MORE RICE WITH LESS WATER THROUGH SRI -- the System of Rice Intensification[1]

Introduction

We recently learned about a method for raising irrigated rice that produces substantially higher yields with **fewer plants** (planting far fewer seedlings per hill and per square meter) and with **fewer inputs** than either traditional methods, i.e., using less water, or more "modern" methods, requiring chemical fertilizer or agrochemicals. It involves using different practices for plant, soil, water and nutrient management. This system of rice intensification has been successfully used in more than a dozen countries and this number of growing.

The System of Rice Intensification is an alternative system for growing rice that was developed in Madagascar in the early 1980s by Father Henri de Laulanié, S.J., who between 1961 and 1995 worked with Malagasy farmers and colleagues to increase rice production in that country. It is now being promoted by a Malagasy NGO, Association Tefy Saina.[2] This system offers many advantages over the usual methods for irrigated rice cultivation and can produce substantial increases in yield.

SRI has already helped several thousand farmers in Madagascar to at least double their yields. With good management of plants, soil, water and nutrients, yields can be increased with this methodology even more -- to 6, 8, even 10 tons per hectare, or more.

SRI begins with a philosophy that rice plants are to be regarded and supported as living creatures that have great potential. This potential will only be realised if we provide plants with the best conditions for their growth. If we help plants to grow in new and better ways, they will repay our efforts several times over.

Unfortunately the traditional system for growing rice has prevented realisation of plants' natural potential by transplanting them too late, by spacing them too closely, and by cutting off the oxygen supply to their roots by continuous flooding of paddies. SRI changes practices that are thousands of years old to bring out rice plants' significant possibilities for greater yield.

With SRI practices, the structure of the rice plants is changed, both above ground and below. In particular, the density and number of roots is increased. This supports more fertile tillers per plant, with more grains per fertile tiller, and often larger grains.

The techniques of SRI include planting rice seedlings widely apart so they have more room to grow. With more space, rice root systems become larger and more extensive, acquiring more nutrients from the soil. This enables them to produce more tillers and more grains, the latter being the purpose for growing rice.

With SRI methods, you can get 50 tillers on a single rice plant, and farmers who have mastered the methods and understand the principles have been able to get 80 or even 100 tillers from a single tiny seedling. It is possible to get 200 grains per fertile tiller, and the very best farmers have gotten as many as 400 to 500 grains on a single tiller (panicle) with this set of methods that have synergistic effects.

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[1] This is a composite presentation from papers written by Norman Uphoff at Cornell University. His contact information is: Tel: 01-607-255-0831; Fax: 01-607-255-1005; E-mail: NTU1@cornell.edu [how about having also some contact information for persons in the Philippines who can give advice and information? BIND? CDSMC? others? closer at hand, local knowledge]

[2] The Cornell International Institute for Food, Agriculture and Development (CIIFAD) has been working with Tefy Saina since 1994 to evaluate this system and get it tested in other countries outside Madagascar. For information from this source, contact: Association Tefy Saina, B. P. 1221, Antananarivo, Madagascar. Tel: 0261-222-0301; E-mail: tefysaina@simicro.mg

Early transplanting

The key to success with SRI is the early transplanting of seedlings, before they are 15 days old, and as early as 8 or 10 days. Seedlings then have only their first small root, with seed still attached, and a first (main) tiller and two tiny leaves. They should be replanted singly rather than in clumps of 3 or 4, and within half an hour of removal from the nursery so the plants do not dry out. They are laid gently into the soil, not pushed in, so that their root lies horizontally in the moist soil, only 1-2 cm deep. In some soils, 2 seedlings per hill may give higher yield, but this can only be determined by experimentation. We recommend that farmers start with 1 seedling per hill to begin, to see the SRI effect, but they should try also 2 per hill.

Slipping the seedling in sideways rather than plunging it into the soil vertically makes the shape of the transplanted seedling more like an L than like a J. With an L shape, it is easier for the tip of the root to resume its growth downward into the soil. Wide spacing gives individual plants more room to spread and to send down roots. Seedlings are planted at least 25 centimetres from each other and in a square pattern, which facilitates weeding subsequently.

Careful transplanting reduces shock and increases the plant's ability to produce numerous tillers and roots during its vegetative growth stage. This gives the rice plant more access to sunlight and air above ground. If the soil is very fertile, or has been made more fertile by application of compost over several seasons, wider spacing (fewer plants per square meter) will give higher yields. With the best soil and management, some of the highest yields are achieved at 50 x 50 spacing, hard as this may be to believe if one is used to plants managed with conventional practices, such as continuous flooding.

Moist but unflooded soil

An important discovery of SRI is that rice is not an aquatic plant. Although it can *survive* when its roots are continuously submerged under water, it does not *thrive* in this situation. Rice does not grow as well in standing water as when its roots are able to get oxygen from direct contact with air. Under submerged conditions, some of the roots' cortex disintegrates to form air pockets (aerenchyma) so that oxygen can reach root tissues. But this is not the most efficient way to sustain the roots, and under flooded conditions, up to 3/4 of roots may die by the time of flowering (panicle initiation).

With SRI, we have discovered that the soil only needs to be kept moist during the period of growth when the plant is putting out tillers, leaves and roots, before it begins to flower and to produce grains. Once flowering begins, a thin layer of water (1-2 cm) should be maintained continuously on the field, though there can be some interruptions in this.

During the vegetative growth phase, the principle to be followed is that rice roots should not be continuously in saturated soil so that oxygen supply is not cut off from the roots, at least not for very long. There are two main methods used by farmers in Madagascar, the basic alternatives between:

(a) **Non-Flooding:** Water is applied only as needed to keep the soil moist, but never letting it become saturated. If there has been no rainfall during the day, irrigation water is applied in the evening or late in the afternoon, and any water still standing on the field the next morning is drained off. This leaves the soil and plants fully exposed to the sun and air during the day. Several times during the growing period, the field is left unwatered for 2-6 days so that the soil dries out to the point where there is surface cracking.

(b) **Alternate Wet-Dry Irrigation:** For convenience and to save labor effort, fields can be alternately flooded and drained, for 3-5 days in each period (the range can be 2-7). Rice plants can tolerate the loss of direct access to oxygen through the soil for some number of days, with this number affected by soil type.

We are still assessing the merits of these two methods, which surely depend in part upon soil structure, drainage conditions, etc. Farmers are encouraged to experiment with different ways of keeping the soil both wet enough to support plant growth without making it so wet that oxygen supply is cut off to the roots for too long a period.

Weeding

When rice fields are not flooded continuously, weeds get a chance to grow. So efforts must be made to eliminate them and prevent competition with the rice plants. A simple mechanical weeder (called a rotating hoe) that is pushed by hand has been developed to enable farmers to eliminate weeds easily, quickly and early. Weeding should start about 10 days after planting and should be done at least twice, but preferably 3 or 4 times, until the canopy closes and makes further weeding difficult (and unnecessary).

There can be dramatic benefits from doing more than one weeding. In one Madagascar community, farmers who did no mechanical weedings got 6.0 tons/ha.; farmers who did one or two weedings got 7.5 tons/ha.; but the farmers who weeded three times averaged 9.2 tons/ha., and the farmers who were willing and able to weed four times got 11.8 tons/ha. We do not understand the biodynamics of what is occurring, but it appears that this weeding with the rotating hoe (which costs about $10 in Madagascar if locally fabricated by blacksmiths) is aerating the soil as it churns up the top surface to removes weeds.

Compost

For SRI, it is recommended to use compost or manure rather than chemical fertilisers, which are expensive and to little to enhance the biological life in the soil. SRI was developed in the 1980s with fertiliser use, and this does enhance yield. But soil that is enriched with compost or manure will usually have better structure so that plant roots can grow more easily and deeply, and soil organic matter supports the growth of microbial populations and greater biodiversity within the soil.

Compost releases its nutrients more slowly than chemical fertilizer so plants usually get more benefit. The compost can be made from any biomass (e.g., rice straw, plant trimmings, weeds and other plant material), with some animal manure added if available. Banana leaves can add more potassium, cuttings from leguminous shrubs add more nitrogen, and other plants such as *Tithonia* and *Afromomum angustifolium* may be high in phosphorus. We think that SRI soil management practices (no flooding, the use of compost, and rotating-hoe weeding) help increase the populations of micro-organisms in the soil which can produce nitrogen for the plant. They can also assist with phosphorus solubilization. Also there is more oxygen in soil which has more worms, ants, termites, etc., which are less abundant in chemically fertilised soil.

Most farmers in Madagascar, given their latitude, can only cultivate one season of rice a year. SRI methods could be productive on more intensively cropped soil, but this needs to be evaluated in each case. Malagasy farmers increasingly plant an inter-season (*contra-saison*) crop of potatoes, beans, peas or other vegetable. They have found that applying their compost to this crop, rather than directly to the rice crop, gives them higher total production. The vegetable crop benefits greatly from the compost, and the rice crop benefits from the slow decomposition of the compost when its "turn" comes.

Pests and diseases

Pest and disease problems appear to be less with SRI, perhaps because the fields are kept less humid. It is known from integrated pest management (IPM) programs that healthier, more vigorous plants have more capacity to resist pest and disease attacks, with enough reduction in damage that the use of chemicals to control the pests or disease is not economic. With a larger root system, rice plants can access larger volumes of soil and tap sources of micronutrients that are otherwise unavailable, which gives the plants the equivalent of a better "balanced diet."

Labour

One of the main reasons cited by farmers and others for not adopting SRI methods is that it requires more labour, at least initially. This is true because intensification generally means more work and management. One study found that SRI required about two-thirds more days of labour per hectare in the first and second year. But after farmers had become better acquainted with and confident in the methods, particularly transplanting, then the labour requirement dropped so that SRI required only about 25% more labour per hectare. Since yields with SRI were several times greater, the amount of rice produced for each day of work invested was increased greatly.

Some farmers find that SRI requires little more labour once they have become proficient with its methods, particularly because transplanting is quicker with fewer plants. (With SRI, the seeding rate is 5-10 kg/ha, compared to 50-100 or more kg/ha conventionally.) Recently, some farmers in Sri Lanka have calculated that once they have mastered SRI techniques and can do them confidently and quickly, their total labor invested per hectare with SRI is actually less than with conventional modern practices (which in Sri Lanka include four sprayings of the field). They like being able to save the cost of agrochemical inputs.

One difference can be for labour to harvest since yields are higher. But nobody complains about having to bring in several times more rice from the field and thresh it, since the household are getting much more benefit from the labour that they have already invested. In Sri Lanka, farmers have found that even the larger harvests with SRI require little if any more work because it is easier and quicker to collect the larger SRI panicles which also retain their grains better than do conventionally-grown plants. They do not need to be as careful about losing grains in the field, they report. Farmers have found that some varieties in Sri Lanka that have been known to drop their grains easily do not do this when grown with SRI methods.

Some farmer households may not have enough labour to be able to cultivate all their land using SRI methods at the outset. In this situation, they should experiment with SRI on a small area to satisfy themselves that this technique will increase their production by a substantial amount. Once satisfied, they will be better off cultivating as much of their available fields with SRI methods as their available labor permits, since SRI methods raise the productivity of farmers' land, labor, capital and water all at the same time.

If farmers can get greater returns from their resources by using SRI methods, it will be more profitable to cultivate just part of their land with SRI methods and then to grow other crops on the remaining land when labor is available. Since SRI requires only about half as much water as with usual irrigation methods, it is well suited to water-constrained situations, provided that there is enough **water control** to be able to apply small amounts on a regular basis or to reflood a field that has been drained. Once the rice plant roots are well established, growing more vigorously than under continuous flooding, they can withstand periods of drought much better than can conventionally-grown rice.

Upland rice

There is now experimentation going on to adapt the concepts of SRI to growing upland (unirrigated) rice. One experiment at Zahamena, trying to avoid using fire as an agricultural practice, got a doubled yield with only one-eighth as mahy seeds, thus producing 16 times more grains per rice seed planted compared with traditional slash-and-burn production.

During the 1997-98 season, a trial adapting SRI methods to upland conditions yielded 4 tons/hectare, compared to the 0.8-1.5 t/ha yields usually obtained with upland production. Compost was used instead of burning (with a little chemical fertilizer added), and seeds were planted sparsely, 30 by 30 cm, two per hill rather than a clump of seeds as is usually sown. Leguminous plants (tephrosia and crotolaria) which grow like weeds in the vicinity were chopped up (into 10 cm lengths) and applied as a mulch (about 7 cm deep) 10 days after plant emergence. This suppressed all weeds, so no weeding was necessary, and it conserved water, as well as probably adding some nutrients to the soil. Over time, such practices should build up soil quality, especially by stopping burning which kills soil micro-organisms. We think that other crops may also benefit from these concepts for improving plant growth.

Conclusions

SRI should be understood as a system of production that through synergistic interactions can produce much higher grain yields than are usually achieved by conventional practices utilising new "high-yielding" varieties and external inputs. The concept of synergy appears to explain why SRI works so well. This refers to positive interaction between and among SRI practices so that the total is more than the sum of its parts. What enhances root growth supports greater tillering; more tillering provides photosynthates to support root growth; both contribute to greater grain filling and larger grains. Each of the management practices used in SRI makes a positive difference in the yield, but the greatest potential of SRI is seen when the practices are used together.

Yields with SRI methods have been typically around 8 tons per hectare in Madagascar, where the national average is 2 t/ha. On-station or farmer-field trials are being conducted by research institutions, NGOs and/or farmers in China, Indonesia, Philippines, Cambodia, Sri Lanka, Bangladesh, Nepal, India, Cote d'Ivoire, Sierra Leone, The Gambia, and Cuba. In all cases where there was good water control maintained, rice yields increased at least 50% but more often by several fold. In China, for example, yields of 9-10.5 t/ha were achieved in the first trials, compared with a national average of 6t/ha. While such high yields could be obtained in China with its best varieties, methods and inputs, SRI required only half as much water as usual, so this was appreciated given that water is becoming a constraint in rice production.

SRI offers higher productivity of water (yield per cubic meter), higher productivity of land (yield per hectare) and of labour (yield per person/day). Also, methane emissions are reduced by keeping paddies unflooded, so by reducing greenhouse gas production, it is an environmentally-friendly method of agriculture, something uncommon. With little or no use of chemical fertilizers, their runoff which lowers groundwater quality is also avoided.

These claims make SRI appear "too good to be true," providing "something for nothing" and defying "the law of diminishing returns." This has prompted resistance not only to accepting SRI as valid, but (rather surprisingly) also even to trying it out. We should certainly be willing to evaluate an innovation which could, if validated, bring so many benefits.

We want to emphasise that the SRI methods described above are not a formula or a recipe. Farmers should expect to make some adjustments in practices like timing, spacing, soil preparation, weeding, and water management, and should try any other thing they think might give their rice a better chance to grow vigorously. Tefy Saina and CIIFAD emphasize that SRI is not "a technology" to be adopted as a "package," but rather a set of practices based on a number of sound agronomic insights and principles. The practices should be experimented with and varied by farmers as they think might best suit their soil, climate and other conditions.

So far, SRI methods used properly have been found to have the potential to at least double the yield of any variety of rice. Some varieties we observe are especially responsive to these methods, with greater root development and tillering, so that they give really high yields. The very highest yields thus far have been achieved with "improved" varieties that have apparently not had tillering capacity bred out of them (an objective of most contemporary rice breeding programs). The upland rice results reported above should encourage farmers to plan and conduct their own trials, perhaps given ideas from the Madagascar experimentation, but seeking to improve upon this system if possible for their local conditions.

One thing that particularly needs to be evaluated by each farmer according to his or her field conditions is the **spacing** of the rice plants. For best yield, one does not want most tillers per plant but most tillers per square meter. Yields from a certain density of rice plants per square meter will depend on the farmer's soil, on temperature and climatic conditions, as well as on the variety of rice used. It must be remembered that soil conditions can change (be improved) over time by good management of organic matter (compost, crop residues, etc.) and water (keeping the soil well-aerated). This will change what kind of rice plant population the soil can best support. So spacing as well as timing, water application and other factors should be evaluated periodically by field testing if farmers want to be getting the most productivity from their scarce resources.

Box 1. How do we know that these practices make a difference in how rice plants grow and can explain the observed increases in yield?

1. Root growth can be massive in response to these practices. A pull test found that a clump of **three** rice plants grown under conventional conditions (mature seedlings, closely spaced, three per hill, grown in standing water) required an average of 28 kilograms of force to be pulled up. **Single** rice plants grown under SRI conditions (young seedling, widely spaced, one per hill, no standing water) required an average of 53 kilograms for uprooting. This means there was more than five times more resistance per plant, reflecting a much larger and more developed root system.

2. Tillering is greatly increased with these methods. Thirty tillers per plant are fairly easy to achieve, and 50 tillers per plant are quite attainable. With really good use of SRI techniques, individual plants can have 100 fertile tillers or even more. This is because there has been no set-back in growth due to late transplanting, and plant roots do not die back due to hypoxic conditions.

3. With SRI methods, fertile tillers produce more grains per panicle, whereas it has been common to observe (with rice grown under flooded, hypoxic conditions) that there is a **negative** correlation between the number of tillers per plant and the number of grains per panicle (fertile tiller). Having a **positive** correlation as seen with SRI helps to explain how yields can go from 2 tons to 8 tons per hectare.

4. Evidence of increased grain weight is still fragmentary, but various reports indicate a 10-15% increase in the number of grams per 1,000 grains. This is plausible given the massive SRI root system that can access more nutrients in the soil and possibly support biological nitrogen fixation (BNF) in the rhizosphere. CARE/Bangladesh, which has begun helping farmers participating in its IPM "farmer field schools" to use SRI, reports a 15% increase in grain weight.

Box 2. Why does SRI work?

SRI practices result in a rice plant structure that is different from what results when traditional practices are followed. Rice plants under SRI have many more tillers, greater development of roots, and more grains per panicle. In order to tiller, plants need to have enough root growth to support their new growth above ground. But roots require certain conditions of soil, water, nutrient, temperature and space for growth. Roots also need energy from the photosynthesis that occurs in the tillers and leaves above ground. Thus, roots and shoots depend on each other. In addition, when growing conditions are optimized, there is are positive relationships among the number of tillers per plant, the number of tillers that become fertile (form panicles), and the number of grains per tiller.

SRI fields will look terrible for four or five weeks after transplanting, because the plants are so thin and small and widely spaced. One sees little green in the field, and because there is no standing water, no blue sky is reflected. The field looks barren, muddy brown. In this first month, the plant is preparing to tiller. During the second month, serious tillering begins. In the third month, the field seems to "explode" with rapid tiller growth. To understand why, you need to understand the concept of **phyllochrons,** a concept that applies to all members of the grass family, including cereals like rice, wheat and barley.

A phyllochron is not a thing but rather a period of time, 5 days at best but usually longer, during which one or more phytomers (units of a tiller, a leaf and a root) emerge from the base of the plant (Table 1). The length of phyllochrons is determined particularly by temperature, but it is also affected by things like day length, humidity, soil moisture, soil compaction, exposure to light and air, and nutrient availability.

If conditions are good, phyllochrons in rice are 6 to 7 days long, though they may be shorter at higher temperatures. Under very good conditions, when phyllochrons are as short as 5 days, the vegetative growth phase of a rice plant may last for as long as 12 phyllochrons before the plant begins initiating panicles and starts its reproductive phase (see Table 1). This is possible when the rate of biological growth is speeded up, so that many period of growth are completed before panicle initiation.

Conversely, under poor conditions, phyllochrons are longer, and fewer will be completed before the flowering phase begins. Here is the most important consideration: only a few tillers are put out during the early phyllochrons (indeed, none during the second and third phyllochrons), but during each successive phyllochron after the third one, each tiller already growing puts out a new tiller from its base (with a lag time of one phyllochron before this process starts) (see Table 1).

During the latter part of the vegetative growth period, with ideal growing conditions, the plant's production of tillers becomes exponential rather than additive. The number of phytomers produced in each period is the sum of the numbers in the **previous two** periods, a familiar pattern of growth in biology known as a Fibonacci series.) With standard cultivation practices, where roots are dying back after the first two weeks, the period of maximum tiller production occurs some time before panicle initiation (PI); when plants are grown under SRI conditions, PI and the maximum production of tillers coincide.

This is why it is best to transplant seedlings during the second or third phyllochron, so as not to disrupt the rapid growth which begins in the fourth phyllochron. Seedling roots are traumatized when they are (a) exposed to the sun and dry out; (b) plunged into an airless environment; and (b) feeder roots, put out from the first root, are lost or damaged during later transplanting. This trauma slows subsequent growth, and not as many phyllochrons are completed before PI. Most current transplanting methods (and timing) set plant growth back by one or two weeks which means that there is no prolific tillering in the last weeks before PI. For maximum tillering, one wants plants to complete as many phyllochrons of growth as possible during their vegetative phase. If seedlings are three or four weeks old when transplanted, the most important (late) phyllochrons when tiller growth is multiplied will never be reached.

Contrary to popular expectation, more tillering does not mean less panicle formation or grain filling. With SRI, there is not a negative correlation between the number of tillers produced by each plant and the number of grains produced by each fertile tiller. All yield components - tillering, panicle formation, and grain filling - can increase under favorable growing conditions.

Adapted from: D. BERKELAAR. 2001. SRI, the system of rice intensification: Less can be more. In: **Echo Development Notes**, No. 70, 8 pp.

Table 1. Increase in number of tillers that can be produced by rice plants in successive phyllocrons (from De Laulanié 1993). The first and later tillers send out more tillers, which send out still more tillers. By the end of the series, plant growth becomes exponential rather than additive.

	Phyllocrons											
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
New tillers	1	0	0	1	1	2	3	5	8	12	20	31
Total tillers	1	1	1	2	3	5	8	13	21	33	53	84

Note: The number of new tillers in later phyllochrons does not follow the Fibonacci series exactly apparently because there is not enough physical space for as many new tillers to emerge as there is genetic potential.