Evaluation of Nutrient Uptake and Nutrient-Use Efficiency of SRI and Conventional Rice Cultivation Methods in MADAGASCAR

Joeli Barison, Cornell University [1]

Despite evidence from several countries that rice yields can be at least doubled with the System of Rice Intensification (SRI) in comparison to conventional practices, there is still some skepticism about it among rice scientists. With the guidance of my thesis advisor, Prof. Erick Fernandes, I have sought to gain a better understanding of the physiological factors that underlie this higher performance with SRI practices.

For this purpose, I undertook an evaluation of the nutrient uptake and nutrient-use efficiency of SRI-grown rice compared with conventionally-grown rice in four areas of Madagascar, including an evaluation of plants grown on the fields of 108 farmers. The objectives of the research were: (1) to determine the nutrient uptake and the nutrient-use efficiency (NUE) of SRI methods compared to conventional systems of cultivation; and (2) to estimate the N, P and K requirements of rice plant cultivated with either SRI or conventional practice.

Evaluations

On-station study of nutrient uptake and NUE comparing SRI and conventional systems

This evaluation was undertaken at the Beforona research center in the eastern part of Madagascar during the 2001 main growing season (October 2000 through May 2001.) The trials were done on clay-sandy soil with 43.8 g organic matter/kg, 27 g organic C/kg, 1.88 g total N/kg, and 17.8 g available P/kg (Olsen method extraction). Exchangeable K was 0.15 cmol(+)/kg exchangeable K, and cation exchange capacity was 2.6 cmol(+)/kg.

Experimental design

Five treatments were arranged in a randomized block design with a three-time block replication. Plot size was equal to 20m^2. Treatments were the following, with SRA being the system of "improved" rice cultivation *(systèm de riziculture ameliorée)*, which the government promotes, with row planting, use of new varieties, and agrochemical inputs.

- T1: SRI cultivation method with compost application
- T2: SRI method without compost
- T3: SRA method with chemical fertilizer (NPK 11-22-16)
- T4: SRA method without fertilizer
- T5: Conventional system used by farmers

Rice grain yields after measurement were adjusted to 14% moisture content. Plant samples were collected at three different stages (panicle initiation, anthesis, and maturity) and were analyzed for their macro-nutrient content (N, P and K.)

On-farm evaluations of nutrient uptake, NUE and nutrient requirements comparing SRI and conventional systems

For more extensive and realistic comparisons between SRI and conventional systems, the on-station trials were complemented by an on-farm survey with farmers in four rice-growing areas of Madagascar (Ambatondrazaka, Imerimandroso, Antsirabe, and Fianarantsoa). 108 farmers, each practicing both SRI and conventional production methods on their farms, were included in our study although only 98 farmers are included in the agronomic analysis here because we could not get com-

[1] *This research is reported and analyzed in more detail in: Joeli Barison (2002): Nutrient-use efficiency and nutrient uptake in conventional and intensive (SRI) rice cultivation systems in Madagascar, a Master's thesis for the Department of Crop and Soil Sciences, Cornell University, Ithaca, NY. This thesis is available electronically upon request to: ciifad@cornell.edu*

Table 1: Characteristics of SRI, SRA and conventional systems

System of cultivation	SRI	SRA	Conventional
Age at transplanting (days)	8	25	45
No. of seedlings/hill	1	2-3	4-6
Spacing (cm)	25 x 25	20 x 20	14 x 14
Water management	Irrigate at night and drain in the morning is recommended, or alternate wetting-drying	Standing water of 3-5 cm	2-3 cm standing water for 2 weeks after transplanting; then 5 cm for rest of season
Fertilization	Compost	NPK and urea	No fertilization

plete data for 10 in the sample. The plants of these farmers were followed closely throughout the growing season, taking soil and plant samples for analysis of macro-nutrient content.

Results

On-station study

Grain yield comparison

Significant grain yield differences were observed among the three systems (Table 2.) The highest grain yield was obtained from plots where SRI was used and compost applied, with grain yield of 6.26 t/ha. This yield was statistically significantly different from that of the SRA system (4.92 t/ha with NPK and urea fertilized plots, and 4.67 t/ha for non-fertilized plots) and the conventional system (grain yield of 2.63 t/ha) (see Table 2; p=0.001, ANOVA test). Actually, this SRI yield was lower than usually obtained with these methods, probably due to late planting of the SRI plots by one month. Previously at the Beforona station, the SRI yield was 10.2 t/ha,.

The higher grain yield observed with SRI cultivation methods in the 2001 season was the result of a higher number of panicles and grains/m^2 (Table 3). For the SRA treatments, the lack of significant difference between the fertilized and non-fertilized plots were due to a greater attack of blast (*Pyricularia oryzae*) in the fertilized plots during the grain-filling period.

Evaluation of the root growth and distribution by root length density

Root length density (RLD), a standard method for the measurement of the root growth and proliferation, was done at harvest time. From our measurements, we noticed that in all of the treatments, root growth decreased rapidly in relation to the soil depth.

Rice plants grown with conventional and SRA methods had higher root growth in the first 20 cm in comparison to those with SRI (see Table 4). Most root growth was observed to be superficial with plants cultivated with conventional methods. However, the root growth of conventional and SRA rice plants began to be offset by SRI plants at a depth of 20-30 cm. Furthermore, greater root growth was noticed with SRI plants at lower depths, below 30 cm. This greater root growth to lower depths suggested that plants cultivated with SRI methods, which include alternate drying and draining of the soil, were capable of developing greater root penetration in comparison to SRA and conventionally grown plants.

Evaluation of nutrient uptake

The highest nutrient uptake of N, P and K was recorded in the SRI plots while the lowest was seen with conventional cultivation practices.

Table 2: Mean grain yields, by treatment

Treatment	Mean	Group
SRI with compost	6.26	A
SRI without compost	5.04	AB
SRA with NPK and urea	4.92	B
SRA without fertilizer	4.68	B
Conventional system	2.63	C

LSD test at 5% indicated by letters

Table 3: Grain yield components in the on-station experiment

Treatment	Plants/m²	Panicles/m²	Grains/m²	1000-grain weight (g)
SRI with compost	16	242	20,445	29.43
SRI without compost	16	248	18,827	29.22
SRA with NPK and urea	25	212	15,634	29.35
SRA without fertilization	25	152	10,826	29.70
Conventional	53	290	9,237	30.12

On-farm evaluation

Grain yield and Harvest Index comparisons in the on-farm survey

A predominant strategy in recent years for breeding rice with increased grain production has been to reduce the share of non-harvestable biomass so that the edible proportion of biomass is higher. This is described as increasing the Harvest Index, i.e., the ratio of grain yield to total biomass. (Note, however, that this HI is calculated for above-ground biomass only, not taking root biomass into account; this is an omission done mostly for practical rather than theoretical reasons.)

This objective of raising the HI has led researchers to create shorter-stature cultivars that produce fewer barren tillers and a higher number of grains per fertile tiller (Khush, 1993). At the same time, conventional strategies for raising yield have recommended an increase in planting density. According to this reasoning, one would expect that higher tiller numbers and reduced planting density should lower the Harvest Index. As seen below, however, this does not happen with SRI.

Comparisons of yield between SRI and conventional systems in the farmer plots surveyed showed that with SRI, the grain yield was significantly higher, with fewer plants and with plants having greater biomass both above and below ground. Farmers who used the SRI method on their rice plots obtained an average yield of 6.36 t/ha compared to an average grain yield of only 3.36 t/ha with conventional methods.

This 89% increase over conventional grain yield for the farmers surveyed in this sample is actually 218% higher than the national average grain yield of 2 t/ha. That farmers in the sample got higher yields with conventional methods than typical nationally suggests that they were either more skilled and/or motivated, and/or had better soil and other growing conditions.

This grain yield increase was accomplished with rice plants that had significantly higher numbers of tillers than conventionally grown rice plants but a *similar* Harvest Index**.** While the Harvest Index with conventional methods averaged 0.49, with SRI methods this ratio was 0.48. Furthermore, a comparison on the Nutrient Harvest Index indicated very similar relationships. The nutrient harvest index was 0.68g N/g, 0.71g P/g, and 0.27g K/g for SRI, compared to 0.65g N/g, 0.72 g P/g, and 0.25 g P/g in rice grown with the conventional methods. See also differences in Table 5.

These numbers indicate that despite the higher tiller number of SRI plants, which normally results in higher non-harvestable biomass, the HI with SRI methods was practically the same, and in some cases higher than with conventionally grown rice. SRI plants apparently benefit from improved rooting development.

Table 4: Root length density (cm/cm³) for SRI, SRA and conventional systems

	Soil layers (cm)					
Treatment	0-5	5-10	10-20	20-30	30-40	40-50
SRI with compost	3.65	0.75	0.61	0.33	0.30	0.23
SRI without compost	3.33	0.71	0.57	0.32	0.25	0.20
SRA with NPK and urea	3.73	0.99	0.65	0.34	0.18	0.09
SRA without fertilization	3.24	0.85	0.55	0.31	0.15	0.07
Conventional system	4.11	1.28	1.19	0.36	0.13	0.06

Table 5: Total aboveground N, P and K uptake of rice plants (kg/ha)

Treatment	N	P	K
SRI with compost	176.74	35.89	153.33
SRI without compost	159.39	34.84	136.92
SRA with NPK and urea	133.63	30.08	113.37
SRA without fertilization	122.62	29.24	116.17
Conventional	62.95	13.34	55.86

The appearance of more nodal roots for every newly formed tiller led to a more developed root system, since root and tiller growth from the apical meristem is coordinated. This increase was stimulated, we think, by the joint effect of better soil aeration by different water management practices and by the transplantation of young seedlings. The resulting root systems can exploit a greater volume of soil and can potentially access greater amounts as well as more diversity of nutrients.

Nutrient uptake of the rice plant

The total above-ground nutrient accumulation for the SRI system averaged 95.07 kg N/ha, 21.03 kg P/ha, and 108.64 kg K/ha. while for plants grown with conventional practices, the average was 49.99 kg N/ha, 12.69 kg P/ha, and 56.77 kg K/ha (Table 6). These results showed that modification of plant, soil, water and nutrient management practices could enhance plant uptake by 91% for N and K, and by 66% for P.

Interestingly, the relatively high increase of accumulated N and K, on one hand, and the lower increase of accumulated P, on the other, suggests that possibly conventional plants had either a low N and K uptake or a high P uptake. It is also possible that in these soils, P was the limiting macro-nutrient and that growth could have been greater with more available P.

To get a clearer picture of nutrient uptake constraints on yield, one should to compare grain yields with nutrient content and concentration differences between SRI and conventional systems. As we have seen, SRI grain yield for these 108 farmers averaged 6.36 t/ha while that of conventional rice was 3.36 t/ha, an increase of 90% in grain yield, reflected in the increased N and K concentrations and content in the rice plants and grain.

It could be possible that the increase of grain yield with SRI compared to that of conventionally grown rice was due to farmers allocating their best sites to SRI or to application of more compost to SRI plots. Results from our soil analyses, however, showed that SRI and conventional plots had similar soil fertility as commonly evaluated. The average nutrient content were 0.16% N, 8.51 ppm P-Olsen, and 0.08 cmol (+)/kg K in the SRI plots, and 0.17% N, 9.39 ppm P and 0.09 cmol(+).kg^{-1} K in the plots conventionally cultivated.

Moreover, *only about 6 farmers in our sample used any compost on their SRI plots*. Excluding their grain yield hardly changed the comparison: grain yield of 6.35 t/ha with SRI vs. 3.36 t/ha with conventional methods. So SRI nutrient practices were not affecting the results; 90% of the farmers were getting their higher SRI yields just from using the other SRI methods, not making any soil nutrient amendments. See Table 6.

Internal nutrient efficiency

Nitrogen internal efficiency (NIE) with conventional practices was higher compared with SRI, but a t-test indicated that it was not significant at the 5% level of confidence (p=0.197.) A significant difference was noticed in regard to the P use-efficiency; more efficient use of P for grain production with SRI cultivation methods was observed. This is apparently the result of higher N uptake with SRI plants, evident in the N : P : K ratio (ratio of N to P and K to P.) The nutrient ratio for plants grown with SRI methods was higher (5 : 1 : 4.9) than with conventional practices (3.9 : 1 : 4.1). See Table 7.

Table 6: Nutrient uptake of rice plants for SRI and conventional systems (kg/ha)

System of cultivation	N	P	K
SRI	95.07	21.03	108.64
Conventional system	49.99	12.69	56.77

Table 7: Evaluation of NIE with SRI and conventional systems

Parameter	Unit	Sample size	Mean: Conv.	Mean: SRI	Two-sample t test p-value
N IE	kg/kg	94	74.9	69.2	0.197
P IE	kg/kg	94	291.1	347.2	0.001
K IE	kg/kg	94	70.4	69.7	0.884

Discussion

Rice plants cultivated with conventional and SRA systems had higher root growth at the top 20 cm than those with SRI methods, but there was better root growth at lower depths evident with SRI plants.

No apparent reduction of the Harvest Index was seen to result from SRI practices. This suggests that even with a higher number of tillers, SRI plants' better root growth and soil penetration enabled them to achieve proportionally higher grain formation.

A 91% increase of N and K uptake, compared with nutrient uptake in conventionally-grown rice plants, in conjunction with a 90% increase in grain yield and a 66% increase of P uptake, reflected a greater capacity of plants cultivated with SRI methods to access and take up P. It is possible that in addition to better nutrient supply, the enhanced root growth with SRI allowed the plants to access sub-soil P that was not available under the conventional system.

What our research did not examine and cannot resolve is whether this effect is more due to changes in plant structure and physiology or to changes in the rhizosphere in response to SRI's practices for plant, soil, water and nutrient management, particularly greater abundance and diversity of beneficial microorganisms or some combination of both. This remains to be explored in future research.

Prospects

The greater nutrient uptake with SRI cultivation methods suggests that rice plants grown with these practices are capable of taking up more nutrients and converting them into directly and indirectly beneficial biomass more grain, and more tillers and leaves that support this grain. We were not able in this research to evaluate the uptake of micronutrients, which could help to account for better production performance and also for reports that SRI plants have greater resistance to pest and disease damage.

Greater nutrient uptake suggests that there might be some increase of available N in the soil due to higher mineralization of organic-N in a soil environment that alternates aerobic and anaerobic conditions. Furthermore, greater activity of N-fixing bacteria such as N_2-fixing endophytes within the root cells and in the root rhizosphere might also be present in the SRI plant-soil environment.

It was not possible to evaluate N-fixation in this research, but we can hypothesize that the greater uptake of N is attributable to the better root growth and root activity in conjunction with greater activity by larger and more diverse soil microbial populations. This hypothesis remains to be experimentally tested through evaluation and assessment of the dynamics of microbial populations associated with SRI plant, soil, water and nutrient management practices. Some initial research on this is reported in the following paper by Prof. Robert Randriamiharisoa.

Reference

Khush, G. S. (1993). Breeding rice for sustainable agricultural systems. In: D. R. Buxton, et al., eds., *International Crop Science* I. Proceedings from International Crop Science Congress, Ames, IA, 14-22 July, 1992, 89-199. Madison, WI: Crop Science Society of America.

