Increasing rice yields and saving water: Lessons for Policy and Practice
- The System of Rice Intensification (SRI)

Erika Styger, SRI-Rice (SRI International Network and Resources Center), Cornell University, Ithaca, NY, USA (eds8@cornell.edu)

The challenge

It is predicted that agricultural production will need to increase by 70% by the year 2050 to feed a population of nine billion people. By that date, 47% of the world's population could be living under severe water stress, according to OECD projections (OECD, 2012). Competition for agriculture water use will become more serious with growing urbanization and industrialization. More extreme weather patterns owing to climate change will increase incidences of drought and flooding. Food security will depend on increasing agriculture production while using less water. How can we get more crop per drop?

In particular, this challenge concerns the water-intensive rice crop, the staple food for more than half of the world population. Growing rice accounts for one-quarter to one-third of global fresh water withdrawals (Bouman et al., 2007). Under the current practice of continuously-flooded rice paddies, rice crops receive two to three times more water than other irrigated cereal crops, even though rice has a similar transpiration rate (internal water used for plant growth and production) as wheat and other cereals. (Tuong et al., 2005, cited by Bouman et al., 2007).

Developing methodologies that improve water-use efficiency, or water productivity (WP) in rice production will allow for saving water and for its reallocation to other uses. Water productivity is defined as the amount of agriculture production (grain yield) per amount of water used and is measured in kg/m3 (kg of rice produced per cubic metre of water, or per 1000 litres of water).

How is water used in an irrigated rice cropping system?

Let's look at the water cycle of an irrigated rice field. The water cycle consists of <u>inflows</u> – irrigation and rainfall, and of <u>outflows</u> – transpiration, evaporation, overbund flow, seepage and percolation. The last-named three outflows refer to water movement either on the land surface or sideways and downward through the soil. Although this water movement is considered a loss for irrigation, water is not lost from the aquifer, as it either replenishes groundwater or becomes available again further downstream. Water is lost from the aquifer when it enters the atmosphere through evaporation (water evaporates from puddled water in the rice paddy, soil, rivers, lakes, rocks or pavement) or through transpiration (loss of water vapour from plants). As it is difficult to measure evaporation and transpiration separately, the two are often combined under the term "evapotranspiration."

How much water is needed to produce 1 kilogram of rice?

To produce 1 kg of rice, on average 2500 l/kg is used under the conventional rice production system (equal to a water productivity of 0.4 kg/m^3), although this varies widely, from 800 l/kg to 5000 l/kg (this includes transpiration, evaporation, percolage and seepage). Transpiration alone requires from 500-1000 litres of water per kg. Evapotranspiration requires an average of 1430 l/kg, ranging from 600 to 1700 l/kg, which is about the same as for other cereals such as wheat (Bouman et al., 2007).

What are the opportunities to reduce water consumption for rice?

There are a number of options for farmers to save water in irrigated rice production: reduced tillage, good land levelling, use of an alternate wetting and drying (AWD) irrigation method, working with raised beds, using mulch to provide soil cover, and cultivating aerobic rice, among others. (Bouman *et al*., 2007; Thakur *et al*., 2011). The World Bank (2012) recommends the prioritization of reducing non-beneficial evaporation to improve irrigation, as seepage and percolation are playing a role in replenishing groundwater tables.

In this article, we focus our discussion on alternate wetting and drying irrigation (AWD), which is a popular method promoted by a large number of research and development organizations. It allows direct reduction of the amount of irrigation water applied to the rice paddy. AWD is also called 'intermittent irrigation' or 'controlled irrigation'. During the vegetative period of the rice crop, irrigation water is applied to obtain flooded conditions, which is followed by letting the rice paddies dry for one to ten days or more. It is recommended that a thin layer of water be maintained during the flowering period. During grain filling, alternate flooding and drying can be applied anew, and, 2-3 weeks before harvest, the paddy can be drained. AWD stands in contrast to conventional irrigation practice, where rice paddies are kept flooded throughout the entire growing season.

AWD is today applied with different rice growing methods. AWD is integrated with the conventional method of growing rice as well as with the System of Rice Intensification (SRI), where AWD is a core component of the system. The difference between the two rice production systems is explained in the next section. It has been shown that in both systems, irrigation water application can be reduced by 20-50% with the application of AWD. However, the impact of reduced irrigation water use on rice productivity differs between the two systems.

For conventional crop management, AWD is applied instead of continuous flooding, which is the standard irrigation method. Although water productivity is increased, yields associated with AWD can either be maintained or decreased compared to continuous flooding. In 31 field experiments analysed by Bouman and Tuong (2001), 92% of the AWD treatments resulted in yield reductions varying from 0% to 70% compared with those of the flooded control plots. Yao et al. (2012) testing "super hybrid" variety and a "water-saving and drought-resistant" variety found a water saving of 24%-38% with AWD compared to continuously flooded plots, but no significant difference in yield between the two treatments.

In contrast, under the SRI system, reducing irrigation water application, done through the AWD method, is one of the main principles of SRI. Here, AWD is co-responsible for saving water and increasing yields. This is reported in a number of studies from Kenya, Tamil Nadu and Andhra Pradesh States in India, and Hangzhou China, among other studies, which report water productivity improvements from 32-100%, with associated yield increases of 5-51%. (Zhao et al., 2009; Chandrapala et al., 2010; Zhao et al., 2010; Geethalakshmi et al., 2011; Ndiiri et al., 2012).

How is planting a rice crop different under the System of Rice Intensification compared to conventionally recommended practices? What is SRI?

SRI is an agro-ecological and knowledge-based methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients while reducing dependency on external inputs (SRI-Rice online, 2012). SRI originated in Madagascar in the 1980s and is based on the cropping principles of:

- improving plant establishment,
- significantly reducing plant population,
- improving soil conditions and
- reducing irrigation water application.

Using practices derived from these principles, farmers can test SRI and then adjust the practices to fit their local conditions, both environmental and socio-economic. In addition to rice, farmers have begun to apply SRI principles to growing other crops such as wheat, sugarcane, and teff (a staple grain in Ethiopia) with excellent results and remarkable yield increases (SRI-Rice online, 2012).

How does SRI work?

- Rice seedlings are transplanted when they reach the two-leaf stage, which can vary from 8 to 12 days depending on climate (versus transplanting at one month old or older in the conventional system).
- Only one seedling is transplanted per hill (rather than 3-5 plants clumped together in one hill).
- Transplanting is done carefully and shallow, in a square grid pattern with a spacing of 25cm × 25cm between plants (rather than deep transplanting with a spacing between hills of 10-15 cm, often with damaged roots). Spacing can be wider in good-quality soils and with profusely tillering varieties, or slightly closer with low-tillering varieties and less fertile soils.
- Weeding is done mechanically with a hand-pushed weeder (or motorized multi-row weeder) that incorporates weeds into the soil and aerates the soil surface (rather than hand weeding or herbicide application).
- Fertilization is based on adding organic matter to the soil (residues, compost, manure, cover crops, etc.) at a recommended rate of 10 t/ha (can be more or less depending on availability and soil fertility status), and complemented with chemical fertilizer as needed (rather than sole reliance on chemical fertilization).
- Irrigation during the vegetative stage of the crop is done with the AWD method, adding a thin layer of water of 2 cm to the paddy, letting the ponded water disappear over a few days until the soil slightly cracks, when another thin layer of water is introduced (rather than continuous flooding). During the flowering period of the rice crop, a thin layer of water is maintained, as during the vegetative stage, AWD can be done again during the grain filling stage, followed by draining the plots 2-4 weeks before harvest.

Additional practices for good and healthy plant establishment are seed selection, seed soaking before seeding, non-densely sown raised-bed nurseries on good soils, careful removal of seedlings from nurseries before planting without disturbing roots, and keeping roots protected with surrounding soil. Shallow transplanting allows for tillers to emerge and develop easily and quickly. To follow SRI practices, farmers are prompted to pay attention to land levelling, so as to avoid drowning the small transplants with irrigation water. Land levelling is thus an important water-saving practice, as it allows even distribution of water throughout the plot, and the depth of the irrigation water can be precisely controlled. Thus, changes in production cost and labour allocations do occur with SRI compared to the conventional system. Depending from which current rice growing practices farmers start out with, soil preparation costs with SRI can be similar, less or more; nursery costs are reduced; costs for transplanting are reduced once people are used to transplanting small seedlings; labour allocation for weeding is reduced if compared to hand weeding, and increased if compared to herbicide application; costs for inputs (seeds, fertilizer, pesticide and water) are reduced; in total: production costs /ha can be reduced by 20-40%. (SRI-Rice online, 2012)

These practices allow smallholder rice farmers to increase their yields by 20-50% and as much as 100%, while decreasing their use of water by 30-50%, using 90% less seed, and 30-100% less chemical fertilizer and pesticides.

How can this difference in performance be explained?

Contrary to the conventional system, under which flooding represents the ideal condition for growing rice, the system of rice intensification is based on improving aeration to the soil, which favours deep and proliferous root development that can support a high above-ground productivity. Thus, water saving in the SRI system is beneficial to rice plant performance.

Root system development is favoured by a number of management interventions: (i) intermittent irrigation allows the roots to breathe better; (ii) application of organic matter enriches soils, stimulates soil microbial development and creates a better environment for roots to grow in; (iii) early transplanting of seedlings minimizes transplanting shock as soil attached to roots during transplanting is kept in place, and helps to protect the roots; (iv) root systems can develop better when transplanted singly – thus eliminating competition that exists in the conventional planting method (with 3-5 seedlings in one hill and closer spacing); (v) use of a mechanical hand-pushed or motorized weeder contributes to soil aeration.

Research by Mishra and Salokhe (2011) and Thakur et al. (2011) shows that roots, under flooded conditions, do not develop as well and have a shorter life span. Under flooded conditions, root system activity declines after mid-season, while in the SRI system, roots remain active longer into the grain filling period. Under continuous flooding, up to three-fourth of the roots degrade by the flowering stage (Kar et al., 1974, cited by Satyanarayana et al., 2007). Under SRI, roots reach deeper and achieve double the volume compared to plants in conventionally planted hills (Thakur et al., 2011). With larger root systems, plants access water at deeper soil horizons, which makes the crop more resilient towards drought stress, as reported from China, India, Cambodia and Sri Lanka. (Satyanarayana et al., 2007).

These more productive phenotypes under SRI are characterized by higher number of tillers per plant, increased plant height, longer and wider leaves, longer panicles, more grains per panicle and improved grain quality (Mishra and Salokhe, 2011; Thakur et al., 2011). The same research has shown plant internal water-use efficiency has also improved, by assimilating more CO_2 per unit of water transpired.

Benefits for rice productivity and water saving under SRI can be summarized as follows:

- 30%-50% less irrigation water is used per hectare, which translates to reduced costs for water pumping, infrastructure maintenance and lower amortization rate as pumps can last longer when used less intensively.
- Rice yields are increased by 25-50%, and sometimes more. This often doubles the water productivity (output of grains/input of water).
- Improved internal water-use efficiency associated with improved phenotypic performance.

Challenges and opportunities for adopting SRI water saving management strategies

Application of the four interacting principles of the SRI methodology (early establishment of healthy plants, reduced plant population, improved soil fertility/health, and reduced application of irrigation water through AWD), allows the crop to develop quickly, limits competition among plants and permits more efficient use of water. The results are: yields increased by 20-50%, less water used, less seed required, and decreased chemical inputs. In theory, if applied worldwide to the entire rice sector, field water savings of 30-50% could translate into saving 7.5-15% of global fresh water, which would then be available for other agricultural crops, drinking water, supporting economic development, and reduce the likelihood of conflicts over scarce water resources.

By contrast, using reduced water applications under conventional rice-growing methods (older seedlings are transplanted in closer spacing), similar or lower yields are obtained compared to continuously flooded fields. In this case, other than for farmers who experience water scarcity, there is limited incentive to reduce the amount of irrigation water as additional efforts to apply AWD correctly do not result in any other direct benefit and fear of yield losses will be high.

How can we get to the integrated application of SRI practices?

Knowledge sharing, extension and research

A good extension approach to share knowledge of SRI with farmers is essential. The belief that more water is ultimately better for the rice plant is deeply ingrained, so the most effective approach is to allow farmers to see for themselves, through field demonstrations, that rice can produce higher yields with less water. Once a farmer has understood this relationship, water saving becomes a strategy for increased production.

SRI is a ready opportunity. It requires no major investments in infrastructure, research or input subsidies. Farm families can consume more rice and improve their incomes within one or two cropping seasons. Farmers in more then 50 countries are currently applying these new principles.

The SRI method allows a farmer to experiment, to re-learn and re-establish best agriculture practices tailored to his or her own situation. The methodology started with rice and is now being applied to sugar cane, wheat, teff, finger millet and other crops with similar results.

Research is critical to understand the technical process of adjusting cropping practices and the social and economic advantages and impacts. As SRI has not been developed on research stations, but in farmers' fields, farmer participation in the research process is essential. Further research is needed to adapt SRI principles to various eco-regions and cropping systems, and to study climate-change resilience of cropping systems where SRI practices are used.

Irrigation infrastructure design

Irrigation canals and dikes are currently designed to transport and hold enough water to maintain flooded fields, thus they are overbuilt for the decreased amounts required for AWD.

In high rainfall areas, plots often become inundated. Conventional irrigation infrastructure is often built to store rainwater (high bunds, etc.). For SRI, flooded conditions reduce yields, thus irrigation schemes should be built so as to allow drainage and control of water for individual plots.

Proper drainage is often neglected in the design of irrigation schemes, and the resulting inability to drain paddies is a widespread problem.

Policies

Although "the word is out," and knowledge and awareness about SRI is quickly spreading, there is still a need for supportive policies in many countries.

A commitment to adopt SRI on a large scale <u>can save money for governments</u> by reducing budget allocations needed for food imports and for agricultural subsidies. For governments to maximize cost savings and efficiencies in national water use, they will need to <u>invest in better control over the delivery of irrigation water</u>. This includes the design and management of water storage, canals, field channels, and drains. It may also require institutional reforms and capacity building for water users to readjust water delivery mechanisms and schedules for more precise water allocation within irrigation schemes.

Reduced subsidies on irrigation water will be important cost savings for governments, and provide a real incentive for farmers to use SRI principles. Investments in training and extension for SRI could be covered in part by reducing present subsidies on water, fertilizer, and electricity for pumping water.

References

Bouman, B.A.M. and Tuong, T.P. 2001. Field water management to save water and increase its productivity in irrigated lowland rice. Agricultural Water Management 49: 11-30.

Bouman, B.A.M., Lampayan, R.M. and Tuong, T.P. 2007. Water management in irrigated rice: coping with water scarcity. International Rice Research Institute (IRRI), Los Baños, Philippines. http://www.knowledgebank.irri.org/ewatermgt/courses/course1/resources/books/water_management_1.pdf

Chandrapala, A.N.G., Yakadri, M., Mahender Kumar, R. and Bhupal Raj, G. 2010. Productivity and economics of rice (*Oryza sativa*)-maize (*Zea mays*) as influenced by methods of crop establishment, Zn and S application in rice. Indian Journal of Agronomy 55 (3): 171-176.

Geethalakshmi, V., Ramesh, T., Palamuthirsolai, A. and Lakshmanan. 2011. Agronomic evaluation of rice cultivation systems for water and grain productivity. Archives of Agronomy and Soil Science 57 (2): 159-166.

Mishra, A. and Salokhe, M.V. 2011. Rice root growth and physiological responses to SRI water management and implications for crop productivity. Paddy and Water Environment 9: 41-52.

Ndiiri, J.A., Mati, B.M., Home, P.G., Odongo, B. and Uphoff, N. 2012. Comparison of water savings of paddy rice Under System Of Rice Intensification (SRI) growing rice In Mwea, Kenya. International Journal of Current Research and Review 4 (6): 63-73.
http://www.ijcrr.com/journals/Vol%204%20issue%206.pdf

OECD. 2012. Water Quality and Agriculture: Meeting the Policy Challenge. Organisation for Economic Co-operation and Development, Paris. France.
http://www.oecdbookshop.org/oecd/display.asp?sf1=identifiers&st1=9789264168060

Satyanarayana, A., Thiyagarajan, T.M. and Uphoff, N. 2007. Opportunities for water saving with higher yield from the system of rice intensification. Irrigation Sciences 25: 99-115.

SRI-Rice online: System of Rice Intensification (SRI); SRI International Network and Resources Centre, (SRI-Rice), Cornell International Institute for Food and Agriculture Development (CIIFAD), Cornell University, Ithaca, New York: http://sri.ciifad.cornell.edu/index.html; SRI with other crops:
http://sri.ciifad.cornell.edu/aboutsri/othercrops/index.html, accessed July 2, 2012

Thakur, A.K., Rath, S., Patil, D.U. and Kumar, A. 2011. Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. Paddy and Water Environment 9: 13-24.

Tuong, T.P., Bouman, B.A.M. and Mortimer, M. 2005. More rice, less water: integrated approaches for increasing water productivity in irrigated rice-based systems in Asia. Plant Production Science 8:231-241.

World Bank. 2012. Managing Water Through Managing Evapo-Transpiration (ET). Learning Module. http://vle.worldbank.org/moodle/course/view.php?id=345

Yao, F., Huang, J., Cui, K., Nie, L., Xiang, J., Liu, X., Wu, W., Chen, M. and Peng, S. 2012. Agronomic performance of high-yielding rice variety grown under alternate wetting and drying irrigation. Field Crops Research 126:16-22

Zhao, L., Wu, L., Li, Y., Xinghua, L., Zhu, D. and Uphoff, N. 2009. Influence of the system of rice intensification on rice yield and nitrogen and water use efficiency with different N application rates. Experimental Agriculture 45: 275-286.

Zhao, L., Wu, L., Li, Y., Sarkar, A., Zhu, D. and Uphoff, N. 2010. Comparisons of yield, water use efficiency, and soil microbial biomass as affected by the System of Rice Intensification. Communications in Soil Science and Plant Analysis 41(1): 1-12.