. Riha, 2006. Does the system of rice intensification outperform conventional best management? A synopsis of the empirical record. *Field Crops Research*, 96, 31-36.

Moser, C. M., and C. B. Barrett. 2003. The disappointing adoption dynamics of a yield-increasing, low-external-input technology: The case of SRI in Madagascar. *Agricultural Systems* 76: 1085-1100.

Namara, R. E., P. Weligamage, and R. Barker. 2004. *Prospects for Adopting System of Rice Intensification in Sri Lanka: A Socioeconomic Assessment*. Research Report 75. Colombo: International Water Management Institute.

Palanisamy, K. and P. Paramasivam. 2000. Water scenario in Tamil Nadu – Present and future. In: S. Kannaiyan and C. Ramasamy, eds. *Agriculture 2000*. Coimbatore, India: Tamil Nadu Agricultural University, pp. 36-46.

Ramasamy, S., H. F. M. ten Berge, and S. Purushothaman. 1997. Yield formation in rice in response to drainage and nitrogen application. *Field Crops Research* 51: 65-82.

Randriamiharisoa, Robert, and Norman Uphoff. 2002. Factorial trials evaluating the separate and combined effects of SRI practices. In: N. Uphoff et al., eds., *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*, pp. 40-46. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development.

Randriamiharisoa, Robert, Joeli Barison, and Norman Uphoff. 2005. Soil biological contributions to the System of Rice Production. In: N. Uphoff et al., eds., *Biological Approaches to Sustainable Soil Systems*. CRC Press, Boca Raton, FL, forthcoming.

Sato, Shuichi. 2006. An evaluation of the System of Rice Intensification (SRI) in Eastern Indonesia for its potential to save water while increasing productivity and profitability. Paper for International Dialogue on Rice and Water: Exploring Options for Food Security and Sustainable Environments, IRRI, Los Baños, March 7-8.

Sheehy, J. E., S. Peng, A. Dobermann, P. L. Mitchell, A. Ferrer, J. Yang, Y. Zou, X. Zhong, and J. Huang. 2004. Fantastic yields in the system of rice intensification: Fact or fallacy? *Field Crops Research*, forthcoming.

Sinclair, Thomas R. 2004. Agronomic UFOs waste valuable scientific resources. *Rice Today* 3: 43.

Singh, S.K. and Talati, J. 2005. Impact of the System of Rice Intensification (SRI) on Rice Yields: Results of a New Sample Study in Purulia District, India. IWMI-Tata Water Policy Research Highlight No. 47. International Water Management Institute, India Program, Anand.

Stoop, W., N. Uphoff, and A. Kassam. 2002. A review of agricultural research issues raised by the System of Rice Intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-poor farmers. Agricultural Systems 71: 249-274.

Stoop, W. and A. Kassam. 2004. The SRI controversy: A response. *Field Crops Research* (forthcoming).

Surridge, Christopher. 2004. Feast or famine? *Nature* 428, March 25, pp. 360-361.

Tao Longxing, Wang Xi, and Min Shaokai. 2002. Physiological effects of SRI methods on the rice plant. 2002. In: In: N. Uphoff et al., eds., *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*, pp. 132-136. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development.

Tech, Chey. 2004. Ecological System of Rice Intensification (SRI) Impact Assessment. CEDAC Field Document. Phnom Penh: Cambodian Center for Agricultural Studies and Development.

Thiyagarajan, T.M. and R. Selvaraju. 2001. Water-saving rice cultivation in India. In: *Water-saving rice production systems. Proceedings of an International Workshop on Water-Saving Rice Production Systems at Nanjing University, China, April 2-4, 2001*, pp. 15-68. Wageningen, Netherlands: Plant Research International B.V.

Thiyagarajan, T.M., C. R. Ranganathan, A. Bhaskaran, K.K. Mathan, and T.V. Karivaradaraju. 2000. Trends in rice area, production and productivity in the different agroclimatic zones of Tamil Nadu. *Madras Agricultural Journal* 87: 4-6, 287-290.

Uphoff, Norman, E. C. M. Fernandes, Yuan Longping, Peng Jiming, S. Rafaralahy, and J. Rabenandrasana, eds. 2002. *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development. On the web from: http://ciifad.cornell.edu/sri/

Uphoff, N. 2003. Higher yields with fewer external inputs? The System of Rice Intensification and potential contributions to agricultural sustainability. International Journal of Agricultural Sustainability, 1: 38-50.

Uphoff, N. 2004. Report on visit to China, August-September 2004, for review of System of Rice Intensification (SRI) activities and progress. [web address]

Uphoff, N. 2005. [*reference to paper to appear in proceedings from September 2002 conference at Killikulam, Tamil Nadu, India, cosponsored by IRRI and TNAU*]

Wang Shaohua, Cao Weixing, Jiang Dong, Dai Tingbo, and Zhu Yan. 2002. Physiological characteristics and high-yield techniques with SRI rice. In: In: N. Uphoff et al., eds., *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*, pp. 116-124. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development.

Wang Xuehua, and Peng Jiming. 2003. A comparison between System of Rice Intensification and conventional cultivation methods. Report for China National Hybrid Rice Research and Development Center, Changsha.

Yanni, Y. G. et al. (2001). The beneficial plant growth-promoting association of *Rhizobium leguminosarum* bv. trifolii with rice roots. *Australian Journal of Plant Physiology* 28: 845-870.

Yuan L. P. 2002. A scientist's perspective on experience with SRI in China for raising the yields of super hybrid rice. In: N. Uphoff et al., eds., *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*, pp. 23-25. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development. Available on the web from: http://ciifad.cornell.edu/sri/

Zheng Jiaguo, Xianjun Lu, Xinlu Jiang, and Yonglu Tang. 2004. The system of rice intensification (SRI) for super-high yields in rice in Sichuan Basin. Poster for 4th International Crop Science Congress, September, Brisbane, Australia.

Zhu Defeng, Cheng Shihua, Zhang Yuping, and Lin Xiaqing. 2002. Tillering patterns and the contribution of tillers to grain yield with hybrid rice and wide spacing. In: N. Uphoff et al., eds., *Assessment of the System of Rice Intensification: Proceedings of an International Conference, Sanya, China, April 1-4, 2000*, pp. 125-131. Ithaca, NY: Cornell International Institute for Food, Agriculture and Development. Available on the web from: http://ciifad.cornell.edu/sri/

Zhu Defeng, Lin Xianqing, Tao Longxing, Zhang Yuping, Lu Shihua, and Jin Xueyong. 2004. SRI practice and adaptability in China. Paper by researchers from the China National Rice Research Institute, Sichuan Academy of Agricultural Sciences, and Northeastern Agricultural University, for publication in China.

Zhu Defeng, Lin Xianqing, Chen Huizhe, Zhang Yuping and Jin Xueyong. 2004a. Effects of SRI methods on rice yield and water saving in China. Abstract for World Rice Research Conference, Tsukuba, Japan, November 4-7, 2004.

ANNEX: EXPERIMENTAL EVALUATIONS OF SRI IN TAMIL NADU

The first assessment of SRI was conducted in 2000 at the wetland farm of Tamil Nadu Agricultural University (TNAU), Coimbatore, with different methods of crop establishment, spacing, and water management. The initial results did not show any advantage from SRI methods as grain yields were lower with plant density of 16 m^{-2} or less. The trials did show, however, that normal yields could be obtained with a plant density of ≥32 m^{-2} without flooding the field. So the evaluation was carried forward given the interest in any water-saving possibilities.

During the next two seasons, on-station experiments were conducted with two different varieties in the same location under controlled conditions as part of a project on water-saving for rice funded by the Dutch Ministry of Agriculture. Various components of SRI were assessed with replicated trials, using a Parshall flume to measure irrigation water use, also monitoring rainfall during the growing season. The plant density used for all treatments was 25 m^{-2} with square planting that permitted the criss-cross (perpendicular) use of a rotary weeder. Since the most common plant density in Tamil Nadu is 50 m^{-2} for medium-duration (125-135 d) variety and 66 m^{-2} for short-duration (105-115d) rice, this was a 50-62% reduction in density.

Overall yield increases were realized from the combined effects of these management practices, with the highest yield obtained from the SRI practices (7,612 kg ha^{-1}). Mean grain yield for all water-saving treatments (6,352 kg ha^{-1}) was on par with conventional practice (6,461 kg ha^{-1}), indicating that use of younger seedlings and soil-aerating weeding had a beneficial effect. Of particular interest was the finding that *in-situ* incorporation of weeds into the soil with the rotating hoe, part of SRI practice, significantly increased yield (6,737 kg ha^{-1}) compared to conventional weeding (6,076 kg ha^{-1}). How much of this effect was due to the return of nutrients to the soil, and how much to soil aeration could not be determined, however.

The productivity of water used in rice production was found to be substantially higher (by 50-82%) under SRI water control, 0.613-0.732 kg m^{-3}, compared to conventional irrigation, 0.398-0.402 kg m^{-3}. Conventional water management (flooding) with conventional crop establishment gave the lowest yield (6,126 kg ha^{-1}), although SRI water management with young seedlings was not much higher in these trials (6,290 kg ha^{-1}). SRI methods did not show consistent advantages in these trials, although mechanical weeding had the strongest impact on yield.

In the next season using rice variety ADTRH 1, a significant positive effect of direct seeding and mechanical weeding was observed. Water-saving irrigation had a negative effect, but this could be attributed to the continuation of limited irrigation up to harvest. A summary table shows the effects attributable to crop establishment, water and weed control (also of green manure treatments) in both seasons. It documents the importance of the combined effects of the new management practices. The beneficial effect of young seedlings is clearly seen (Table A1).

Table A1. Grain yield, kg ha-1, @ 14% moisture of hybrid rice in wet and dry seasons as influenced by management practices, TNAU, Coimbatore, India

Management Package	Wet season: CORH-2 (hybrid)	Dry season: ADTRH-1 (hybrid)	Effect of changed management practice(s) when compared to conventional practices
▪ Conventional seedlings ▪ Conventional irrigation ▪ Conventional weeding	6000	6261	Normal yield for this site
▪ Conventional seedlings ▪ Water-saving irrigation ▪ Conventional weeding	6195	5809	Water-saving irrigation slightly increased yield in the wet season, but reduced it in the dry season, by 7%
▪ Conventional seedlings ▪ Conventional irrigation ▪ Mechanical weeding	6343	6311	Introducing mechanical (soil-aerating) weeding increased yield in both seasons
▪ Conventional seedlings ▪ Water-saving irrigation ▪ Mechanical weeding	6348	6080	Water-saving irrigation and mechanical weeding increased yield in wet season by 6%, but reduced it in dry season by 3%
▪ Younger seedlings ▪ Conventional irrigation ▪ Mechanical weeding	7612	6941	Younger seedlings in wet season and direct seeding in dry season plus mechanical weeding increased yield by 27% in wet season and 11% in dry season
▪ Younger seedlings ▪ Water-saving irrigation ▪ Mechanical weeding	7126	6612	Modifying all three management practices increased the yield by 19 % in wet season and 6 % in dry season -- with a water saving of about 50 %

Conventional seedlings	:	21 d old from standard nursery
Younger seedlings	:	14 d old from unflooded nursery in wet season and wet-seeded in dry season
Conventional irrigation	:	Irrigating to 5 cm depth one day after disappearance of ponded water
Water-saving irrigation	:	Irrigating to 2 cm depth after surface cracks develop (up to flowering in the wet season and up to maturity in the dry season)
Conventional weeding	:	Hand weeding (or herbicide + hand weeding)
Mechanical weeding	:	Rotary weeding 5 times in between hills planted squarely (20x20 cm)

Water productivity (grain yield per unit of total water used, considering both irrigation and rainfall) varied in the wet season between 0.349 to 0.788 kg m^{-3} and in the dry season between 0.384 to 0.898 kg m^{-3} for different crop establishment and water-control practices (Table A2). The highest water productivity was obtained from using conventional seedlings and limited irrigation in both crop seasons, with water productivity increased by 46% and 49% in the wet and dry season, respectively, compared to conventional flooded irrigation. With the use of modified crop establishment methods i.e., young seedlings, water productivity increased by 36 and 45% in the wet and dry season, respectively, compared to transplanting 24 d old seedlings (Thiyagarajan et al., 2002). These water productivity levels are in line with data for India presented by Bouman and Tuong (2000), indicating productivity levels from 0.2 to 0.4 kg m^{-3}.

Table A2. Water productivity for conventional and SRI planting under conventional and limited irrigation during wet season (September 2001-January 2002) and dry season (January-June 2002), TNAU, Coimbatore, India

	Conventional planting		Modified SRI planting	
	Conventional irrigation	Modified SRI irrigation	Conventional irrigation	Modified SRI irrigation
Wet season				
Total number of irrigations	14	9	16	11
Total water irrigated (m^3 ha^{-1})	11,853	5,205	13,347	6,699
Cumulative rainfall during the crop period (m^3 ha^{-1})	3,560	3,560	3,560	3,560
Total water used (m^3 ha^{-1})	15,143	8,765	16,907	10,259
Yield (kg ha^{-1})	6,126	6,413	6,796	6,290
Water productivity (kg m^{-3})	0.398	0.732	0.402	0.613
Dry season				
Total number of irrigations	21	15	25	18
Total water irrigated (m^3 ha^{-1})	13,406	6,213	16,634	8,419
Cumulative rainfall during the crop period (m^3 ha^{-1})	560	560	560	560
Total water used (m^3 ha^{-1})	13,966	6,773	17,194	8,979
Yield (kg ha^{-1})	6,205	5,899	6,778	6,442
Water productivity (kg m^{-3})	0.444	0.871	0.394	0.718

Further experiments were conducted in rabi season November 2003-February 2004 with split-plot design and cultivar ADT 43 (110 d duration) at the TNAU Agricultural College and Research Institute, Killikulam (8º46' N; 77º42' E; 40 m above MSL).[4] The main plot compared two methods of cultivation (SRI vs. conventional), while sub-plots assessed five nitrogen management practices: two levels of N: 60 and 120 kg N ha^{-1} in the form of prilled urea (PU) and polymer-coated urea (PCU) vs. no nitrogen application. The respective practices followed for the SRI and conventional methods are given in Table A3.

[4] Pertinent agronomic information: sandy clay loam soil (pH 8.2; EC 0.35dSm^{-1}; organic carbon 8.7 g.kg^{-1}; CEC 37.5 c mol (p+) kg^{-1}; mineralization N 160 kg.ha^{-1}; Olsen P 15.5 kg.ha^{-1}; NH_4OAcK 220 kg.ha^{-1}).

Table A3. Differences in practices followed with conventional and SRI methods of cultivation

Practices	Conventional	SRI
Nursery	Area: 800 m^2 Seed rate: 20 kg ha^{-1}	Area: 100 m^2 Seed rate: 7.5 kg ha^{-1}
Planting	21 d seedlings planted at 20x15 cm spacing, 2-3 $hill^{-1}$	14d seedlings planted at 20x20 cm spacing, 1 $hill^{-1}$
Irrigation	Irrigate to 5 cm depth one day after the disappearance of ponded water	Up to panicle initiation, irrigate to 2.5 cm depth after hairline crack formation; thereafter, irrigate to 2.5 cm depth after disappearance of ponded water.
Weeding	Removal of weeds at 15, 30 and 45 DAT manually	Rotary weeding in between rows at 15, 30 and 45 DAT

One of the objectives of this experiment was to assess the effectiveness of PCU fertilization compared with SRI practice. Data on crop growth parameters were recorded, and SPAD value, chlorophyll content (at panicle initiation stage), lodging ratio, and grain yield were collected. The grain yields achieved for the whole experiment were relatively low because of an initial setback to the entire crop due to pest damage. However, despite this, the SRI methods of cultivation gave a 28% increase in grain yield, with SRI yield improvements observed under all N management practices (Table A4). Of most scientific interest were the systematic changes in phenotypical characteristics of the rice plants grown with SRI methods vs. those conventionally grown. A comparison of parameters such as root growth, chlorophyll content, lodging resistance and grain production showed consistently more favorable values for SRI practices (Table A5).

Table A4: Grain yield under conventional and SRI method of cultivation with different N management practices

N management	Grain yield (kg ha^{-1})		Additional effect of SRI methods (%)
	Conventional	SRI	
No nitrogen	2345	2867	22.3
60 kg N ha^{-1} (PU)	2626	3476	32.4
60 kg N ha^{-1} (PCU)	2997	3972	32.5
120 kg N ha^{-1} (PU)	3470	4299	23.9
120 kg N ha^{-1} (PCU)	3755	4848	29.1

Table A5: Plant characteristics and grain yield (mean values) under conventional and SRI methods of cultivation

Parameters	Conventional	SRI	*LSD (5%)*	SRI Change (%)
Root length (cm)	13.2	15.6	*1.7*	+18.2
Root volume (m^3 ha^{-1})	10.8	12.9	*0.7*	+19.4
Tiller density (m^{-2})	458	477	*7.3*	+4.1
SPAD value	33.9	36.1	*1.14*	+6.5
Chlorophyll a (mg g^{-1})	1.72	2.41	*0.06*	+40.1
Chlorophyll b (mg g^{-1})	1.00	1.07	*0.01*	+7.0
No. of panicles m^{-2}	437	453	*5*	+3.7
No. of grains m^{-2}	117	148	*26*	+26.5
Lodging ratio (%)	48.5	42.7	*1.6*	-12.0
Grain yield (kg ha^{-1})	3,039	3,893	*515*	+28.1
Fertilizer partial factor productivity (kg [kg N] $^{-1}$)	39.5	50.8	-	+28.6
Agronomic efficiency	10.1	15.3	-	+51.5
Physiological efficiency	32.5	41.1	-	+26.5
Recovery efficiency	30.3	37.6	-	+24.1