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TECHNICAL REPORT

On-farm evaluation of a low-input rice production system in Panama

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Abstract On-farm trials were conducted to evaluate the potential of the System of Rice Intensification (SRI), a low-input crop management system, to increase rice yields and reduce water consumption on subsistence farms in several regions of Panama and to determine how inherent soil fertility might affect SRI yields and the yield response to SRI management in the first season of SRI management. SRI practices increased yield by 47% on average and showed potential to increase yield by over 90%, while reducing water consumption by as much as 86%. SRI yields were correlated with available soil K and the difference between SRI and the conventional system yields was positively correlated with extractable Ca, Mg and Mn. The results of this study indicate that SRI is a promising rice production system for smallholder farmers in rural Panama farming under Panamanian soil conditions.

Keywords Low-input agriculture · Panama · Potassium · Rice · Soil fertility · System of Rice Intensification (SRI)

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Introduction

The System of Rice Intensification (SRI) is an emerging low-input method for production of rice (*Oryza sativa*) that has the potential to increase crop yields while reducing the consumption of water, seed and mineral fertilizer (Barison 2003; Randriamiharisoa et al. 2006). Developed in Madagascar in the 1980s, the first SRI experiments outside of Madagascar began in 1999, leading to its adoption in some parts of Asia, Africa and Latin America (Wang et al. 2002).

The SRI method involves early transplanting, lower plant density, use of organic fertilizer to supply all or some of the required nutrients, and intermittent wetting and drying of the soil rather than the prolonged flooding practiced in conventional rice paddy systems (Stoop et al. 2002). Some reports indicate that mineral fertilizer and water inputs can be reduced by up to 50% with SRI (Barison 2003).

With SRI, fields can be irrigated intermittently, when they begin to dry (every 3–10 days depending on the climate and soil), in contrast to maintaining flooded paddies which are irrigated continuously. SRI has been found to increase yields significantly compared to the conventional system when implemented on strongly weathered soils of low fertility (Acrisols and Ferralsols), and to produce relatively high yields (7–10 t ha^{-1}) in more fertile soils (Gleysols, Luvisols) (authors' unpublished data).

The adoption of SRI in Latin America has been slower than in Asia, in part due to a lack of local field trials and extension work. In 2001, Cuba became the first country in Latin American to establish SRI trials (Perez 2002). Since then, the system has been tested in several other countries including Brazil, Costa Rica, Ecuador, Peru, and now Panama (Gehring et al. 2008; CIIFAD 2010; Chang 2008).

The majority of trials have reported positive results in terms of yields and resource-saving. Several reports indicate that weeds were a problem that reduce yields or require more labour in the SRI system (Chang 2008; CIIFAD 2010). Most of the data so far are from isolated trials; more extensive and robust experimentation in Latin America is required before conclusions can be drawn about SRI's suitability in the region.

The SRI is a low-input technology that could possibly boost rice production in rural Panama, where poverty is endemic, with 36% of the rural population living in poverty and 20% living in extreme poverty (Government of Panama 2003). The rural poor are mostly concentrated in areas with highly weathered soils, mostly Ultisols and Alfisols, having low inherent fertility. Such soils are dominated by low activity clays (kaolinite) and have low soil organic carbon and associated nutrients (N, P and S). Both Ultisols and Alfisols have low cation exchange capacity, however, Ultisols are more weathered and have low concentrations of plant-available K, Ca and Mg (Van Wambeke 1992). In many Panamanian farms, soil K fertility is further decreased because K-rich rice straw is removed at harvest.

The fertility of these tropical soils can be improved by adding nutrients (i.e. organic and mineral fertilizers) and liming (Van Wambeke 1992). Rural Panamanian farmers have limited access to mineral fertilizers, and most rely on chicken manure and household composts to replenish soil nutrients. The advantage of applying organic fertilizers is that they supply essential N, P and K, which are the main nutrients limiting rice production, as well as other macro- and micro-nutrients.

In many regions, such as the Azuero Peninsula and other parts of central Panama, agricultural production is also limited by water availability from December through April. Farmers also find that rainfall is becoming more unreliable as well as insufficient, so water supply is expected to become a more influential factor in rice production.

This study thus was an initial evaluation of the potential of SRI practice to increase rice yields while reducing water consumption. It was undertaken on subsistence farms in five provinces across central Panama. The project provided practical information on SRI to Panamanian producers' representative of the large population of smallholder households which depend on rice for part or much of their subsistence. At the same time, it sought to develop agronomic recommendations for SRI utilization based on farmers' experiences and on scientific findings.

Methods

Farm sites

Working with a Panamanian NGO, *Patronato de Nutrición*, 10 collective farms were identified in different parts of rural Panama where subsistence farmers are producing rice as their staple food. The Patronato, with public and private funding, purchases land in areas of extreme poverty, helping local households establish the farm and operate it as a democratically self-governed community. It provides the communities with training and inputs for producing food more efficiently and sustainably, to improve household nutrition, reduce hunger, and raise incomes.

Each farm has about 5 ha of productive land, which the surrounding families farm collectively and whose harvests they share. While the land belongs to the Patronato, it collects neither a share of the harvest nor rent. Patronato agronomists visit the farms regularly to advise on agronomic practices and to bring agricultural supplies (seeds, tools, etc.). The Patronato is currently working with over 300 such farms across Panama.

The 10 farms selected are located in the country's central provinces of Veraguas, Cocle, Panama, Colon and Herrera (Fig. 1). All of the farms are located in mountainous areas in the interior of the country, with the exception of one farm which is located in the lowlands (Aguas Claras 1). The number of farmers in each collective who participated in the trials ranged from 2 to 8, with a total of 46 farmers involved (Table 1).

On-farm trials comparing SRI to the conventional system of rice cultivation

To begin, a half-day workshop was held at each farm, during which SRI methods were discussed with farmers on the selected collective. All participating farms were provided with rice seed, a locally developed variety, IDIAP 38, which is suitable for either flooded or aerobic soils, and which grows well in acid soils. They received also a specialized SRI rotary weeding tool, and a notebook that contained instructions about the system and space for record-keeping.

Each participating farm cultivated a plot of approximately 10 × 10 m using SRI methods. This SRI trial plot was situated adjacent to a rice plot of equal dimensions where the farmers used conventional methods recommended currently by the government's Agriculture Department. This involves flooding the soil continuously throughout the growing season and transplanting seedlings at an average age of 20 days, with spacing of 20 cm and two or three seedlings per hill. The SRI methods evaluated in comparison included: transplanting single, young seedlings 10-days-old with square spacing at least 25 cm; using organic fertilizer; and promoting aerobic soil conditions by flooding the plot approximately once per week and by using the weeding implement provided.

The farmers were asked to record how frequently they flooded each plot and also how much they fertilized their plots. Only organic fertilizer (average of 8 t ha^{-1} of chicken

Fig. 1 Map of Panama showing locations of the 10 evaluation sites. The *numbers* on the map represent the locations of the farms and correspond with the farm numbers given in Tables 1, 2 and 3

Table 1 Names and locations of the *Patronato de Nutrición* collective farms that participated in the trials, and the number of farmers at each farm

	Farm	Township	District	Province	Farmers
1	Aguas Claras 1	Santa Rosa	Colon	Colon	4
2	Aguas Claras 2	Tulu	Penonome	Cocle	2
3	Barrigon	Vigui	Las Palmas	Verguas	5
4	Cocuyal	El Rincon	Las Palmas	Veraguas	8
5	La Mata	San Jose	Canazas	Veraguas	4
6	La Puente	El Alto	Santa Fe	Veraguas	7
7	Las Lajas	Ciri de Los Sotos	Capira	Panama	4
8	Loma Cope	Los Cerros de Paja	Los Pozos	Herrera	7
9	Palmilla	Chigri	Penonome	Cocle	3
10	San Juan	La Yeguada	Calobre	Verguas	2

manure, household compost or waste from coffee production) was used with the exception of three farms that also used mineral fertilizer (Aguas Claras 1, 110 kg N ha^{-1}; Barrigon, 28 kg N ha^{-1}, 55 kg P ha^{-1} and 28 kg K ha^{-1}; Palmilla, 64 kg N ha^{-1}). The same amounts of fertilizer were applied to both the conventional and SRI plots in each case.

One of the main challenges in switching from a flooded to an aerobic rice production system is weed control. In Panama, continuous flooding is used primarily to control excessive weed growth, although weed growth is vigorous enough that manual weeding with a machete is still required several times during the growing season. SRI farmers in Madagascar and parts of Asia have adopted the use of a manually operated weeding tool with rotating blades that uproots and incorporates weeds into the soil, thus reducing the weed population and adding organic matter. As part of this study, the SRI weeding tool was evaluated to determine its effectiveness in controlling weeds in SRI. The participating farmers used the SRI weeding tool provided at least three times during the vegetative growth of the rice crop.

The rice grain was harvested from each plot, dried in the sun, and then weighed with a calibrated scale. Yield was calculated as grain weight/plot area. After the harvest, each group of farmers went through an oral questionnaire about SRI with an evaluator. Questions were asked about water savings, weed control, transplanting, and their future use of SRI.

Soil analysis

Before the experiment began, soil surface samples (0–10 cm) were collected from each farm by compositing 10 random cores per plot. Soil texture, soil pH and available soil nutrient concentrations were determined. Available nutrients (Ca, Cu, K, Mg, Mn, P and Zn) were extracted with Mehlich-3 solution (Mehlich 1984). The concentration of amorphous Al and Fe (Fe-ox and Al-ox) and associated P (P-ox) were determined by oxalate extraction with detection by inductively coupled plasma optical emission spectrometry (Schoumans 2000).

Statistical analysis

Statistical analysis was conducted using the JMP interface of Statistical Analysis Software (2008, SAS Institute). Soil and yield data were log transformed to normalize and reduce the scale of the data set. Correlation analysis for the soil and yield dataset was performed using the restricted maximum likelihood method.

Results and discussion

Yield

Rice crops were planted in September 2009 and harvested in January 2010. Yields ranged from 0.61 to 7.48 t ha^{-1} in the conventional system and from 1.21 to 8.98 t ha^{-1} with SRI (Table 2). Yields were higher in SRI in 8 of the 10 farms and were similar to the conventional system in the other two farms.

In Cocuyal, La Mata and Las Lajas, yields increased by more than 90% with SRI, while in Barrigon, Loma, Cope and Palmilla, yields were 30% greater in SRI than the conventional system. Yields were 8 and 6% lower with SRI than the conventional system at San Juan and La Puente, respectively. Both of these sites were in the same region of Veraguas and had similar sandy soils with low cation (Ca, K and Mg) concentrations. Thus, these results may be related to the rapid rate of water infiltration in these soils or the lower nutrient status. However, the actual reduction in yield was only 1.8 and 2.3 kg per 100 m^2 plot and was not considered an economic loss by the farmers, given the potential saving of water an advantage. The mean yield increase with SRI methods was 47% across the 10 on-farm trials in Panama.

Water savings

All farms could maintain sufficient soil moisture in their SRI plots by irrigating once or twice a week, in contrast to the conventional plots that were irrigated daily to maintain flooded conditions. In this situation, SRI management reduced water consumption by between 71–86% in the on-farm trials. All farmers viewed the water savings achieved with SRI as beneficial to their community.

The farmers reported that reductions in water consumption on their farm would benefit the community by liberating more water for other agricultural activities, such as bean and corn production, and for aquaculture. They also pointed out that water may not be as abundant in future years, and thus it is important to have a rice production system that can succeed with less water. Farmers also viewed the SRI water management as beneficial because of the fertilizer loss in water runoff that would be reduced compared to the conventional flooded system.

Table 2 SRI and conventional rice yields, showing also differences between SRI and conventional yields, and response ratio to SRI (LnRR)

Farm	SRI yield (t ha^{-1})	Conventional yield (t ha^{-1})	Yield difference (t ha^{-1})	LnRR
1	8.98	7.48	1.50	0.18
2	5.18	3.19	1.99	0.48
3	4.94	3.63	1.32	0.31
4	5.22	2.72	2.49	0.65
5	1.21	0.61	0.60	0.68
6	1.70	1.81	−0.11	−0.07
7	2.99	1.54	1.45	0.66
8	8.12	5.91	2.21	0.32
9	6.41	4.44	1.97	0.37
10	2.79	3.02	−0.23	−0.08

LnRR natural logarithm of (SRI yield/conventional yield)

Weed control

This was not found to be a problem with SRI management. While more weeds were reported in the SRI plots than the conventional plots (because there was no continuous flooding), farmers were able to control weeds easily with the weeding tool. All farms reported that the weeding tool was effective in controlling the weeds. Several farms even reported that they saved time using the weeding tool because it was more efficient than weeding by hand or machete.

With SRI, it was seen to be important to transplant the seedlings in straight rows, with regular spacing, so that the weeding tool could pass through the rows. Weeds growing extremely close to the rice plants still had to be removed by hand. All farmers planned to continue using the weeding tool in the future.

Seedling transplant

Most farmers did not report any problems with transplanting the younger seedlings or with using wider spacing. Two farming collectives (Cocuyal and Barrigon) reported that it had taken more time to plant in perfectly straight lines, but overall this was seen as an advantage because the weeding tool could pass readily between the rows. Several farmers reported that it was easier to handle and transplant smaller rice seedlings compared to the larger plants used in the conventional system.

The main obstacle to the adoption of SRI in large-scale rice production is the transition to low density planting. In most parts of Latin America, large-scale rice production systems use direct seeding with a high plant density, whereas the basic methodology of SRI relies on wide spacing of singly transplanted seedlings.

Transplanting of rice is presently used by some small-scale and subsistence farmers in Panama, and thus SRI may be more suitable for small-scale operations. This problem could be overcome, however, by the mechanization of transplantings. A Costa Rican producer has successfully implemented SRI on a larger-scale using a mechanical transplanter adjusted for extremely low density planting (CIIFAD 2010). Mechanical transplanters, however, are currently not common or easily obtained in Latin America. The paper in this issue from Pakistan presents a capital-intensive mechanized methodology for applying SRI concepts and principles to large-scale rice production.

Soil nutrients and yields

Soil nutrient status is a key determinant of crop yield. As with grain yield, soil nutrient status varied greatly among the farms (Table 3). Soils ranged in texture from clay to sandy clay to loamy sand. Soil pH ranged from 5.2 to 6.5, so none of the soils were below the threshold soil pH for potential aluminum toxicity (pH 4.3). The available soil P and K at several sites fell below the critical levels for rice production (5 and 37 mg K kg^{-1}) (Dobermann and Fairhurst 2000; Name and Villarreal 2004). Potassium deficiency is common in Panamanian soils where K fertilizer is not used (Name and Villarreal 2004). Two of the sites, La Puente and San Juan, also had critically low available soil Ca and Mg. Low concentrations of available K occurred mainly in the sandy clay soils. Given this wide range of soil properties and yields, we attempted to find relationships that could explain both SRI and conventional yields, and the yield difference between the two systems.

Correlation analysis of soil nutrients and yield responses showed significant ($P < 0.05$) correlations among several of the pairs (Table 4). SRI and conventional yields were significantly correlated ($r = 0.94$), demonstrating that potential yields were site-specific and depended on inherent soil fertility, local microclimate and historical agronomic management on the farm.

SRI yield was positively correlated with available soil K ($r = 0.64$) and both SRI and conventional yields were correlated with available soil Cu ($r = 0.71$ and 0.70, respectively). The yield difference was correlated with available soil Ca ($r = 0.75$), Mg ($r = 0.77$) and Mn ($r = 0.71$), suggesting that these nutrients may play a role in determining the yield increase in SRI compared to the conventional system.

The available soil Ca concentration was positively correlated with soil Mg ($r = 0.97$) and soil Mn (0.66), while Fe-ox was positively correlated with extractable Ca ($r = 0.82$) and Mg ($r = 0.80$). These nutrients are associated with CEC on mineral surfaces, suggesting that soils with greater CEC retain and release greater quantities of plant-available macro- and micro-nutrient cations into the soil solution.

Of interest was that rice yield was not correlated with soil P fractions (Mehlich-3 or oxalate extractable), even though P was very low at many of the sites (Table 3). This may indicate that sufficient P was supplied by the addition of manure throughout the growing season.

Soil biological activity is also an important factor affecting nutrient cycling and overall soil fertility that would be promoted by the aerobic soil conditions in SRI. However, in this study, soil biological parameters were not evaluated due logistical constraints. Another experiment, to be reported separately, looked in some detail at soil nutrient dynamics and biological activity with SRI compared to the conventional system. Here, we were interested in examining whether SRI methods could improve food security, helping the rural population meet their needs for rice, a staple food, while helping to preserve their soil and water resources.

Table 3 Soil properties and available soil nutrients in the top 0–10 cm of soil

Farm	Texture	pH	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Al-ox (mg kg^{-1})	Fe-ox (mg kg^{-1})	P-ox (mg kg^{-1})
1	Silty clay	5.6	3.0	105	5275	1446	161	7.1	14.8	575	1693	29.4
2	Silty clay	6.5	47.8	129	1422	148	261	3.3	3.6	483	1192	46.6
3	Clay	5.6	3.7	112	2131	425	87	3.0	0.9	1061	1974	6.9
4	Clay	5.8	26.1	165	1420	363	149	4.0	2.8	455	2001	8.4
5	Clay	6.4	6.3	21	1267	226	35	1.9	0.7	647	1174	8.9
6	Sandy clay	5.2	44.5	13	235	20	2	3.6	3.5	622	861	26.8
7	Sandy clay	5.2	0.1	32	2469	855	190	3.2	7.6	587	1749	1.6
8	Sandy clay	5.8	3.8	37	1117	262	113	6.7	4.4	181	925	4.8
9	Loamy sand	5.9	31.3	62	1037	225	95	3.5	1.7	1365	1019	35.6
10	Sandy clay loam	5.2	15.8	78	302	33	90	1.9	2.1	524	643	9.3

Table 4 Correlations among soil nutrients and grain yield

	P	K	Ca	Mg	Mn	Cu	Zn	Al-ox	Fe-ox	P-ox	SRI yield	Con. yield	Yield dif.	LnRR
pH	0.32	0.26	0.27	0.19	0.28	−0.11	−0.32	−0.03	0.09	0.39	0.07	−0.10	0.48	0.54
P		0.07	−0.57	−0.65*	−0.37	−0.14	−0.33	0.15	−0.43	0.75*	−0.12	−0.08	−0.23	−0.28
K			0.48	0.40	0.73*	0.05	0.11	0.09	0.44	0.17	0.64*	0.61	0.52	0.16
Ca				0.97**	0.66*	0.31	0.46	0.06	0.82*	−0.14	0.49	0.34	0.75*	0.59
Mg					0.65*	0.37	0.42	0.04	0.80*	−0.26	0.51	0.35	0.77*	0.61
Mn						0.08	0.32	−0.17	0.39	−0.21	0.62	0.45	0.71*	0.48
Cu							0.62	−0.41	0.14	0.17	0.71*	0.70*	0.41	−0.17
Zn								−0.37	0.24	0.03	0.46	0.46	0.22	−0.11
Al-ox									0.20	0.30	−0.19	−0.15	−0.07	−0.01
Fe-ox										−0.26	0.26	0.12	0.62	0.61
P-ox											0.16	0.25	−0.05	−0.36
SRI yield												0.94**	0.71	−0.02
Conv. yield													0.45	−0.33
Yield difference														0.66*

Yield difference is SRI yield − conventional yield, and *LnRR* Ln (SRI yield/conventional yield) (restricted maximum likelihood; * $P < 0.05$; ** $P < 0.001$)

Conclusion

The results of these initial field trials with SRI methods indicate that rice yields can be substantially increased or at least maintained with reduced inputs of water and seeds on smallholder farms in Panama, using a low-external input, organically fertilized system. The main advantages of SRI, as perceived by farmers, are increased yield, water savings, and saving of labour time, using the SRI weeding tool.

SRI yield was positively correlated with soil K, and both SRI and conventional system yields were correlated with soil Cu. The yield difference between SRI and the conventional system was correlated with Ca, Mg and Mn. Panamanian farmers may need to adjust their storage and handling of organic wastes to ensure that on-farm fertilizers like chicken manure and household compost supply adequate quantities of nutrients to supply the needs of rice grown under SRI conditions.

Based on the results of this initial evaluation and farmer assessments, we conclude that SRI is a promising rice production system for smallholder farmers in rural Panama. The farmers involved in the evaluation report that they will continue using SRI methods and will recommend them to producers in other parts of the country. More research is required to further elucidate the effects of soil fertility on the yield response to SRI practice. Findings from the soil biology analyses being conducted may help to illuminate the soil–crop yield relationships involved in SRI yield enhancement.

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