SRI, THE SYSTEM OF RICE INTENSIFICATION: LESS CAN BE MORE
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We recently learned about a method of raising rice that produces substantially higher yields with the planting of far fewer seedlings and the use of fewer inputs than either traditional methods (i.e., water) or more "modern" methods (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 a number of countries (although so far mostly in Madagascar).

What is SRI?

SRI involves the use of certain management practices which together provide better growing conditions for rice plants, particularly in the root zone, than those for plants grown under traditional practices. SRI was developed in Madagascar in the early 1980s by Father Henri de Laulaníe, a Jesuit priest who spent over 30 years in that country working with farmers. In 1990, Association Tefy Saina (ATS) was formed as a Malagasy NGO to promote SRI. Four years later, the Cornell International Institute for Food, Agriculture and Development (CIIFAD), began cooperating with Tefy Saina to introduce SRI around the Ranomafana National Park in eastern Madagascar, supported by the U.S. Agency for International Development. It has since been tested in China, India, Indonesia, the Philippines, Sri Lanka and Bangladesh with positive results.

The results with SRI methods are remarkable (see Table 1). In Madagascar, on some of the poorest soil to be found and where yields of 2 tons/hectare were the norm, farmers using SRI are now averaging over 8 tons/hectare, with some getting 10 to 15 tons/hectare. A few farmers have even gotten over 20 tons/hectare. In other parts of the country, over a five-year period, hundreds of farmers averaged 8 to 9 tons/hectare.

SRI methods have at least doubled the yields of any variety of rice that has been tried. No external inputs are necessary for a farmer to benefit from SRI. The methods should work with any seeds that are now being used. However, you do need to have an open mind about new methods and a willingness to experiment. With SRI, plants are treated as the living organisms that they are, rather than as machines to be manipulated. The potential within plants is drawn out by giving them the best possible conditions for their growth.

At first, the practices that constitute SRI seem somewhat counterintuitive. SRI challenges assumptions and practices that have been in place for hundreds, even thousands of years. Most rice farmers plant fairly mature seedlings (20-30 days old), in clumps, fairly close together, with standing water maintained on the field for as much of the season as possible. Why? These practices seem to reduce the risk of crop failure. It seems logical that more mature plants should survive better; that planting in clumps will ensure that some plants will survive transplanting; that planting more seedlings should result in more yield; and that planting in standing water means the plants will never lack water and weeds will have little opportunity to grow.

Despite this reasoning, farmers have not found that using SRI practices puts their crops at any more risk than do traditional methods. Four "novel" practices in particular are key in SRI:

1. **Seedlings are transplanted early.** Rice seedlings are transplanted when only the first two leaves have emerged from the initial tiller or stalk, usually when they are between 8 and 15 days old (see Figure 1). Seedlings should be grown in a nursery in which the soil is kept moist but not flooded. When transplanting seedlings, carefully remove them from the nursery bed with a trowel, and keep them moist. Do not let them dry out. The seed sac (the remains of the germinated seed) should be kept attached to the infant root, because it is an important energy source for the young seedling. Seedlings should be transplanted as soon as possible after being removed from the nursery--within half an hour and preferably within 15 minutes. When placing seedlings in the field, carefully lay the roots sideways in the soil with a horizontal motion, so that the root tip is not inadvertently left pointing upward (this happens when seedlings are plunged straight downward into the soil). The root tip needs to be able to grow downward. Careful transplanting of seedlings when they are very young reduces shock and increases the plants' ability to produce numerous tillers and roots during their vegetative growth stage. Grains of rice are eventually produced on the panicles (i.e. the "ears" of grain above the stalk, produced by fertile tillers). More tillers result in more panicles, and with SRI methods, more grains are produced on each panicle.

Figure 1: With SRI, seedlings are planted when they are 8 to 15 days old, when there are just two leaves. The plants at the top are 8 days old. With traditional methods, seedlings are

planted when they are several weeks old. The seedlings shown at the bottom are 31 days old. Photos by Joshua Harber.

2. Seedlings are planted singly rather than in clumps. Seedlings are transplanted singly rather than in clumps of two or three or more. This means that individual plants have room to spread and to send down roots. They do not compete as much with other rice plants for space, for light, or for nutrients in the soil. Root systems become altogether different when plants are set out singly, and when the next practice is followed:

3. **Wide spacing**. Rather than in tight rows, seedlings are planted in a square pattern with plenty of space between them in all directions. Usually they are spaced at least 25 cm x 25 cm (see Figure 2). Feel free to experiment with the spacing, because the optimum spacing (producing the highest number of fertile tillers per square meter) depends on soil structure, soil nutrients, temperature, moisture and other conditions. The general rule is that plants should have plenty of room to grow. If you also use the other practices mentioned here, seldom will the best spacing be closer than 20 cm x 20 cm. The maximum yields have been obtained on good soil with 50 x 50 cm spacing, just four plants per square meter.

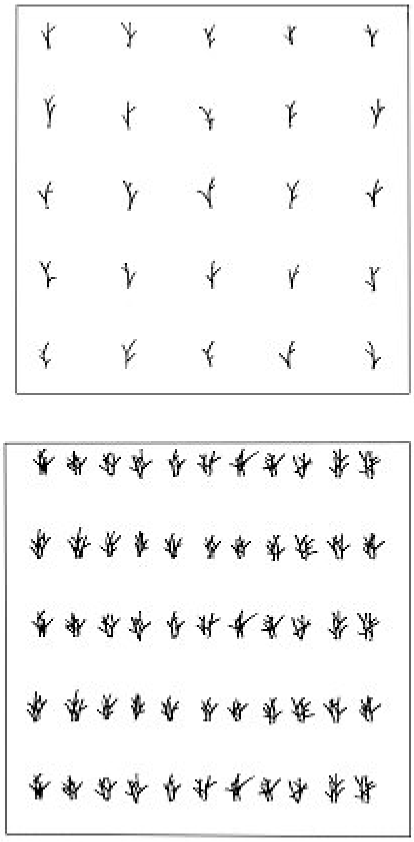

Figure 2: SRI seedlings (above) are very widely spaced compared with seedlings planted with traditional methods (below). These diagrams show seedlings at approximately one month of age, when seedlings are roughly the same size. However, SRI seedlings, having been transplanted several weeks earlier, by this time have already undergone transplant shock and may have begun to tiller. Sketches by Christi Sobel

To space the plants carefully (which makes weeding easier), you can place sticks at appropriate intervals (e.g. every 25 cm) along the edge of the field, then stretch strings between them. The strings should be marked at the same intervals so that you can plant in a square pattern. Leaving wide spaces between each plant ensures that roots have adequate room to grow, and the plants will be exposed to more sunlight, air and nutrients. The result is more root growth (and thus better nutrient uptake) and more tillering. The square pattern also facilitates weeding (see number 6, below).

When farmers are more experienced, they can save time by just marking cross-hatched lines on the field surface with rakes or other devices. Notice that SRI uses a much lower seeding rate than do traditional methods; one evaluation of SRI revealed that the rate of seed application was only 7 kg/ha, compared to the traditional seeding rate of 107 kg/ha! Yet yields were doubled because each plant produced so much more grain.

4. **Moist but unflooded soil conditions.** Rice has traditionally been grown submerged in water. Clearly rice is able to tolerate standing water. However, standing water creates hypoxic soil conditions (lacking in oxygen) for the roots and hardly seems to be ideal! Rice roots have been shown to degenerate under flooded conditions, losing ¾ of their roots by the time the plants reach the flowering stage. This die-back of roots under flooded conditions has been called “senescence,” implying that it is a natural process. But it actually represents suffocation, which impedes plant functioning and growth.

With SRI, farmers use less than half of the water they would use if they kept their paddies constantly flooded. Soil is kept moist but not saturated during the vegetative growth period, ensuring that more oxygen is available in the soil for the roots. Occasionally (perhaps once a week) the soil should be allowed to dry to the point of cracking. This will allow oxygen to enter the soil and will also induce the roots to grow and “search” for water. After all, when the soil is flooded, roots have no need to grow and spread, and they lack enough oxygen to grow vigorously.

Unflooded conditions, combined with mechanical weeding, result in more air in the soil, and greater root growth means that the rest of the plant will have access to more nutrients. When soil is saturated, air pockets (known as aerenchyma) form in the roots of submerged plants in order to transport oxygen. These air pockets take up to 30-40% of the roots’ cortex and probably impede the transport of nutrients from the roots to the rest of the plant. More water may be applied before weeding to make the process of weeding easier (see 5, below). Otherwise, water is best applied in the evening (if there has been no rain during the day), and any water remaining on the surface is drained in the morning. This leaves the field open to both air and warmth during the day; flooded fields will reflect a good part of the solar radiation reaching them, and absorb less of the warmth which helps plants grow. With SRI, unflooded conditions are only maintained during the period of vegetative growth. Later, after flowering, 1-3 centimeters of water are kept standing on the field, as is done with traditional practices. The field is drained completely 25 days before harvesting.

In addition to these four principal practices, two other practices are extremely beneficial when using SRI. These practices are not controversial and have long been recognized as valuable for crops.

5. **Weeding**. This can be done by hand or with a simple mechanical tool (see Figure 3). Farmers in Madagascar find it advantageous, both in terms of reducing labor and of increasing yield, to use a mechanical hand weeder developed by the International Rice Research Institute in the 1960s. It has vertical rotating toothed wheels that churn up the soil as the weeder is pushed down and across the alleys formed by the square formation of planting. Weeding is labor-intensive—it may take up to 25 days of labor to weed one hectare—but the increase in yield means that the work will more than pay for itself.

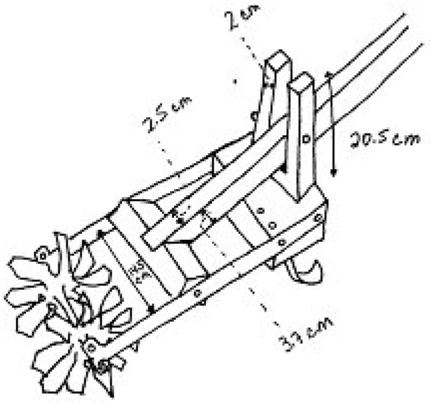

Figure 3: One example of a mechanical weeder with vertical rotating toothed wheels, often used with SRI. Plans are available at ECHO for this weeder and for a larger weeder with five wheels. Sketches of weeders by Paya deMarken, Peace Corps Volunteer in Madagascar.

The first weeding should be done ten to twelve days after transplanting, and the second weeding within fourteen days. At least two or three weedings are recommended, but another one or two can significantly increase the yield, adding one to two tons per hectare. Probably more important than removing weeds, this practice of churning the soil seems to improve soil structure and increase aeration of the soil.

Organic inputs. SRI was developed initially with chemical fertilizers to increase yield on the very poor soils of Madagascar. But when subsidies were removed in the later 1980s, recommendations switched to use of compost, and even better results were observed. The compost can be made from any biomass (e.g. rice straw, plant trimmings 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 phosphorous. Compost adds nutrients to the soil slowly and can also contribute to a better soil structure. It seems fairly intuitive that some form of nutrient input is necessary on poor soils if chemical fertilizer is not added. With huge yields of rice being harvested, something needs to be returned to the soil!

Why does SRI work?

The concept of **synergy** appears to help explain why SRI works so well. In this context, synergy means that practices used in SRI interact in positive, reinforcing ways so that the whole is more than the total of its parts. Each of the management practices used in SRI makes a positive difference in the yield, but the real potential of SRI is seen only when the practices are used together.

When used together, 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 root development, and more grains per panicle. In order to tiller, plants need to have enough root growth to support 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 tillers and leaves above ground. Thus the roots and shoots depend on each other. In addition, when growing conditions are optimized, there is a positive relationship between the number of tillers per plant, the number of tillers that become fertile (panicles), and the number of grains per tiller.

SRI fields will look terrible for a month or more after transplanting, because the plants are so thin and small and widely spaced. In the 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 members of the grass family, including cereals like rice, wheat and barley.

A phyllochron is not a thing. It is the period of time between the emergence of one phytomer (a set of tiller, leaf and root which emerges from the base of the plant) and the emergence of the next (see Table 2). The length of phyllochrons is determined particularly by temperature, but it is also affected by things like day length, humidity, soil quality, exposure to light and air, and nutrient availability.

If conditions are good, phyllochrons in rice are five to seven days long, though they may be shorter at higher temperatures. Under very good conditions, the vegetative growth phase of a rice plant may last as long as 12 phyllochrons before the plant begins initiating panicles and starts its reproductive phase (see Table 2). This is possible when the rate of biological growth is speeded up, so that many growth intervals are completed before panicle initiation.

Conversely, under poor conditions, phyllochrons last longer, and fewer of them 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 (and none at all 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 2). During the latter part of the vegetative growth period, with ideal growing conditions, the plant's production of tillers becomes exponential rather than additive. (It corresponds to what is known as the Fibonacci series in biology.) Instead of a "maximum period" of tiller production being reached some time before panicle initiation (PI), as happens with standard cultivation practices, with SRI both 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 exposed to the sun and dry out; when they are plunged into an airless environment; and when feeder roots, put out from the first root, are lost or damaged during late 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 and also slow subsequent growth. For maximum tillering, you want plants to complete as many phyllochrons 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 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.

This sounds too good to be true. What is the catch?

SRI requires more labor per hectare than traditional methods of growing rice. When farmers are not familiar and comfortable with transplanting tiny seedlings with fairly exact spacing and depth of planting, this operation can initially take twice as long. But once farmers are comfortable and skilled with the technique, transplanting takes LESS time because there are so many fewer plants to put in.

With SRI, more time is spent applying water carefully than when fields are kept flooded all the time. This means that fields should initially be constructed with appropriate irrigation systems that allow water to be "put on" and "taken off" the field at regular intervals. Most rice fields are not set up like this (i.e. they were designed to hold the maximum amount of water), so some reconstruction of fields may be necessary before initiating SRI production systems.

Weeding takes more time if there is no standing water. However, the yields may be increased several-fold due to the increased soil aeration which results from weeding with the rotary push-hoe. The extra yield more than pays for the extra expense of weeding.

At first, SRI can take 50 to 100% more labor (and more skilled and exacting labor), but over time, this amount is reduced. Experienced SRI farmers say it can even require less labor once techniques are mastered and confidence is gained. Since yields can be two, three, and even four times more than with current practices, the returns to both labor and to land are much higher, justifying the greater investment of labor.

Some farmers are skeptical of SRI's benefits. It seems almost like magic at first, though there are good scientific reasons to explain each part of the process. These farmers should be encouraged to try the methods out in a small area, to satisfy themselves about the benefits and to start gaining the skills on a small scale.

Planting and weeding are initially the most labor-intensive part of SRI. Many families are constrained by the amount of labor that is available, either within the household or for hire. If someone does not have enough labor available to plant and tend all the rice fields using SRI, he or she can cultivate just part of the land with rice using SRI methods, getting higher returns for both labor and land. Then other crops can be planted on the remainder of the land at times when labor is available.

Is SRI sustainable? How can you get such high yields?

Scientists are not certain, and many are very skeptical, about how such high yields can be obtained on such poor soil as that found in Madagascar. Fortunately, SRI methods have been found to produce much improved yields in other countries (China, India, Indonesia, the Philippines, Sri Lanka and Bangladesh), so we know that it is not a methodology with success limited to one country.

Little systematic evaluation has yet been done by plant or soil scientists. However, here are a few proposed explanations for which there is some basis in scientific literature:
1) Biological nitrogen fixation (BNF). Free-living bacteria and other microbes around the roots of rice may fix nitrogen for the plants. The presence of such bacteria has been documented for sugar cane, which is in the grass family along with rice. Where nitrogen fertilizer had not been applied (since this suppresses production of the enzyme nitrogenase required for BNF), microbial action fixed 150-200 kilograms of nitrogen per hectare for the cane. However, less nitrogen fixing occurs where chemical fertilizers have previously been applied. It is known that about 80% of the bacteria in and around rice roots have nitrogen-fixing capability, but this potential will not be realized where inorganic N has been

applied, or possibly in anaerobic, water-logged soil.
2) Other research suggests that plants can grow very well with extremely low concentrations of nutrients, as long as those nutrients are supplied evenly and consistently over time. We know that compost furnishes a low, steady supply of nutrients.
3) Plants with extensive root growth have better access to whatever nutrients exist in the soil. Extensive root growth can result when the roots of young seedlings have lots of space and oxygen, and when water and nutrients are scarce enough that roots need to "go looking" for them. Such extensive roots may be able to extract more balanced nutrients from the soil, including some scarce but necessary micronutrients.

Much more remains to be studied about and learned from SRI, but scientists are starting to take an interest in it as reports of superior yields increase. SRI should be seen not as a technology to be applied mechanistically, but rather as a methodology to be tested and adapted to farmers' conditions. Farmers need to be good observers and good learners to make the best use of the insights that SRI provides.

In summary, the main elements of SRI are as follows: Transplant young seedlings to preserve their potential for tillering and root growth while they also benefit from other favorable growing conditions. Provide the plants with wide spacing, without competition either in hills or between hills. Keep the soil well aerated but sufficiently moist, so that the roots can "breathe"; for this, use both water management and weeding practices that aerate the soil. Finally, provide nutrients that feed the soil as well as the plant, so that a rich and healthy soil gives plants the nutrients and positive environment needed for best growth and performance.

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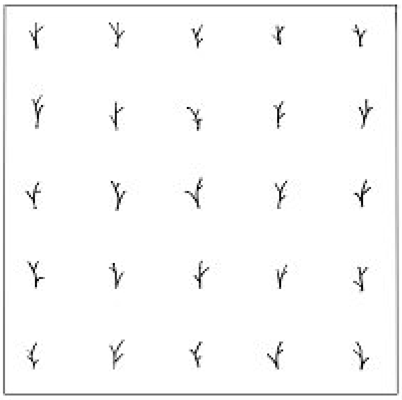

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