Report to the Rockefeller Foundation

Project Name: Research/Extension on the System of Rice Intensification in Madagascar

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Grantee: The System of Rice Intensification (SRI) Consortium in Madagascar -- Association Tefy Saina, ESSA (University of Antananarivo), FOFIFA, and CIIFAD (Cornell University)

I. Introduction

The System of Rice Intensification (SRI) was crystallized in 1983 by Fr. Henri de Laulanié, S.J., at a school that he operated in Antsirabe, Madagascar, for young rural adults to improve their ability to achieve better lives and a better environment. This was the culmination of 20 years of working with farmers in that country, observing and experimenting to find means to raise the productivity rice, Madagascar's staple crop which provides over half of the country's daily calories.

This method of rice cultivation permits, without requiring any financial investments, a doubling or more of the 2-3 t/ha yield that farmers get with their traditional methods of rice cultivation, and it surpasses the yields with improved modern methods that are more costly to employ.

In 1990, Fr. de Laulanié presented for the first time an explanation for this system to NGO technicians working on rural development, citing the mechanism for tillering in rice that had been discovered by the Japanese agronomist Katayama more than 60 years before and made known to him in 1988 through a report written by Didier Moreau. After this seminar, Association Tefy Saina was formed as a NGO to promote the spread of SRI and to improve rural development and conditions of life more generally.

In 1992, there were about 1,000 farmers practicing SRI in Madagascar, but still the dissemination of this remarkable methodology has been slow. In 1994, Tefy Saina began working with the Cornell International Institute for Food, Agriculture and Development (CIIFAD) in the peripheral zone around Ranomafana National Park to introduce SRI to farmers there, so they would have an attractive alternative to continuing slash-and-burn rice cultivation which was encroaching upon the park's tropical rain forest ecosystems. Over the next four years, the number using SRI with Tefy Saina instruction and assistance went from 38 to 275.[1]

In 1998, the Faculty of Agricultural Sciences (ESSA) at the University of Antananarivo began encouraging some of its best students to their baccalaureate thesis research (*memoire de fin d'etudes*) on SRI, beginning to establish a stronger scientific understanding for how and why SRI

[1] At the end of that fourth year, 800 farmers had signed up for instruction and assistance in the next season, and the number would probably have reached 1,000 by planting time, but precipitous withdrawal of USAID assistance limited Tefy Saina's field operations and created much uncertainty, so only 400 used SRI the next season, still a 10-fold increase in 5 years (that could have been a 25-fold increase.)

methods induce rice plant genomes to produce a different and more productive phenotype. In 1999, the first researcher from FOFIFA, the government's agricultural research agency, began working with Tefy Saina, CIIFAD and the University of Antananarivo on SRI evaluation.

This emerging collaboration among the four partners led for formation of a consortium for the evaluation and dissemination of SRI in Madagascar, which was awarded a grant of $35,000 from the Rockefeller Foundation in November 1999. This was originally a two-year grant, but a variety of local and national circumstances delayed field work so that the planned work could not be completed within the time framework proposed. There have been two no-cost extensions that provided for support of SRI activity through June, 2003. The grant was made to improve our understanding, first, of SRI, of its potentials and its limitations, and, second, of the dissemination process, identifying what can best facilitate this process and what obstacles or impediments need to be overcome.

This report covers work done during 2002-2003 but presented in the context of a final report that summarizes what the partners have learned and done about SRI during the grant period. The activity has been enhanced by a separate grant from the Foundation to support an international conference on SRI held in Sanya, China, in April 2002, organized by CIIFAD and Tefy Saina, and co-sponsored by the China National Rice Research Institute and the China National Hybrid Rice Research and Development Center, which hosted the event. The proceedings of this event have been submitted to the Foundation and are available on the web at http://ciifad.cornell.edu/sri/

II. Association Tefy Saina: Understanding SRI Adoption and Constraints on This

2.A Activities under the Grant: The first large-scale opportunity for Tefy Saina to begin disseminating SRI was under the Ranomafana National Park Project referred to above. This area was one of great biodiversity for both flora and fauna under pressure of extinction with the loss of the forest ecosystems they depend on for continued existence. CIIFAD was working on a number of alternatives to slash-and-burn (agroforestry, aquaculture, horticulture, irrigation improvement). Tefy Saina undertook to demonstrate to farmers the opportunities that SRI opened for them. The villages in the peripheral zone around the park were quite isolated one from another. Most were accessible only by foot on unmotorable roads. In 1994, Tefy Saina began introducing SRI to farmers in eventually 46 villages. Its efforts continued through 1999 with support directly or indirectly from USAID.

2.A.1 ***Activities in the Peripheral Zone around Ranomafana National Park*****:** Under this grant, it was possible for Tefy Saina to visit 35 of the 46 villages between September 2000 and March 2001. With the help of technicians working with both traditional and administrative local authorities, it was possible to interview 376 farmers and to conduct 8 farmer-workshops with 199 participants. These workshops were organized to enabale the farmers to speak freely and to think together about SRI experience, pointing out advantages and inconveniences, look for solutions to the main problems that were encountered when adopting SRI.

2.A.2 ***Activities beyond Ranomafana National Park*****:** SRI has been diffused to all six provinces of Madagascar through various training sessions and extension activities of the Ministry of Agriculture. The Ministry gave some support to this dissemination through its project "Opération de Développement Rizicole" in connection with the World-Bank funded "Programme National de Vulgarisation Agricole" (PNVA). Activities were focused around Fiananarantsoa, Ambositra, Antsirabe, Antananarivo and Antsiranana.

Madagascar is a very large country, and an exhaustive evaluation of the spread of SRI was not possible with the time and funds available. Ideally, the focuses for evaluation would be Antananarivo, Fianarantsoa, Morondava, Marovoay and Lac Alaotra, from which to make some reasonable estimation of the spread of SRI in the country. Given the constraints of logistics and time, the province of Antananarivo was the focus of our activities.

We were able to visit 20 rural communes (units of local administration) in 13 districts, each district being an administrative unit with 10 to 25 rural communes. The data were obtained from responsible staff of the Ministry of Agriculture who are working in the different localities. This information gives instructive information on the extent of rice production in the locality, the total area cultivated, the number of SRI cultivators and the total area cultivated with SRI methods, and the yields from these areas, average, minimum and maximum. In addition, there were four farmer-workshops conducted, with participation of 128 farmers to provide qualitative information that supplemented our quantitative data.

2.B Results of Grant Activities

2.B.1 ***Results in the Peripheral Zone around Ranomafana National Park*****:** In 1997, at the end of the USAID-funded Ranomafana National Park Project in which Tefy Saina and CIIFAD worked together to introduce SRI, there were 275 farmers practicing SRI, as noted above, with a rapid growth trajectory evident. The real success was that average yields were between 6 and 8 tons/hectare. Some even higher yields beyond 10 tons/hectare were also achieved. In comparison with the national average yield of 2 tons/hectare, this represented very substantial progress.

From our inquiry covering 376 farmers, we were enable to identify 212 who had practiced SRI in the 2000-2001 season. If this was a complete number of SRI users, it would represent a decline of 23% in the number from 1997, though this would also be a 458% increase from the initial level in 1994, which would represent an annual growth rate of 33%. There is reason to believe that the number of users is higher than this, but these are the numbers we were able to pin down.

We gathered data on yield levels in the 2000-2001 season, and for the 212 farmers practicing SRI whom we could identify and interview, we found the following figures:

Yield levels	No. of households	% of households
Less than 5 tons/hectare	6	2.8%
5 to 10 tons/hectare	163	76.9%
Over 10 tons/hectare	43	20.3%

These results are very encouraging, especially when considering that the costs of production for these farmers using SRI is less than if they adopted modern methods for rice production, including the need to purchase fertilizer, new higher-yield variety seeds, and agrochemicals. There are also individual success stories that we think are indicative of what the future can hold for farmers using SRI. The case of Honoré Ralainandrasana is most eloquent. He began with only 0.25 ha of SRI in 1994, getting a yield of 12.5 tons/hectare. Year by year he increased his area under SRI, and in 2000 cultivated 8 hectares of SRI rice. He now owns this much paddy land and has three houses, one of them in the city of Fianarantsoa.

2.B.2 ***Results beyond Ranomafana National Park*****:** SRI was first introduced in the province of Antananarivo in 1990. In 1998, there was an evaluation done by the Ministry of Agriculture which estimated that 9,099 farmers were using SRI, with yields averaging between 7 and 9.13 tons/hectare.

Our survey of 20 rural communities in 13 districts during 2001-2002 produced the following results:

Total of rural communes concerned	227
Rice cultivators	211,128
Area cultivated with rice	126,278 ha
Average size of rice cultivation	0.6 ha
SRI cultivators	7,307
Area cultivated with SRI methods	1,315.3 ha.
Minimum area	0.1 ha
Average area	0.18 ha
Maximum area	2.00 ha
Rice yield with SRI methods	
Minimum yield	3.00 t/ha
Average yield	6.17 t/ha
Maximum yield	17.00 t/ha
Number of SRI cultivators per commune	32

From the report in 1998, it appears that the number of SRI farmers has fallen by 20% in 2000-2001. However, these data are for only 227 rural communes out of the 259. If we take the average of 32 SRI farmers per commune, this would project 8,331 for the province, only 8% less than the 1998 figure. This would suggest that the level of SRI use in the province had not changed much between 1998 and 2001.

If we look at the province of Fianarantsoa, which is one of the major rice-producing areas, there is more evidence of adoption than in Antananarivo. We estimate that in 2000-2001, there were at least 20,000 SRI users in Madagscar, which would amount to a growth rate of 40%, similar to the rate we found, 33%, for the Peripheral Zone around Ranomafana.

2.B.3 ***Problems Encountered by Farmers*****:** The purpose of our study was to assess the blockages to SRI adoption. From the various interviews and workshops, we can say that the main constraints that farmers have experienced with SRI are the following:

Problems	Farmer Comments
1. Control of rats and seed-eating birds in the dry nursery	1. Installation of physical barriers to protect against rats and birds.
2. Transplanting requires too much labor time	2. This is a problem that is transient, as once farmers gain more experience with SRI transplanting and develop their skill in this, the time reduces. Within three years, most farmers find tht SRI transplanting takes no more time than before, and often less time.
3. Weeding is a constraint without the 'rotating hoe' which is too expensive for farmers with limited cash incomes	3. This problem is a real one, but weeders can be hand-made from wood to keep their cost down. As SRI spreads, there should be more weeders manufactured locally and the price should become lower
4. Management of water is difficult without cooperation among users	4. Collective management of water is necessary to achieve equitable distribution. Irrigation infrastructure can be financed by government or donors
5. SRI requires more labor in the field at bad times for the household	5. The demand for SRI labor comes at a time when household food stocks and cash liquidity are very low. There needs to be some system for rural credit that could enable households to capture the productivity gains that SRI permits
6. If everyone cultivates SRI and there is overproduction, the price of rice paid by merchants will fall	6.There will need to be facilities for storage of the crop so that farmers need not sell all at harvest time and accept whatever price is offered. Over time, farmers should redeploy their resources to higher-value production

2.B.4 ***Progress toward Self-Sufficiency in Rice*****:** SRI is seen in the short run as a means to alleviate food insecurity and to improve the environment. Over the longer run, it should be a strategy for modernizing and improving agriculture, first by improving the thinking and motivation of farmers, and second by encouraging diversification of agricultural production to higher-value and more nutritious crops.

Self-provisioning of basic foodstuffs is a short-run strategy, but a necessary step. Thousands of rural Malagasy households which grow their own rice cannot produce enough to meet all their basic food needs. Because of their chronic indebtedness, they must sell much of their produce at harvest time, when prices are at their lowest, and in turn must buy back rice at a higher price within a matter of months. SRI is expected to help break out of this trap in which the rural poor in Madagascar find themselves.

In 1960, Madagascar exported 25,000 tons of rice. The consumption per inhabitant was 150 kg of rice per annum, or the equivalent of 1,350 kg of paddy rice (unmilled) for a family of 6 persons. Since then it has become a rice-importing country. In 2000, the consumption of rice had declined to 110-112 kg per person, a decline of 27% from the level at time of independence.

For Malagasys to be self-sufficient in 1960, the cultivated paddy area for a family achieving a yield of 2 ton/ha 0.68 ha. In the Peripheral Zone of Ranomafana, farmers attaining a yield of 10 tons/ha would need 0.135 ha, and with a yield of 5 tons/ha, still only 0.27 ha, to assure household food sufficiency. In the province of Antananarivo, the average area of paddy cultivation is 0.60 ha; with an SRI yield of 6,170 kg/ha, the area needed for household food sufficiency would be 0.22 ha, comparedd to the average in this region of 0.38 ha. Achieving the higher yields attainable with SRI would easily meet their food security needs, compared to the present situation of low yields with conventional methods.

SRI is spreading, though not as quickly as Tefy Saina has hoped and expected. The Ministry of Agriculture now estimates that about 10% of rice farmers in Madagascar are using SRI methods, though many not yet completely. A recent joint document of the MOA and EU (October 2002) expects that all of the major rice-growing province of Fianarantsoa will be "covered by SRI" by 2006. For this to occur, solutions will need to be found to the problems identified above.

III. FOFIFA: Evaluating SRI Practices and Potentials on Farmers' Fields

3.A Activities Under the Grant: FOFIFA activities under the grant extended from 2000 to 2003, having started working on SRI a year earlier with CIIFAD support. Three years of experiments related to SRI were designed and carried out on farmers' fields, focused in the highland region of Madagascar, including some technology verification trials. Dissemination efforts were undertaken in the fourth year. The objective was to understand how to increase rice yields in Madagascar by looking for the best technical practices for rice intensification in diverse agroecological conditions. In 1999, there was one experiment on farmers' fields in the Ranomafana area for upland rice cultivation, using *tephrosia* and *crotalaria* mulch with a viewe to finding an alternative to slash-and-burn cultivation. Once RF support became available, more ambitous evaluations were possible. From 2000 to 2003, six experiments on SRI for irrigated lowland areas were conducted on farmers' field to assess alternative combinations of practices:

1. ***Transplanting density*:** Changes in chemical, physical and biological properties of soil occur under intensive rice cropping conditions. During the transplanting of seedlings in paddy fields, spacing between hills may need to be varied according to soil fertility and rice variety. As treatments for these trials, three seedling densities (1, 2 or 3 per hill) were evaluated with four spacings (20, 30, 40, or 50 cm in a square pattern). Current SRI recommendations are for 1 seedling per hill, but possibly with different soil conditions or varieties, this may not be optimal. Wider spacing is recommended with SRI, but what exact spacing will give optimum yield likewise depends on these factors.

2. ***Water control*:** Correlation between the development of roots system and the upper vegetative part of rice plant has been known for a long time. Some effects of soil moisture

such as aerated soil vs. saturated soil were studied. The trials were focused on the influence of a stable water level for the evolution of plants' growth and development, as well as for root development, tillering capacity, and finally panicle formation. Four water levels were tested (dry, shallow, deep, and very deep water) at three periods (vegetative phase, reproductive phase, or continuously during both the vegetative and reproductive phases).

3. ***Weeding control*:** Soil aeration and suppressing weeds seem ideally to result from using a rotary weeder four times on the rice field during the tillering stage. An experiment comparing the use of herbicide, manual weeding, and mechanical weeding was done to assess their labor cost and efficiency for weed control. The effect of timing of herbicide application on young seedlings was studied also.

4. ***Soil fertility and fertilizer for rice*:** In general, paddy fields in the highland of Madagascar have low fertility without any amendments of fertilizer. Phosphorus deficiency is common with these soils. An experiment was done comparing the efficiency of compost and chemical fertilizer, respectively, for increasing rice productivity. The rice intensification program is oriented to the integrated use of inorganic and organic fertilizers.

5. ***Rotational cropping system on irrigated lowland area conditions*:** Usually only one crop a year is grown in the highland, given temperature constraints, so paddy fields are left in fallow, uncultivated for six month after the harvest of rice. Recently we have become concerned with factors stimulating uptake of nutrients (mainly N, P, and K) by roots of rice plants, for example *mycorrhizal associations* in the rhizosphere. It is a symbiotic nutritional system between roots and fungus in the soil. We conducted a trial on the rotational cropping of potatoes and irrigated rice in the paddy field.

6. ***High-yielding varieties*:** Fertile soil with rice intensification can involve sometimes disease problems certainly due to high rates of nitrogen application to the soil. A set of trials was done using tall (*indica*) and short (*japonica*) varieties that were, respectively, sensitive and resistant to blast. The purpose was to assess the health and productivity of plants bred for high yield.

3.B Results of Grant Activities: Some adjustments of SRI practices can be suggested for dissemination of SRI based on findings from FOFIFA trials during 3 years of experimentation.

1. *Young seedlings no more than 8 days old can be used even under temperate climate.*
In the nursery, the young sprouted seeds need warm cover for accelerating their growth. Seedlings with 2 leaves can be obtained within 8 days by spreading over the seeds some powdered chicken manure, after putting on a thin layer of rice straw, and putting on top a plastic cover. Every morning, pull off the plastic cover and sprinkle the bed with water and then after 4 days, pull off all covers over the seed bed which will begin to show the first leaf of seedlings.

2. Having shorter length of roots makes the transplanting of young seedlings easier.
In the seedbed, experimental results showed that seedlings with roots only 3 cm in length can be obtained by growing seedlings on a compacted soil surface. This makes easy and fast to transplant the young seedling, and the number of labor-days needed for transplanting is reduced

to 23 man-days for transplanting one hectare of paddy field. This makes SRI similar to the conventional practice (SRA) in terms of labor cost, and the plants perform equally well.

3. Seedling density of one per hill when transplanting is not always optimal.
Our experiments confirmed that, as expected, optimal density of transplanting can vary depending on soil fertility.

- For fertile soil, it is better to use 1 plant per hill rather than 3 lants per hill. For example, in 1999 at Soatanana, wide spacing (50x50 cm) gave very high tillering (70 tillers per plant average) because there was a good nutrient supply for the root system of the plants. Yield was 2,740 kg from 0.13 hecrares.
- In the case of poorer soil, tranplanting of 1, 2 or 3 seedlings per hill gave essentially the same grain yields. No benefit was seen in having only 1 seedling per hill as generally recommended with SRI (Table 1 in appendix). Only different spacing between hills gave a statistically significant result (Table 2). Use of 3 seedlings per hill is more efficient for utilizing available soil nutrients with poor soil conditions.

Other SRI evaluations have showed a real difference between 1 and 3 seedlings per hill. The factorial trials conducted in 2000 and 2001 for the University of Antananarivo at Morondava and Anjomakely, with 288 and 140 trial plots respectively, showed an average yield increase, with all other practices being equal, of 0.5 t/ha when planting 1 seedling/hill vs. 3 seedlings/hill.

The best density of transplanting depends on plant type as well as soil fertility. When transplanted at a spacing of 30x30 cm, a tall variety like *Mailaka X265* can give the best yield. Beyond this optimum, there is evidently a decrease of yield. Either plant lodging occurs with narrow spacing 20x20 cm or there is underutilized soil surface with large spacing 50x50 cm.

4. **Mailaka X265** ***appears to be the most suitable variety for the agroecological conditions most common in highland Madagascar.*** This improved *Indica* variety has:
- Good capacity of tillering with SRI management, with more fertile tillers (panicles).
- Good (efficient) response to fertilizer supply
- High yielding performance.

5. ***Aerated soil due to careful water management applying a minimum of water, supported by weed control measures and rotational cropping, gives best results.***
Experimental results showed that aeration of the paddy soil is important for root development and plant nutrition. An average grain yield at least 8 t/ha was fairly consistently obtained by using new intensification methods such as practicing:
- Vegetable cropping in the dry season followed by intensive rice cropping in the wet season.
- Water management with a system of alternating dry soil and wet soil by irrigation.
- Weed control and simultaneous aeration of soil by practicing weeding with a 'rotating hoe' 4 times before canopy closure.
- Biological fertilization of soil by use of good compost which is applied earlier on the potato crop that is grown preceding rice.

The findings from this research with summary data are reported in tables in an appendix to this report. These show that SRI needs always to be treated as an empirical matter, to assess how different management factors will affect yields.

IV. ESSA: Evaluating SRI Mechanisms and Explanations

4.A Activities Under the Grant

The study of SRI mechanism by the Faculty of Agriculture (ESSA) commenced with two student theses in 1998-99, supported by CIIFAD. This grant made it possible to expand the scope of research, exploring the role and importance of different kinds of fertilization and examining the effects of root growth withl SRI practices. With prior studies in mind, we elaborated a program of research in 2000-2003 to produce useable results, drawing also on support from CIIFAD. This program of research, utilizing the talents of some of the best students in the Faculty of Agriculture at the University of Antananarivo, has advanced our scientific knowledge of SRI and its potentials considerably. The focuses of research activities in this program were:

1. ***Multi-factorial trials:*** We have tried to determine the influences of different variables on SRI yield by assessing the respective and combined effects of these factors on yield, as well as other dependent variables like yield components. The independent variables assessed were: age of plants at transplanting, management or water, spacing of plants, and application of soil nutrient amendments. In one set of trials, high-yielding vs. traditional local varieties were compared, with soil being held constant in the second, soil was varied (better vs. poorer, clay vs. loam) while variety was kept the same for all trials (N = 288 in the first set, and N = 240 in the second set).

2. ***Multi-locational trials:*** By carrying out multifactorial trials in several locations, we were able to assess also possible differences in agroclimatic and agroecological conditions. The different locations in which trials were conducted included:
   - Morandava: tropical, dry and arid climate, poor and sandy soils
   - Anjomakely (near Antananarivo): temperate, more moderate climate, better soils
   - Beforona : warm and humid climate, mixed soils

3. ***Studies of biological nitrogen fixation (BNF)*****:** By application of varying doses of different kinds of fertilizer, evaluation of the yields obtained to determine how efficacious these are and what levels of organic fertilization are necessary or optimal with SRI.

4. ***Relationship between BNF and the aerobic soil condition of SRI*****:** Application of different types of weeding, e.g., with the rotating hoe vs. mulching.

5. ***Characterization of the contribution of* Azospirillum *for BNF*****:** Identification of this endophytic bacteria and counting its frequency under different plant, soil, water and nutrient conditions, with SRI and conventional methods.

6. ***Seed inoculation to test the impact of* Azospirillum *isolates on roots with SRI*:** This work tested the possibility of inoculating rice seeds used in SRI to achieve higher yields.

7. ***Evaluation of practical methods for farmers to benefit from* Azospirillum:** In 2002-2003, we have treated seeds with solutions prepared with roots of SRI plants having more than 45 tillers, to see whether BNF-microorganisms could be transferred to new plants.

4.B Results of Grant Activities

Our work has generated data that offer scientific explanations for the obtaining of higher yields with SRI methods. The strategy of research has followed the following logic: observations, confirmation of results, examination of the role of microorganisms in obtaining those higher yields, and use of methodologies to validate the hypotheses. We believe that in just three years with very modest investment from the Rockefeller Foundation and CIIFAD, we have established findings of much significance for food security and environmental conservation.

1. The role of soil aeration (oxygenation) in explaining the mechanisms of SRI

The multi-factorial and multi-locational trials constituted the first stage of our studies. The most powerful SRI practice, other things being equal, is the use of young plants, preferably about 8 days old. But their giving full expression to their genetic potential depends on the soil growing conditions of the plant's roots. For this we see that the careful water management and application is a powerful factor affecting the growth of SRI rice, augmented by the frequent use of a 'rotating hoe' which not only removed weeds but aerates the soil. These two factors combine to increase oxygenation of the roots and root zone.

2. Why does SRI give better results with 'oxygenation?

Our hypothesis on this was driven by observations from the multi-factorial trials where it was seen that without chemical fertilization, water management could add significantly to yield. In the 2000 trials at Morondava which has poor sandy soil (Andriankaja 2000), the average yield for older seedlings (16 days), 3 per hill, continuously flooded, with either NPK or compost was 2.58 t/ha; going to young seedlings (8 days), 1 per hill, flooded and fertilized raised the average to 4.30 t/ha (66%), while going from conventional practices including flooding to SRI practices with water management (aerated soil) increased average yield to 5.95 t/ha, another 40% not based on any differences in fertilization.

This confirmed our thinking that there must be some augmentation in the nutrient availability, particularly N, in the rhizosphere of SRI plants between tillering and maturity due to SRI's water and other management practices. Our analysis focused on *Azospirillum* because this is a known N-fixing bacteria, and it is relatively easy to identify and count. The research by Raobelison (2000) confirmed the suspicion, though we do not infer that this species by itself is contributing all of the nutrient supplementation with SRI. Rather, this is indicative of the dramatic changes in the rhizosphere and in the plant itself that SRI practices induce.

Azospirillum Populations, Tillering and Rice Yield Associated with Different Cultivation Practices and Nutrient Amendments

	Azospirillium (10^3/ml)			
CLAY SOIL (better)	Rhizosphere	In the roots	Tillers/plant	Yield (t/ha)
Traditional cultivation, no amendments	25	65	17	1.8
SRI cultivation, with no amendments	25	1,100	45	6.1
SRI cultivation, with NPK amendments	25	450	68	9.0
SRI cultivation, with compost amendments	25	1,400	78	10.5
LOAM SOIL (poorer)				
SRI cultivation, with no amendments	25	75	32	2.1
SRI cultivation, with compost amendments	25	2,000	47	6.6

Data from: F. D. E. Raobelison, *Suive experimental de la teneur en elements fertilisants liberes par la fumure organique au cours du cycle de developpement du riz: Cas du SRI au CDIA, Beforona*. Faculty of Agriculture, University of Antananarivo, 2000. Reported in: Robert Philipposon Randriamiharisoa. "Research Results on Biological Nitrogen Fixation with the System of Rice Intensification." In: *Assessments of the System of Rice Intensification: Proceedings of an international conference, Sanya, China, April 1-4, 2002*, edited by N. Uphoff, et al., pp. 148-157. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY, 2002.

This pointed our thinking to the conclusion that the oxygenation of the roots permits micro-organisms that accomplish BNF to provide supplementary N to rice plants when they grown according to SRI methods.

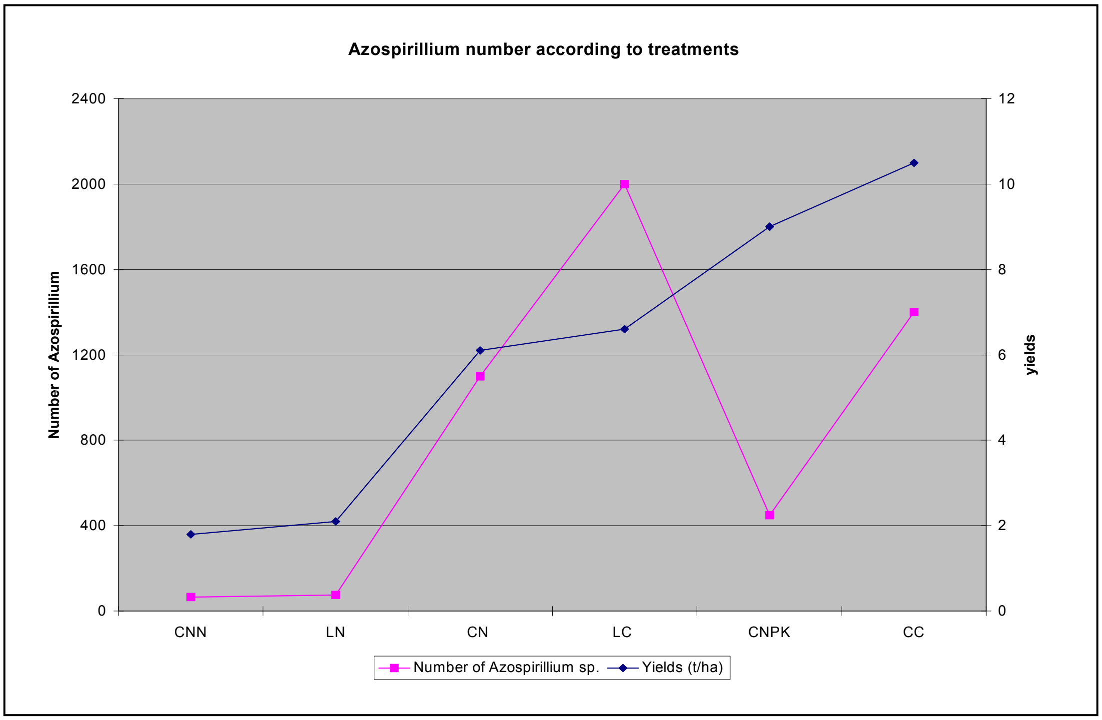
3. Identification of N-fixing bacteria in the roots of SRI rice plants

We have determined from microbiological studies that the principal associative bacteria that are known to fix N exist in the roots of SRI plants. Utilizing the table of Mac Grady, 3 types of *Azospirillum* have been found: A. brasilense, A. lipoferum, and A. amazonense. They have been isolated and appear to be the three types most responsible for improved yield, although there could be contributions from other bacteria as well as funguses. The latter being aerobic require aerated soil for performing their plant-supporting functions; we have not yet investigated the role of mycorrhizal fungal associations.

Azospirillum Identification According to SRI Treatments

Treatments		Name and Number of *Azospirillum*			Tillers
Soil Texture and Manage-ment Practices	**Fertilizer Amendments**	**Rhizosphere ($n = 25 \times 10^3$ /ml)**	**Roots ($n \times 10^3$ /mg)**		**(N)**
Clay (Traditional)	No	*A. brasilense, A. lipoferum*	*A.brasilense, A. lipoferum*	65	17
Loam (SRI)	No	*A. brasilense, A. lipoferum*	*A.brasilense, A. lipoferum, A. amazonense?*	75	32
Clay (SRI)	No	*A. brasilense, A. lipoferum*	*A.brasilense, A. lipoferum, A. amazonense?*	1,100	45
Loam (SRI)	Compost	*A. brasilense, A. lipoferum*	*A.brasilense, A. lipoferum, A. amazonense?*	2,000	47
Clay (SRI)	N P K	*A. brasilense, A. lipoferum*	*A.brasilense, A. lipoferum, A. amazonense?*	450	68
Clay (SRI)	Compost	*A.brasilense, A. lipoferum*	*A.brasilense, A. lipoferum, A. amazonense?*	1,400	78

Control comparisons: Traditional rice cultivation (non-SRI): clumps of 30-day-old seedlings, no water management, no weeder operation, just weeding by hand. Rice plants that are provided with chemical fertilizer had fewer colonies of *Azospirillium* sp ($n = 450x10^3$/mg), compared to those fertilized with compost ($n = 1400x10^3$/mg). Nevertheless, both of them brought the best yields. The three colonies retrieved from them and identified were: *A. brasilense, A.lipoferum*, and *A. amazonense.* Research conducted during 2001-2002 at Beforona research station, operated by CIIFAD under the Landscape Development Interventions Project funded by USAID.



CNN	:	Clay , no fertilizer, traditional cultivation (not SRI)
LN	:	Loam, no fertilizer, SRI
CN	:	Clay, no fertilizer, SRI
LC	:	Loam with compost, SRI
CNPK	:	Clay with NPK, SRI
CC	:	Clay with compost, SRI

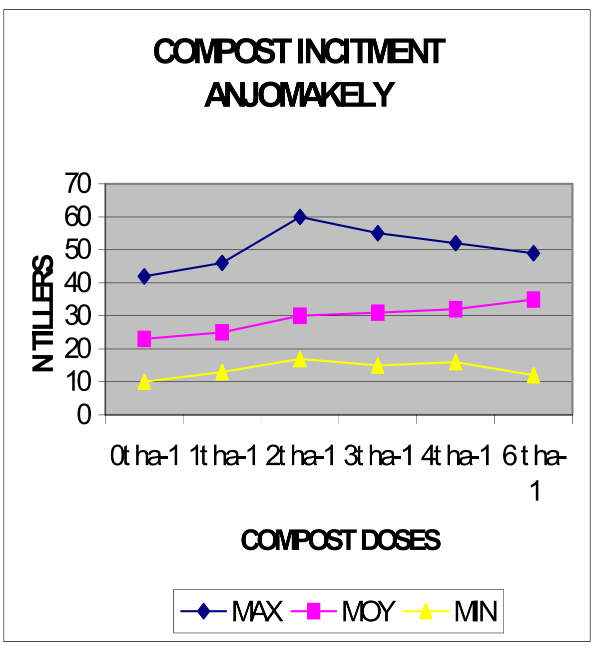
4. Determination of the most efficacious application of compost with SRI methods to obtain the effects of BNF

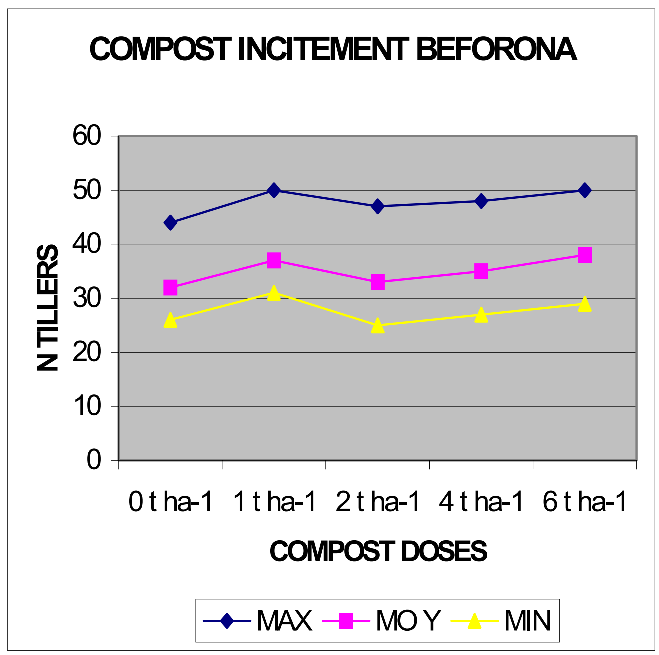
The issue of 'incitation' of microorganisms responsible for BNF was studied by Randriansolo in 2001 at Beforona and Anjomakely, applying 1 ton/ha compost instead of the 5-10 tons/ha more commonly used in Madagascar.

Doses of Compost Indicating the 'Incitement' Threshold of Microorganisms for Fixing Nitrogen: Effects on Tillering

Compost Applications		Average Number of Tillers								
		Anjomakely			Beforona			Fianarantsoa		
		Max	Ave	Min	Max	Ave	Min	Max	Ave	Min
DOSES	0 t/ha	42	23	10	44	32	26	35	20	14
	1 t/ha	46	25	13	50	37	31	39	25	18
	2 t/ha	60	30	17	47	33	25	42	29	15
	3 t/ha	55	31	15	-	-	-	40	34	20
	4 t/ha	52	32	16	48	35	27	38	32	23
	6 t/ha	49	35	12	50	38	29	-	-	-

Conditions: single seedlings aged 8 days at transplanting; water management: alternate drying and wetting of 3 days each with 10cm water level at most. Research in 2001-2002.





These results indicate that there is an 'incitement' threshold for compost when used with SRI methods, a level of just 1 to 2 t/ha compared to the recommended use of 5 to 10 t/ha. This means that a good yield can be obtained without having to apply large amounts of compost to the field -- although the very highest yields achieved with SRI methods, up to 21 tons/ha, have come with large applications of compost over half a dozen years, a rate of about 40 tons/ha.

In a study of 108 farmers in four locations who used both SRI and conventional methods of rice cultivation on their farms for his MS thesis in Crop and Soil Sciences at Cornell University, Joeli Barison (who conducted the first ESSA research on SRI back in 1998), found that 80% of farmers were not applying either organic or inorganic amendments to their rice fields, whether using SRI or conventional methods, and yet the yields on the SRI plots were almost double those from non-SRI plots.

One of the reasons given why sceptics think SRI cannot be adopted widely is that they say there is not enough compost to make large applications needed to get high yield. Yet we find in carefully controlled experiments that large amounts are not needed for a very respectable yield response. The tiller counts reported in the figures above are evidence of phenotypical changes in the well-nourished plants. The yields were in the 7-8 ton/ha range, representing 2-3 times the usual yields obtained in Madagascar

5. *Effect of seed inoculation with* Azospirillum *on tillering and root length using SRI practices*
We saw that *Azospirillum* concentrations in rice plant roots, especially with the practices that SRI introduces for managing plants, soil and water, contributed to much higher yield. Experiments were conducted in 2002-2003 with the inoculation of seeds using an extract from SRI roots that had been crushed and soaked in water, with an incubation period of 10 days, to accumulate populations of this N-fixing bacteria. These could be transferred to rice seeds through soaking before they were planted in the nursery. The hypothesis was that such inoculation would make the use of compost more effective for supporting plant growth and performance. The trials were done with replications in six sub-blocs randomly assigned. Tillering from plants grown from inoculated seeds is shown in the table below for four different levels of compost application.

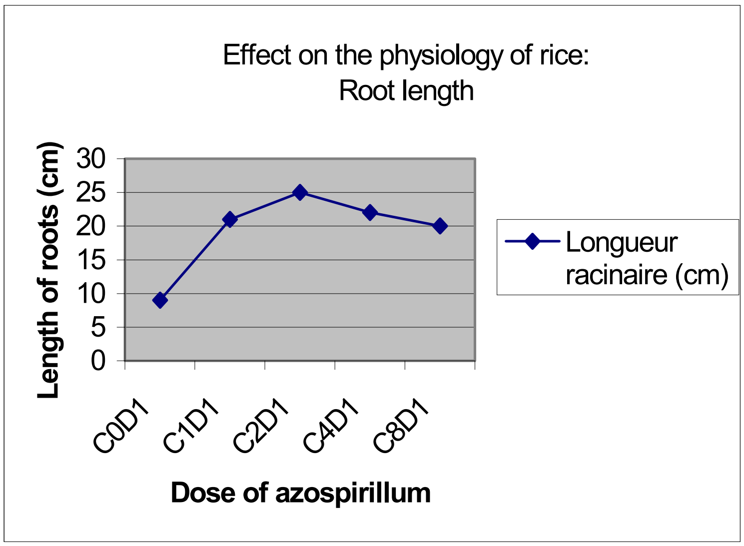
Number of Tillers per Plant Obtained with the Inoculation of Rice Seeds Using an Extract of *Azospirillum*, 09/03/02, at Beforona Station

Sub-Blocs	Control	1t/ha Compost	2t/ha Compost	4t/ha Compost	6t/ha Compost
1	28	32	30	31	34
2	25	36	35	38	38
3	30	35	37	36	40
4	23	32	33	35	38
5	26	31	30	33	35
6	29	32	32	32	36
Average	26.8	33.0	32.8	34.1	36.8

The table shows a strong tillering response to the addition of compost, with just 1 t/ha of compost increasing tillers from inoculated plants by 23.1%. But there was no linear response to the increments of compost, with an application of 6 t/ha giving only 37.3% more than on the control plots. There was an increase in tillering with this higher amount of compost added, but not a sufficient increase to justify the effort of making and applying six times as much volume per hectare. Indeed, no advantage was seen in applying 2 t/ha compared to 1 t/ha. This has prompted us to think in terms of compost as 'inciting' or 'priming' soil microbiological processes.

A similar effect was seen on the growth of rice plant roots in response to seed inoculation with *Azospirillum*. Fortunately, the dose applied could be fairly small to achieve a substantial effect. A single dose of 50cc made from 480 g of compost and applied to 25 g of rice weeds doubled the length of roots, from <10 cm in the control plants to >20 cm, as seen in the figure below. Halving the dose to 25 cc increased average root length further to 25 cm, but further dilution, to one-quarter (12.5 cc) and one-eighth strength (6.25 cc), showed no additional benefit, though still with as much effect the full initial dose of 50 cc, as seen in the figure below.

Effect of *Azospirillum* innoculation on root length with SRI



Key: COD1 = control (no inoculation); C1D1 = Single dose: 50 cc of solution; C2DI = Half dose, 25 cc; C4D1 = Quarter dose, 12.5 cc; C8D1 = One-eighth dose, 6.25 cc. Results were obtained from trials conducted by Patrick Rajaomilson for field study for ESSA, June 2003.

Rice yelds reflected these tillering patterns as seen in the accompanying table.

Doses	Tillers	Yield (t/ha)
C0: Control (no inoculation)	13	2.5
C1D1: Base dose (50cc)		
C2D1: Half dose (25 cc)	42	8.5
C3D1: Quarter dose (12.5 cc)	37	7.2
C4D1: Eighth dose (6.25 cc)	32	7.0

Our work on soil microbiology and plant response and performance is still in an early stage. The trials conducted and reported here are opening some new 'doors' for building upon the foundation that SRI practice and experience has created for increasing rice productivity in Madagascar, and elsewhere. There is scope and need for much more work to be done on the effects of changing plant, soil, water and nutrient management practices in such ways that the benefits of soil microorganisms can be concomitantly 'managed' for agronomic benefits.

This grant has enabled ESSA, in cooperation with Tefy Saina, FOFIFA and CIIFAD, to advance the scientific understanding of SRI, but there are still many questions unanswered about present practice. Based upon our research, we think there remain many opportunities for productive further work to expand the benefits that the System of Rice Intensification offers.

APPENDIX: Tables for FOFIFA Section III

Table 1. Effects of number of seedlings transplanted per hill on grain yield (t/ha) with the improved Indica rice variety *Mailaka X265*

Spacing (cm)	1 seedling	2 seedlings	3 seedlings
20 x 20	10.4	9.2	8.8
30 x 30	8.2	7.5	8.8
40 x 40	7.3	6.8	7.5
50 x 50	5.5	6.1	6.9
Average	7.8 *a*	7.4 *a*	8.0 *a*

Table 2. Effects of different densities of transplanting of seedlings on grain yield (t/ha) over three years, 1999 – 2002

Spacing - Seedling number	1999	2001	2002
20x20 – 1	10.4*		
20x20 – 2	9.2*		
20x20 – 3	8.8*		
Average 20x20 cm	9.4 *a*		
30x30 – 1	8.2	10.5	5.4
30x30 – 2	7.5		8.9
30x30 – 3	8.8	12.5	12.9
Average 30x30 cm	8.1 *b*		
40x40 – 1	7.3		
40x40 – 2	6.8		
40x40 – 3	7.5		
Average 40x40 cm	7.2 *b*		
50x50 -1	5.5	7.9	
50x50 -2	6.1		
50x50 -3	6.9		
Average 50x50 cm	6.1 *c*		

Least significant difference $_{0.01}$ = 1.1t/ha

*   Appearance of plant lodging

Table 3. Data recorded on demonstration plots of Indica rice variety *Mailaka X265*, transplanted with 1, 2 or 3 seedlings per hill

	1 seedling	2 seedlings	3 seedlings
Hill no. /0.009 m^2	1	1	1
Hill no./m^2	11	11	11
Panicle no./hill	21	41	60
Weight (g) of full grain/hill	53	87	126
Full grain no./hill	1938	3380	4674
Weight (g) of 1000 grains	25	25	26
Grain number/ panicle	69	82	78
Yield (t/ha)	5.4	8.9	12.9