Farm Diversity and Heterogeneous Impacts of System Technologies on Yield, Income and Poverty: The System of Rice Intensification in Timor Leste

Martin Noltze, Stefan Schwarze and Matin Qaim

Department of Agricultural Economics and Rural Development
Georg-August-University of Goettingen

mnoltze@uni-goettingen.de, s.schwarze@agr.uni-goettingen.de, mqaim@uni-goettingen.de

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Abstract

Natural resource management practices, such as the System of Rice Intensification (SRI), have been proposed to tackle agricultural challenges such as decreasing productivity growth and environmental degradation. Yet, the benefits of system technologies for farmers are often debated. Impacts seem to be context-specific, which is especially relevant in the small farm sector with its large degree of agroecological and socioeconomic heterogeneity. This was not always considered in previous research. We analyze the impacts of SRI adoption on rice yield and household income among smallholder farmers in Timor Leste. Heterogeneity is accounted for in an endogenous switching regression framework. Comparing mean yield and income levels, we find no significant differences between SRI adopters and non-adopters. This is due to negative selection bias; SRI seems to be adopted more on plots and by farmers with less than average yields. Controlling for this bias reveals significant yield and income gains. Poor and non-poor households benefit from SRI adoption; small farms benefit more than larger farms. The results also suggest that SRI may not be beneficial when compared to conventional rice grown under favorable conditions and with best management practices.

Keywords: Impact assessment, endogenous switching regression, system of rice intensification, Timor Leste

1. Introduction

Input-intensive agricultural technologies have driven a revolution of global cereal production since the mid-1960s. Substantial yield gains were achieved through greater use of improved seeds, irrigation, chemical fertilizer, pesticides, and mechanization (Foresight, 2011). However, this technology model was not successful everywhere, and it also contributed to environmental problems in some situations, such as loss of biodiversity and soil fertility, salinization, and water scarcity (Altieri, 2002; McIntyre et al., 2009). More recently, yield gains have also been diminishing, which is especially true for rice in Asia (Pandey et al., 2010). Without a new and more sustainable boost to productivity, agricultural supply will hardly be able to keep pace with the rapidly rising demand caused by population and income growth and changing consumer preferences (Foresight, 2011).

Natural resource management practices have been proposed to improve the efficiency of cropping systems in a systemic and sustainable way (Altieri, 2002; Rammel et al., 2007). Accordingly, the term system technology is also used here. System technologies build primarily on improved and integrated agronomic practices, responding to a wide range of challenges in different agroecological and socioeconomic environments. Prominent approaches are conservation agriculture, agroforestry, and organic farming, which have raised considerable attention within the last few decades (Knowler and Bradshaw, 2007; Rigby and Cáceres, 2001). However, many system technologies have not been widely adopted, and their benefits seem to be highly context-specific (Barrett et al., 2004; Giller et al., 2009; Lee, 2005). Especially in the small farm sector, the conditions are often highly diverse (Giller et al., 2011; Marenya and Barrett, 2007). Moreover, the associated practices have to be adapted locally (Giller et al., 2009; Rammel et al., 2007), and small farms may have varying knowledge and ability to do so properly. Such aspects were not always considered in previous research, sometimes resulting in contradictory findings about impacts (Alary et al., 2007; Glover, 2011; Kassam et al., 2009; Knowler and Bradshaw, 2007; Lee, 2005).

In this article, we analyze the impacts of system technology, using the system of rice intensification (SRI) in Timor Leste as a concrete example. Even though SRI has been widely promoted in some countries, the benefits are still debated (Anitha and Chellappan, 2011; Barrett et al., 2004; Dobermann, 2004; Latif et al., 2005; Moser and Barrett, 2006; Senthilkumar et al., 2008; Sheehy et al., 2004; Stoop et al., 2002; Tsujimoto et al., 2009). Various empirical designs to assess impacts have been used (McDonald et al., 2006). Many studies build on field trial results, which may not be replicable under farmer conditions (Barrett et al., 2004). Moreover, most available research has focused on yield and input use, without examining wider household welfare effects.

Here, we go beyond this available evidence and analyze the links between SRI adoption, rice yields, household income, and poverty. The empirical analysis builds on detailed survey data collected from smallholder farm households in Timor Leste. We account for possible selection bias in SRI adoption and for heterogeneity in technology impacts by using an endogenous switching regression framework (Alene and Manyong, 2007; Di Falco et al., 2011; Rao and Qaim, 2011; Wollni and Brümmer, 2012). The rest of this article is organized as follows. The next section introduces the principles of SRI. Section 3 presents the analytical framework, survey design, and descriptive statistics. Estimation results will be shown and discussed in section 4. The last section concludes.

2. The system of rice intensification

SRI is claimed to be a high-yielding and environmentally friendly technology that relies on changing farmers' agronomic practices towards a more efficient use of natural resources (Uphoff and Randriamiharisoa, 2002). Since SRI does not depend on additional external inputs, it is also considered suitable for resource-poor producers (Africare et al., 2010). SRI is usually understood as a package of possible practices, which have to be adapted to local conditions (Glover, 2011; McDonald et al., 2006; Stoop, 2011). In accordance with the SRI International Network and Resources Center of the Cornell International Institute for Food, Agriculture and Development (SRI-Rice), the following four core components have been identified:

Intermittent irrigation. Rice fields are recommended to be saturated instead of continuously flooded. This water-saving method minimizes anaerobic conditions, which hamper the growth of roots and soil organisms affecting plant architecture and canopy structure.

Early transplanting. Planting seedlings younger than 15 days, which shall encourage tillering, reduce the transplanting shock, and extend the cropping cycle.

Single seedlings. Planting only single seedlings per hill enhances tillering and root-system development, leading to increased drought tolerance and more efficient nutrient uptake.

Wide spacing. Rice plants should be planted in a square pattern with a minimum distance of 20 x 20 cm. Together with single seedlings this practice increases the exposure of plants to sunlight, air, and nutrients.

This package of core components is reported to produce higher yields with less water and seeds (Barah, 2009; Zhao et al., 2009). Moreover, studies found rice under SRI being more robust against extreme weather events, pests, and diseases due to improved plant vigor and root strength (Stoop et al., 2002). The effects of these components are described as multifold and complementary (Ceesay et al., 2006; Thakur et al., 2010). For example, intermittent irrigation aims to tackle various challenges such as the loss of soil quality and water scarcity, whereas early transplanting and wide spacing are both meant to boost tillering. However, not all studies found synergies between these core components (Anitha and Chellappan, 2011; Menete et al., 2008).

Additionally recommended practices for SRI farmers include improved nursery management, the use of organic fertilizer, and regular weeding. Use of organic fertilizer, such as compost or manure, can help to substitute for inorganic fertilizer, apart from stimulating growth-promoting soil bacteria (Mishra et al., 2007). In Timor Leste, organic fertilization has not yet been widely promoted in SRI programs (Noltze et al., 2012). Weeding is more important in SRI than in traditional rice, because weeds spread more rapidly under non-flooded conditions.

3. Material and methods

3.1 Analytical framework

We want to analyze impacts of SRI on rice yield and household income, using cross-section survey data from Timor Leste. In posttest-only designs, treatment and control groups (adopters and non-adopters) are usually not randomly formed. This could imply selection bias, one prominent source of endogeneity. For example, a study will under- or overestimate the true impact of a given technology, if observed or unobserved farm and farmer characteristics affect the probability of adoption and the outcome simultaneously. One solution to account for endogeneity is the use of instrumental variable (IV) models.

Another relevant question is how to incorporate the impact of the new technology into the econometric model. Standard treatment effects IV models include a treatment dummy as explanatory variable, assuming that the impact on the outcome variable can be represented as a simple slope shift. In other words, a homogenous impact that is independent of farm and farmer characteristics is assumed. As was explained above, this is inappropriate for NRM technologies. We expect that farm and farmer conditions may systematically influence SRI impacts on yields and household incomes. This can be accounted for through an endogenous switching regression framework (Maddala, 1983).

A switching regression consists of two stages. The first stage is a selection equation, which is based on a dichotomous choice criterion function. With regard to expected benefits, the farmer evaluates whether or not to adopt a new technology on the basis of resource endowments and farm management options. The expected utility of SRI adoption, $\mathrm{I}^*_{\mathrm{SRI}}$, is compared to the expected utility of following conventional practices, $\mathrm{I}^*_{\mathrm{CON}}$. Farmers will adopt SRI if $\mathrm{I}^*_{\mathrm{SRI}} > \mathrm{I}^*_{\mathrm{CON}}$ and will not adopt if $\mathrm{I}^*_{\mathrm{SRI}} \leq \mathrm{I}^*_{\mathrm{CON}}$. I^* is not observable, but we observe I, which is a simple adoption dummy. Thus, the first-stage equation can be estimated with a probit model and be written in simplified form as:

$$\mathrm{I}^* = \mathrm{S}'\alpha + \varepsilon_{\mathrm{v}} \qquad (1)$$

$$\mathrm{I} = 1 \text{ if } \mathrm{I}^*_{\mathrm{SRI}} > \mathrm{I}^*_{\mathrm{CON}} \qquad (2)$$

$$\mathrm{I} = 0 \text{ if } \mathrm{I}^*_{\mathrm{SRI}} \leq \mathrm{I}^*_{\mathrm{CON}}. \qquad (3)$$

where vector S includes a variety of farm and household characteristics, α is a vector of parameters to be estimated, and ε_v is a random error term with mean zero and variance σ^2.

In the second stage, two regime equations can be specified explaining the outcome of interest based on the results of the estimated criterion function. The relationship between a vector of explanatory variables X and the outcome Y can be represented as $Y = f(X)$ and specified for each regime as:

$$Y_{SRI} = X'\beta_{SRI} + \varepsilon_s \text{ if } I = 1, \quad (4)$$

$$Y_{CON} = X'\beta_{CON} + \varepsilon_c \text{ if } I = 0. \quad (5)$$

where β_{SRI} and β_{CON} are parameters to be estimated. While the variables in S' and X' are allowed to overlap, proper identification requires at least one variable in S' that does not appear in X'. Therefore the criterion function is estimated based on all exogenous variables specified in the regime equations plus one or more instruments. The error terms $\varepsilon_v, \varepsilon_s$ and ε_c follow a tri-variate normal distribution with zero mean and a non-singular covariance matrix specified as (Fuglie and Bosch, 1995):

$$\text{cov}(\varepsilon_s, \varepsilon_c, \varepsilon_v) = \begin{bmatrix} \sigma_s^2 & \sigma_{sc} & \sigma_{sv} \\ \sigma_{sc} & \sigma_c^2 & \sigma_{cv} \\ \sigma_{sv} & \sigma_{cv} & \sigma_v^2 \end{bmatrix} \quad (6)$$

where σ_v^2, σ_s^2 and σ_c^2 are the variances of the error terms ε_v, ε_s and ε_c, respectively. σ_{sc} is the covariance of ε_s and ε_c; σ_{sv} is the covariance of ε_s and ε_v; σ_{cv} is the covariance of ε_c and ε_v. The variance of σ^2 is assumed to be one (Greene, 2008). Under these assumptions, the truncated error terms $(\varepsilon_s | I = 1)$ and $(\varepsilon_c | I = 0)$ are:

$$E(\varepsilon_s | I = 1) = E(\varepsilon_S | \varepsilon > -S'\alpha) = \sigma_{sv} \frac{\phi(S'\alpha/\sigma)}{\Phi(S'\alpha/\sigma)} = \sigma_{sv}\lambda_s \quad (7)$$

$$E(\varepsilon_c | I = 0) = E(\varepsilon_c | \varepsilon \le -S'\alpha) = \sigma_{cv} \frac{\phi(S'\alpha/\sigma)}{1-\Phi(S'\alpha/\sigma)} = \sigma_{cv}\lambda_c \quad (8)$$

where ϕ and Φ are the probability density and cumulative distribution functions of the standard normal distribution, respectively. λ_s and λ_c are the inverse mills ratios (IMRs) evaluated at $S'\alpha$.

Switching regression has often been applied using a two-stage procedure, in which the IMRs are included in the regime equations (Freeman and Ehui, 1998; Fuglie and Bosch, 1995). However, Lokshin and Sajaia (2004) developed a more efficient procedure using a full information maximum likelihood (FIML) method. FIML uses a simultaneous estimation procedure and is employed in this study.

We estimate two different endogenous switching regression models, one at the plot level to explain the factors influencing rice yields in SRI and conventional regimes, and the other at the household level to explain incomes in the two regimes. The explanatory variables used differ between the two models and are discussed further below. In choosing appropriate covariates, we build on the available literature on adoption and impacts of agricultural technologies (Abdulai et al., 2011; Doss, 2006; Läpple and Rensburg, 2011).

In addition to estimating the marginal effects of X' on yield and income, we are interested in the treatment effects of SRI adoption. To derive the average treatment effects on the treated (ATT), we need to compare the yield of SRI plots with and without SRI adoption and the income of SRI households with and without SRI plots. Moreover, the average treatment effects on the untreated (ATU) are of interest, in order to better understand impact heterogeneity. The observed and unobserved counterfactual outcomes for SRI adopters and non-adopters can be calculated using the estimates from the switching regression model (Lokshin and Sajaia, 2004).

SRI plots/households with adoption (observed):

$$\mathrm{E}(\mathrm{Y}_{\mathrm{SRI}} |\ \mathrm{I} = 1) = \mathrm{X}'\beta_{\mathrm{SRI}} + \sigma_{\mathrm{sv}}\lambda_{\mathrm{s}} \quad (9)$$

SRI plots/households without adoption (counterfactual):

$$\mathrm{E}(\mathrm{Y}_{\mathrm{CON}} |\ \mathrm{I} = 1) = \mathrm{X}'\beta_{\mathrm{CON}} + \sigma_{\mathrm{cv}}\lambda_{\mathrm{s}} \quad (10)$$

Non-SRI plots/households without adoption (observed):

$$\mathrm{E}(\mathrm{Y}_{\mathrm{CON}} |\ \mathrm{I} = 0) = \mathrm{X}'\beta_{\mathrm{CON}} + \sigma_{\mathrm{cv}}\lambda_{\mathrm{c}} \quad (11)$$

Non-SRI plots/households with adoption (counterfactual):

$$\mathrm{E}(\mathrm{Y}_{\mathrm{SRI}} |\ \mathrm{I} = 0) = \mathrm{X}'\beta_{\mathrm{SRI}} + \sigma_{\mathrm{sv}}\lambda_{\mathrm{c}}. \quad (12)$$

Equations (9) to (12) can be used to derive unbiased treatment effects ATT and ATU that control for observed and unobserved heterogeneity (Alene and Manyong, 2007; Fuglie and Bosch, 1995; Maddala, 1983):

$$\mathrm{ATT} = \mathrm{E}(\mathrm{Y}_{\mathrm{SRI}}|\mathrm{I} = 1) - \mathrm{E}(\mathrm{Y}_{\mathrm{CON}}|\mathrm{I} = 1) \quad (13)$$

$$\mathrm{ATU} = \mathrm{E}(\mathrm{Y}_{\mathrm{SRI}}|\mathrm{I} = 0) - \mathrm{E}(\mathrm{Y}_{\mathrm{CON}}|\mathrm{I} = 0). \quad (14)$$

3.2 Survey design

This study was carried out in the two western border districts of Timor Leste, Bobonaro and Covalima, where SRI has been introduced since 2007 by the Second Rural Development Program of Timor Leste (RDPII). Jointly implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Timorese Ministry of Agriculture and Fisheries (MAF), the program aims to strengthen the domestic rice sector and thus reduce the country's dependency on rice imports (Deichert et al., 2009). The rice sector in Timor Leste is constrained by low levels of mechanization, insufficient irrigation, and weak transport infrastructure (World Food Program, 2005). At the farm level, this implies shortages of rice seeds and irrigation water and limited access to external inputs such as fertilizer and pesticides. RDPII works through the national extension service using a training approach with farmer groups.

We conducted a farm household survey between August and December 2009. Complete household lists of all rice producers in the two study districts were generated, before stratified random sampling was used to select 200 households from both participants (in total 1228) and non-participants (in total 3220) of the SRI training program. Participants were purposively oversampled, in order to improve estimation efficiency. A total of 397 households were interviewed, using a structured questionnaire. In addition, we collected detailed plot level and soil sample data from 475 paddy fields belonging to the sample households.

SRI is a complex technology, which is based on a set of different components, as outlined in section 2. We define SRI plots as plots on which the four SRI core components have been adopted. All other plots are classified as conventional plots. SRI adopters are farmers who cultivate at least one SRI plot. While in the survey we stratified between participants and non-participants in SRI training programs, this is not equivalent to SRI adopters and non-adopters. Not all participants have adopted SRI. On the other hand, some non-participants of the training program have adopted. Our sample includes 159 SRI households (40% of all sample households), who have adopted SRI on 167 plots (35% of all sample plots).

3.3 Sample descriptive statistics

Timor Leste is a highly mountainous region with a shortage of land suitable for intensive crop production (World Food Program, 2005). Paddy fields are commonly located in the lowlands, either in valleys or coastal plains. Annual rainfall levels and seasonal variability restrict most farmers to only one cropping season per year. Besides rice, which is the main crop for most of the sample farmers, secondary field crops such as cassava, maize, and vegetables are grown. Almost all households own livestock. Cropping is primarily subsistence oriented; surplus produce is sold in local markets. For rice, farmers also have the opportunity to sell through government channels at a subsidized price.

Rice farmers in our sample own 1.9 ha of land on average (Table 1). Paddy fields account for 68% of this total, although there are differences between SRI adopters and non-adopters. SRI farmers own significantly more land, and they also cultivate larger rice areas. In the group of adopters, 89% have regularly participated in SRI training. SRI farmers are more likely to be located in the district of Bobonaro, where SRI was introduced first. Interestingly, households whose main economic activity is farming are less likely to adopt SRI. Other farm and household characteristics hardly differ between adopters and non-adopters.

Table 1. Descriptive statistics

	Means (SD)						
	All		SRI		non-SRI		
Household level characteristics	n=397		n=159		n=238		
Farm and location characteristics							
Total land area owned (hectare)	1.88	(1.17)	2.04	(1.29)	1.78	(1.08)	**
Total rice area cultivated (hectare)	1.27	(0.86)	1.38	(0.90)	1.19	(0.76)	**
Livestock units [a]	5.87	(7.20)	5.85	(6.72)	5.87	(7.51)	
Household living in District Bobonaro (%)	48.86	(50.05)	56.60	(43.92)	43.69	(49.70)	**
Household living in urban area (%)	41.30	(49.30)	39.62	(49.06)	42.43	(49.52)	
Walking distance to nearest input market (min.)	58.39	(54.56)	63.01	(57.08)	55.31	(52.71)	
Household has electricity in main house (%)	29.72	(45.76)	26.41	(44.22)	31.93	(46.71)	
Household characteristics							
Age of household head (years)	45.89	(12.81)	46.81	(11.89)	45.27	(13.37)	
Gender of household head being male (%)	97.73	(15.71)	97.48	(15.70)	97.98	(14.37)	
Household head years of schooling (years)	4.09	(4.56)	4.03	(4.52)	4.13	(4.59)	
Household size (number of members)	6.64	(2.27)	6.73	(2.23)	6.58	(2.31)	
Household members in work age (age 18-65)	3.21	(1,52)	3.20	(1.53)	3.21	(1.51)	
Main occupation of household head is farmer (%)	91.43	(28.01)	86.79	(33.96)	94.53	(22.77)	**
Financial capital and contextual variables							
Access to formal credit sources (%)	11.33	(31.74)	11.94	(32.53)	10.92	(31.26)	
Participation in SRI training (%)	50.12	(50.06)	88.67	(31.78)	24.36	(43.02)	***
SRI training participants in village (%)	36.55	(29.42)	45.13	(28.45)	30.82	(28.71)	***
Plot level characteristics	n=475		n=167		n=308		
Technical							
Plot size (hectare)	1.07	(0.66)	1.12	(0.67)	1.04	(0.65)	
Technical irrigation system (%)	87.37	(33.26)	98.20	(13.32)	81.33	(39.02)	***
Control over water management possible (%)	88.34	(32.13)	98.00	(15.38)	83.16	(37.48)	***
Water availability (months)	5.09	(3.24)	4.57	(3.07)	5.40	(3.29)	***
Time from house to plot (min)	34.20	(37.45)	30.14	(32.42)	36.40	(39.78)	*
Soil data							
Sand (%)	14.35	(13.47)	14.47	(13.36)	14.28	(13.45)	
Clay (%)	17.84	(11.61)	18.85	(11.28)	17.28	(11.76)	
Silt (%)	67.81	(16.24)	66.67	(16.37)	68.43	(16.14)	
Saturation, share of water held in unit soil (%)	57.09	(0.47)	57.20	(0.88)	57.03	(0.55)	
pH	6.52	(0.39)	6.56	(0.39)	6.49	(0.39)	*
Conductivity (mS/cm)	2.31	(1.25)	2.22	(1.05)	2.36	(1.34)	

*,**,*** Mean values of SRI and non-SRI are significantly different at the 10%, 5% and 1% level, respectively. [a] Livestock units are developed according to Turner and Taylor (1998). Source: Own survey data.

Farmers in the research area own usually either one or two rice plots with an average size of about 1 ha each. One fifth of all households cultivate more than one rice plot at the same time; 5% and 18% of all SRI households have at least one additional SRI or conventional plot, respectively. Different adoption patterns among plots within the same household motivate a closer look at inter-plot differences. The lower part of Table 1 shows that SRI is preferably applied on plots with a technical irrigation system, which can be individually controlled by the farmer.[1] Moreover, shorter water availability seems to be associated with SRI adoption. We also find that SRI plots are located closer to the homestead. Soil samples were drawn from one randomly selected point on each plot and analyzed using easy-to-use testing procedures in field laboratories. Structure tests reveal that the plots mostly have silty soils with lower shares of sand and clay. The pH values are significantly higher on SRI plots, but still in an acceptable range of around 6.5. Electrical conductivity, which is affected by various soil attributes such as clay content, temperature, organic materials, and salinity (Ezrin et al., 2010), ranges from 0.36 to 6.87 mS/cm.

3.4 Rice yield and household income

Rice yields are somewhat lower on SRI plots than on conventional plots (Table 2). Even though this difference is not statistically significant, it is against expectations, because SRI is actually meant to increase yields over conventional practices. The reasons may be threefold. First, SRI may be adopted more on plots with lower than average yield potential, which would imply negative selection bias. Second, SRI may not be very suitable for the conditions in Timor Leste. Third, adopting farmers may lack the capacity or experience to fully harness SRI potentials. In Timor Leste, the dissemination of SRI is still in its early stage, with adopters having only between one and three years of experience. In their study in Madagascar, Barrett et al. (2004) found that average productivity remained low in the initial phase of SRI adoption, but increased rapidly in subsequent years. Such aspects will be further analyzed below.

[1] Technical irrigation systems are characterized by permanent irrigation infrastructure with tertiary water supply channels, locks, and separate drainpipes. In some cases, water application to rice plots depends on collective decisions taken by water user groups. For example, a farmer may have to open the dams on his plot, in order to provide water to the neighboring plots. In those cases, individual control over water management is not possible, which seems to complicate SRI adoption.

Table 2. Costs and returns on SRI and non-SRI plots

	All (SD)		SRI (SD)		Non-SRI (SD)		Diff.	
Yield (tons/ha)	3.13	(2.53)	2.94	(2.22)	3.24	(2.69)	0.30	
Market price of paddy rice (US$/kg)	0.30							
Gross revenue (US$/ha)	898.38	(767.75)	865.70	(670.08)	916.10	(816.34)	-50.40	
Seed quantity (kg/ha)	51.80	(68.66)	14.47	(19.98)	72.38	(76.86)	-57.90	***
Seed costs (US$/ha)	20.72	(27.46)	5.79	(7.99)	28.95	(30.74)	-23.16	***
Pesticide and herbicide costs (US$/ha)	15.99	(17.83)	14.09	(15.21)	17.03	(19.05)	-2.93	*
Fertilizer costs (US$/ha)	8.58	(22.57)	12.33	(27.40)	6.52	(19.16)	5.81	***
Labor (days/ha)	204.35	(149.76)	209.11	(151.58)	201.75	(148.94)	7.36	
Hired labor costs (US$/ha)	125.87	(129.71)	115.84	(126.62)	131.36	(131.24)	-15.53	
Total variable costs (US$/ha)	171.25	(142.59)	148.06	(139.16)	184.03	(143.08)	-35.96	***
Net income (US$/ha)	725.91	(756.22)	717.64	(645.26)	730.39	(811.02)	-12.74	

*, **, *** Statistically significant at the 10%, 5% and 1% level, respectively. Source: Own survey data.

Table 2 also shows a comparison of input use and costs on SRI and conventional rice plots. Overall, the variable cost of production is lower on SRI plots, largely because SRI farmers spend significantly less on seeds. This is due to the use of single seedlings and wider plant spacing under SRI. The use of pesticides and herbicides is also slightly lower on SRI plots, while the use of chemical fertilizer is slightly higher. There is also a small (insignificant) difference in labor inputs. SRI is known to have higher labor requirements (Barrett et al., 2004), even though in Timor Leste recommendations of regular weeding and some other labor-intensive practices are not yet completely followed by all adopters. Interestingly, hired labor costs are somewhat lower on SRI plots, but hired labor is rarely used for farm operations specifically related to SRI. Regular observation, adjustment of soil moisture levels, and other monitoring activities require management time from the farm family itself, especially during the early adoption stage where experimentation is encouraged.

Table 3 shows that sample households tend to have quite diversified farm and off-farm income sources. Rice cultivation is the major source and accounts for about one-third of total household income on average. Typical sources of off-farm employment in the study region include wage labor in agriculture and construction. Self-employed activities include small businesses in retail trade, food processing, handicrafts, and dry wood collection. SRI-adopting households have slightly (but not significantly) higher incomes than non-adopting households, although their share of rice income is lower. Average per capita incomes are below one US$ per day for both SRI and non-SRI households. The poverty rate is around 70%, using the national basic needs poverty line (Table 3).

Table 3. Annual household income in US$ by activity

	All	(%)	SRI	(%)	Non-SRI	(%)	
Rice	702.72	(36.37)	690.58	(32.43)	710.83	(39.48)	
Other field crops	294.07	(15.22)	390.66	(18.34)	229.54	(12.75)	*
Livestock	139.39	(7.21)	135.29	(6.35)	142.13	(7.90)	
Fishery	128.97	(6.67)	150.94	(7.09)	114.29	(6.35)	
Forestry	10.50	(0.54)	3.59	(0.17)	15.12	(0.84)	
Wage employment	357.03	(18.48)	494.20	(23.21)	265.40	(14.74)	*
Self employment	230.98	(11.95)	192.59	(9.04)	256.63	(14.25)	
Assistance (aid, government programs)	68.62	(3.55)	61.89	(2.91)	73.11	(4.06)	
Total household income	1932.28	(100)	2119.75	(100)	1807.04	(100)	
Per-capita income per day	0.88		0.94		0.84		
Poverty rate [a]	0.68		0.67		0.71		

* Difference in mean values between SRI and non-SRI is statistically significant at the 10% level.
Notes: [a] Based on basic needs poverty line (World Bank, 2008), adjusted to August 2009 using the consumer price index (National Statistics Directorate, 2011), which results in 0.94 US$ per day. N=397 households. Source: Own survey data.

4. Results and discussion

We now analyze the effects of SRI adoption on rice yield and household income using the endogenous switching regression framework, as explained above. To analyze yield effects, a production function is specified at the plot level. To analyze income effects, we estimate an income model at the household level. The estimated coefficients are used to calculate average treatment effects of SRI adoption. In the following, we first discuss the plot level analysis, before we turn to aspects of household income and poverty.

4.1 Yield effects

To estimate net yield effects of SRI adoption, we have specified Cobb-Douglas production functions for the SRI and conventional regimes. The dependent variable is the logarithm of rice yield in tons per ha. Likewise, the input variables refer to one ha and are expressed in logarithmic terms. A Wald test showed that the Cobb-Douglas is preferred over the more flexible translog functional form. A number of other explanatory variables are included to control for differences in terms of plot level characteristics and human capital.

In the endogenous switching regression framework, the regime equations are estimated jointly with a criterion function that explains into which regime a particular observation falls. Proper identification requires that the criterion function contains all variables from the regime equations plus at least one instrument (Kabunga et al., 2012; Lokshin and Sajaia, 2004). We use the percentage of SRI training participants in the farmer’s village as the instrument, which is correlated with individual adoption behavior. Farmers living in villages with many other SRI training participants can more easily acquire specific technological information through farmer networks. On the other hand, the share of village training participants is not correlated with rice yields.[2] As some farmers cultivate more than one rice plot, and household characteristics might also determine plot level outcomes, we use a household cluster correction procedure to obtain reliable standard errors for the estimation. The results are shown in Table 4. Due to missing values for some of the variables, not all plot observations could be included in this estimation.

The criterion function is shown in the first column. The most important factors influencing SRI adoption at the plot level are availability of a technical irrigation system and the possibility to control water individually. While SRI can reduce the use of irrigation water significantly, moisture saturated but not flooded conditions require careful individual water management.

The two regime equations are shown in the second and third column of Table 4. Labor has the biggest production elasticity in both regimes. Increasing labor input by 1% would increases rice yield by about 0.3% on average. For some of the coefficients there are notable differences between SRI and conventional plots, confirming that the switching regression framework is more appropriate than data pooling in one production function. A case in point is the estimate for pesticides and herbicides, which is relatively big and significant in the SRI regime, while it is insignificant in the conventional regime. Weeds in particular spread more rapidly under non-flooded conditions. Regular weeding is recommended with SRI but not always followed, so that chemical weed control can become more important.

[2] Another potential candidate as instrument would have been individual participation in SRI training, but this is more likely to be endogenous itself.

Table 4. Endogenous switching regression results for yield

	Criterion function	Regime equations SRI	Conventional
Labor (days/ha) in log	0.3937***	0.2716***	0.3440***
	(0.1447)	(0.1045)	(0.1150)
Seed quantity (kg/ha) in log	-1.0246***	0.1042	0.0924
	(0.1112)	(0.1754)	(0.0720)
Fertilizer costs (US$/ha) in log	0.0179	0.0699*	0.0393
	(0.0603)	(0.0396)	(0.0431)
Pesticide and herbicides costs (US$/ha) in log	-0.0539	0.1178***	0.0173
	(0.0702)	(0.0450)	(0.0468)
Time from homestead to plot (minutes)	-0.0016	-0.0034*	0.0001
	(0.002)	(0.0017)	(0.0011)
Technical irrigation system (1=yes)	2.0051***	-0.3459	0.3085**
	(0.4237)	(0.6236)	(0.1538)
Control over water management possible (1=yes)	1.0796***	-0.6970*	0.0754
	(0.3666)	(0.3729)	(0.1384)
Conductivity (mS/cm)	-0.0323	-0.1366**	-0.0870
	(0.0864)	(0.0657)	(0.0633)
pH	-0.2908	0.0270	-0.1340
	(0.2265)	(0.1364)	(0.1314)
Saturation, share of water held in unit soil (%)	0.0073	-0.0038	0.0160**
	(0.0099)	(0.0050)	(0.0065)
Hybrid seeds (1=yes)	0.125	-0.4827***	-0.4281
	(0.2553)	(0.1498)	(0.2793)
Age of household head (years)	0.0005	0.0024	0.0091**
	(0.0079)	(0.0057)	(0.0046)
Household head years of schooling (years)	0.0199	0.0045	0.0318**
	(0.0209)	(0.0168)	(0.0125)
Training participants in village (%)	0.0061*		
	(0.0033)		
Constant	-0.8004	0.1473	-2.0969**
	(1.7253)	(1.3039)	(1.1992)
Number of observations			429
Log pseudo-likelihood			-661.757
Wald test for independent equations χ^2			3.41*
$\ln \sigma_s$, $\ln \sigma_c$		-0.3748***	-0.1261*
		(0.0938)	(0.0699)
ρ_{sv}, ρ_{cv}		0.1670	-0.3689*
		(0.4215)	(0.2037)

*,**,*** Significant at the 10%, 5% and 1% level, respectively. Notes: Coefficient estimates are shown with robust standard errors in parentheses. The dependent variable is the log of rice yield measured in tons per ha. Source: Own survey data.

Other differences in coefficient estimates between the two regimes are related to irrigation, individual water control, and soil conditions.[3] Having a technical irrigation system increases yields on conventional plots by over 30%, while the effect on SRI plots is insignificant. The latter is due to the

[3] Due to a close correlation between some of the soil characteristics, not all of them could be included in the model. Besides pH, conductivity was found to be a good summary measure that is related to rice yields (Ezrin, 2010).

fact that almost all SRI plots have an irrigation system, so that there is hardly any data variation for this variable. In contrast, time required to reach the plot from the homestead has no effect for conventional rice yields, while it has a significantly negative effect for SRI yields. This is plausible, since experimenting with this new technology requires more regular plot visits for monitoring. The travel time associated with this is not captured in the labor input variable.

SRI is not related to any specific rice variety, and we did not find a relationship between the most widely used varieties and yields, except for hybrids. In 2009, the Timorese Ministry of Agriculture and Fisheries introduced hybrid rice to a small number of farmers in the district of Bobonaro. Hybrid seeds were distributed through the national extension service, so that SRI farmers were among the first to obtain these seeds. Hybrid seeds were used on 18% of all SRI plots, as compared to 7% of all conventional plots. Unfortunately, it was later found out that the hybrid seeds distributed were of inferior quality and germinated poorly. While this is unrelated to the suitability of hybrid rice in general, in our estimates the use of hybrid seeds decreases yield by over 40%. This effect is highly significant on SRI plots and may be another factor explaining why SRI yields were found to be lower than conventional yields in the comparative analysis. The lower part of Table 4 presents the estimated covariance terms together with the result from a Wald test of joint independence of all three equations (Fuglie and Bosch, 1995; Lokshin and Sajaia, 2004). These statistics confirm that there is heterogeneity, which would cause a bias if not controlled for.

We now use equations (13) and (14) to calculate the average treatment effects of SRI adoption on rice yields. Results are shown in Table 5. Strikingly, SRI farmers would have significantly lower yields had they not adopted the technology, implying an ATT of 46%. This result clearly points at negative selection bias in a simple comparison of yield, which the ATT controls for. Negative selection bias means that SRI is adopted on plots and by farmers that would have below average yields without adoption. This may be due to both observed and unobserved factors. Wider use of inferior seeds is also likely to play a role. The ATU, which is also shown in Table 5, is positive and significant too, but much smaller than the ATT. Mean yields on non-SRI plots could be 11% higher when SRI were used on these plots. This large difference between ATT and ATU underlines heterogeneity in impacts due to various agroecological and socioeconomic factors. It also suggests that SRI may not be yield increasing when compared to conventional rice grown under favorable conditions and with best management practices, which was also pointed out by McDonald et al. (2006).

Table 5. Average treatment effects of SRI on rice yield

		With SRI		Without SRI			
	Observations	Mean yield [a]	SD	Mean yield [a]	SD	Treatment effect [a]	in %
SRI plots	158	0.750	0.404	0.515	0.398	ATT: 0.242***	45.67
Non-SRI plots	271	0.944	0.497	0.853	0.393	ATU: 0.095**	10.69

, * Significant at the 5% and 1% level, respectively. Notes: [a] The yields shown are predictions based on the coefficients estimated with the endogenous switching regression model. As the dependent variables in the model are the logarithm of yields in tons per hectare, the predictions are also given in logarithmic form. Converting the mean back to tons would lead to inaccuracies, due to the inequality of arithmetic and geometric means. Source: Own survey data.

4.2 Household income effects

We now estimate the endogenous switching regression model of total income at the household level, differentiating between SRI and non-SRI households. The dependent variable in the regime equations is the logarithm of annual household income measured in US$, while the explanatory variables are included in linear form. As before in the plot-level yield analysis, the share of training participants in the village serves as instrument for SRI adoption in the criterion function. Due to missing values for some of the variables, a few household observations could not be included. The estimation results are shown in Table 6. Household heads whose main occupation is farming are much less likely to adopt SRI than part-time farmers. This may be related to more frequent outside contacts through off-farm activities and thus better information flows. But risk perceptions may also play a role. Households that heavily depend on farm income may be more hesitant to adopt early and experiment with the new technology. Because of their greater dependence on farming, incomes of non-SRI adopters are also more strongly influenced by farm size (see third column of Table 6). One additional ha increases their household incomes by 24%. On the other hand, livestock ownership contributes more to the incomes of SRI adopters.

Table 6. Endogenous switching regression results for income

	Criterion function	Regime equations SRI	Conventional
Total land area owned (ha)	0.0755	0.0474	0.2354***
	(0.0621)	(0.0656)	(0.0637)
Livestock units	-0.0063	0.0506***	0.0171*
	(0.0103)	(0.0118)	(0.0094)
Household size (number of members)	0.0071	0.0468	0.0163
	(0.0325)	(0.0343)	(0.0297)
Household head years of schooling (years)	0.0001	-0.0144	0.0140
	(0.0188)	(0.0221)	(0.0166)
Main occupation of household head is farmer (1=yes)	-0.6305**	-0.7849**	-0.5851*
	(0.2723)	(0.3098)	(0.3012)
Gender of household head being male (1=yes)	0.1699	-0.4409	0.7995*
	(0.4587)	(0.4955)	(0.4323)
Age of household head (years)	0.0076	-0.0066	0.0048
	(0.0066)	(0.0083)	(0.0057)
Access to formal credit sources (1=yes)	-0.0463	0.4769**	0.1658
	(0.2250)	(0.2423)	(0.2144)
Household has electricity in main house (1=yes)	-0.0606	0.5039**	0.3997**
	(0.1943)	(0.2500)	(0.1663)
Walking distance to nearest input market (minutes)	0.0017	0.0018	0.0006
	(0.0013)	(0.0015)	(0.0006)
Household living in urban area (1=yes)	-0.0277	-0.1764	0.4035***
	(0.1761)	(0.2107)	(0.1554)
SRI training participants in village (%)	0.0104***		
	(0.0024)		
Constant	-0.7965	7.6775***	5.5676***
	(0.6906)	(0.8308)	(0.6421)
Number of observations			370
Log pseudo-likelihood			-723.4593
Likelihood ratio test for independent equations χ^2			36.42***
$\ln \sigma_s$, $\ln \sigma_c$		-0.0888*	-0.0842*
		(0.0631)	(0.0522)
ρ_{sv}, ρ_{cv}		0.1040	-0.1436
		(0.3948)	(0.2728)

*,**,*** Significant at the 10%, 5% and 1% level, respectively. Notes: Coefficient estimates are shown with robust standard errors in parentheses. The dependent variable is the log of annual household income measured in US$. Source: Own survey data.

In both regimes, main occupation in farming has a large and significant negative effect on incomes, suggesting that off-farm activities, when accessible, are more lucrative on average. This is underlined by the large and significant positive effects of electricity in both regimes. Electricity is less important for farming but can be an important factor for self-employed activities that require cooling or home production and processing of goods. Access to formal sources of credit has a particularly large positive effect for SRI households. Credit facilitates the purchase of farm inputs, but also investments in off-farm enterprises, thus contributing to higher profitability of self-employed activities.

Table 7 presents the average treatment effects of SRI on household income. The ATT shows that adopters benefit economically from SRI adoption. This effect is statistically significant, but with 2.3% in magnitude it is relatively small. Rice is only one source of income for the households, so that the total household income gains should be much smaller than the yield gains detected above. But even when accounting for this, the percentage change is smaller than expected, suggesting that income sources other than rice may also be affected indirectly by SRI adoption. For instance, a larger allocation of family labor and management time to rice may entail opportunity costs in other household activities. Household income gains may potentially rise in the future, when more experience with SRI allows a reduction in the required management time. The ATU in Table 7 suggests that non-adopting households would not benefit if they switched to SRI. Hence, their decision of non-adoption seems to be rational.

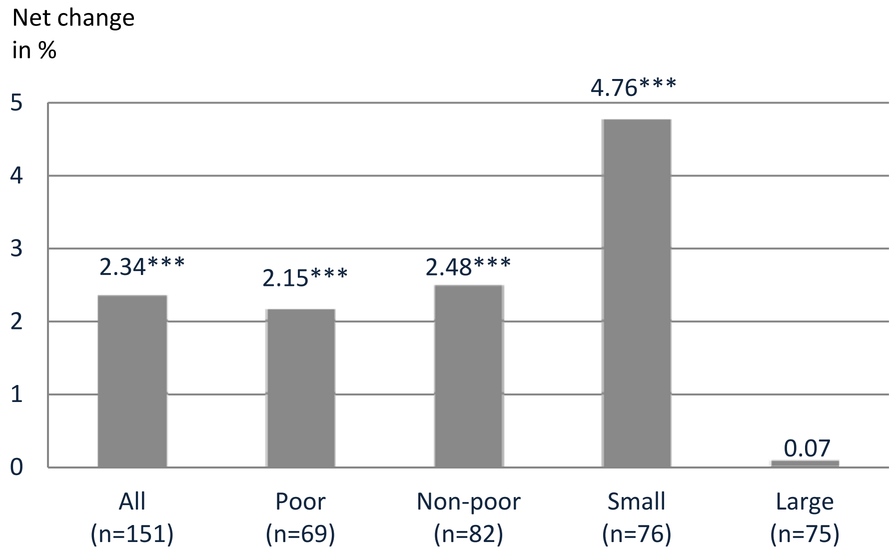
Table 7. Average treatment effects of SRI on household income

		With SRI		Without SRI			
	Observations	Mean income [a]	SD	Mean income [a]	SD	Treatment effect [a]	in %
SRI households	151	7.242	0.550	7.076	0.599	ATT: 0.166***	2.34
Non-SRI households	219	6.980	0.579	7.133	0.555	ATU: -0.153***	-2.15

*** Significant at the 1% level. Notes: [a] The incomes shown are predictions based on the coefficients estimated with the endogenous switching regression model. As the dependent variables in the model are the logarithm of annual household income in US$, the predictions are also given in logarithmic form. Converting the mean back to US$ would lead to inaccuracies, due to the inequality of arithmetic and geometric means. Source: Own survey data.

Figure 1 shows a disaggregation of the ATT by income status and farm size for the group of SRI adopters. Both poor and non-poor households benefit from SRI adoption in a similar magnitude, suggesting that the technology has the potential to contribute to poverty reduction. With a 4.8% income gain, small farms even benefit significantly more than large farms. This is due to the higher importance of rice in the income portfolio of small farms. Their higher degree of specialization also means that SRI adoption is associated with lower opportunity costs in other economic activities.

Figure 1. The effect of SRI adoption on the income of adopters by poverty status and farm size categories



*** Significant at the 1% level. Notes: Poor and non-poor are defined as explained in Table 3. Small farms are those with less than 2 ha of land owned (large farms have ≥ 2ha). Source: Own survey data. The net change is the percentage change of the logarithm of annual household income in US$.

5. Conclusion

In this article we have analyzed the impacts of SRI on yield and household income in Timor Leste. Simple comparison of yields and incomes between SRI adopters and non-adopters did not reveal significant differences. However, we found negative selection bias. Controlling for this bias in an endogenous switching regression framework, we identified large and significant yield gains of 46% for SRI adopters. SRI is associated with somewhat higher family labor and management requirements, but with lower use of external inputs such as water, seeds, and pesticides. We also found small but significant positive household income effects through SRI adoption. Both poor and non-poor households benefit, underlining that SRI has the potential to reduce poverty in some situations. SRI-adopting small farms benefit over-proportionally.

Projections show that current non-adopters of SRI would realize much smaller yield gains and slightly negative income effects when they switched to SRI. This suggests that the impacts are very context-specific, depending on micro-level agroecological and socioeconomic conditions. SRI does not seem to be beneficial when compared to conventional rice grown under very favorable conditions and with best management practices. Such heterogeneity in impacts can also be expected for other system technologies, but was often not accounted for in previous economic studies.

The impact of system technologies also depends on the farmers' capacity to adapt general principles to local conditions. In the case of SRI, choosing optimal water levels, transplanting time, and spacing at the individual plot level is knowledge intensive and relies on farmers' ability and motivation to experiment. Hence, successful adoption also depends crucially on good information flows and effective extension services. Even the best extension will not be able to tailor recommendations for each farm and each plot. But strengthening extension services in developing countries could contribute to a creative environment of community-based learning and knowledge transfer within farming communities. Innovative technology transfer models, such as farmer-to-farmer extension as well as participatory learning and knowledge sharing, may support more widespread and successful adoption of system technologies. In terms of adoption incentives, it also needs to be considered that much of the costs associated with system technologies (including learning and opportunity costs) accrue at the individual farm and household level, while some of the benefits of reduced input use and environmental conservation accrue to society at large. Assessing such broader implications requires analysis beyond the farm gate and should be subject to further research.

References

Abdulai, A., Owusu, V., Bakan, J.E.A., 2011. Adoption of safer irrigation technologies and cropping patterns: Evidence from southern Ghana. Ecological Economics 70, 1415-1423.

Africare, Oxfam America, WWF-ICRISAT Project, 2010. More Rice for People, More Water for the Planet. WWF-ICRISAT Project, Hyderabad, India.

Alary, V., Nefzaoui, A., Jemaa, M.B., 2007. Promoting the adoption of natural resource management technology in arid and semi-arid areas: Modelling the impact of spineless cactus in alley cropping in Central Tunisia. Agricultural Systems 94, 573-585.

Altieri, M.A., 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems and Environment 93, 1-24.

Alene, A.D., Manyong, V., 2007. The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: an endogenous switching regression analysis. Empirical Economics 32, 141-159.

Anitha, S., Chellappan, M., 2011. Comparison of the system of rice intensification (SRI), recommended practices, and farmers' methods of rice (Oryza sativa L.) production in the humid tropics of Kerala, India. Journal of Tropical Agriculture 49, 64-71.

Barah, B., 2009. Economic and Ecological Benefits of System of Rice Intensification (SRI) in Tamil Nadu. Agricultural Economics Research Review 22, 209-214.

Barrett, C., Moser, C., McHugh, O., Barison, J., 2004. Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. American Journal of Agricultural Economics 86, 869-888.

Ceesay, M., Reid, W.S., Fernandes, E.C.M., Uphoff, N.T., 2006. The effects of repeated soil wetting and drying on lowland rice yield with System of Rice Intensification (SRI) methods. International Journal of Agricultural Sustainability 4, 5-14.

Deichert, G., Barros, J., & Noltze, M. (2009). Introducing the System of Rice Intensification in Timor Leste - Experiences and Prospects. Paper presented at the 7th PAWEES Conference on Promising Practices for the Development of Sustainable Paddy Fields.

Di Falco, S., Veronesi, M., Yesuf, M., 2011. Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia. American Journal of Agricultural Economics 93, 829-846.

DNS, National Statistics Directorate, 2011. Consumer Price Index - Timor Leste. Dili.

Dobermann, A., 2004. A critical assessment of the system of rice intensification (SRI). Agricultural Systems 79, 261-281.

Doss, C., 2006. Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement. Agricultural Economics 34, 207-220.

Ezrin, M., Amin, M., Anuar, A., Aimrun, W., 2010. Relationship between Rice Yield and Apparent Electrical Conductivity of Paddy Soils. American Journal of Applied Sciences 7, 63–70.

Foresight, 2011. The Future of Food and Farming. The Government Office for Science, London.

Freeman, H., Ehui, S.K., 1998. Credit constraints and smallholder dairy production in the East African highlands: application of a switching regression model. Agricultural Economics 19, 33-44.

Fuglie, K.O., Bosch, D.J., 1995. Economic and environmental implications of soil nitrogen testing: A switching-regression analysis. American Journal of Agricultural Economics 77, 891-900.

Giller, K.E., Tittonell, P., Rufino, M.C., van Wijk, M.T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E.C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W.J., Sanogo, O.M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'ungu, J., Mwale, M., Nwaga, D., Pacini, C., Vanlauwe, B., 2011. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. Agricultural Systems 104, 191-203.

Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114, 23-34.

Glover, D., 2011. The system of rice intensification: time for an empirical turn. NJAS-Wageningen Journal of Life Sciences 57, 217-224.

Greene, W., 2008. Econometric Analysis. Prentice Hall, Englewood Cliffs.

Kabunga, N.S., Dubois, T., Qaim, M., 2012. Yield effects of tissue culture bananas in Kenya: accounting for selection bias and the role of complementary inputs. Journal of Agricultural Economics, doi: 10.1111/j.1477-9552.2012.00337.x.

Kassam, A., Friedrich, T., Shaxson, F., Pretty, J., 2009. The spread of conservation agriculture: justification, sustainability and uptake. International Journal of Agricultural Sustainability 7, 292-320.

Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32, 25-48.

Lapple, D., van Rensburg, T., 2011. Adoption or organic farming: Are there differences between early and late adoption? Ecological Economics 70, 1406-1414.

Latif, M., Islam, M., Ali, M., Saleque, M., 2005. Validation of the system of rice intensification (SRI) in Bangladesh. Field Crops Research 93, 281-292.

Lee, D., 2005. Agricultural sustainability and technology adoption: Issues and policies for developing countries. American Journal of Agricultural Economics 87, 1325-1334.

Lokshin, M., Sajaia, Z., 2004. Maximum likelihood estimation of endogenous switching regression models. Stata Journal 4, 282-289.

Maddala, G.S., 1983. Limited-dependent and qualitative variables in econometrics. Cambridge University Press.

Marenya, P., Barrett, C., 2009. State-conditional fertilizer yield response on western Kenyan farms. American Journal of Agricultural Economics 91, 991-1006.

McDonald, A., Hobbs, P., Riha, S., 2006. Does the system of rice intensification outperform conventional best management? A synopsis of the empirical record. Field Crops Research 96, 31-36.

McIntyre, B.D., Herren, H.R., Wakhungu, J., Watson, R.T., 2009. Agriculture at a crossroads - global report. International assessment of agricultural knowledge, science and technology for development (IAASTD), Washington.

Menete, M., Van Es, H., Brito, R., DeGloria, S., Famba, S., 2008. Evaluation of system of rice intensification (SRI) component practices and their synergies on salt-affected soils. Field Crops Research 109, 34-44.

Mishra, A., Whitten, M., Ketelaar, J., Salokhe, V., 2007. The system of rice intensification (SRI): a challenge for science, and an opportunity for farmer empowerment towards sustainable agriculture. International Journal of Agricultural Sustainability 4, 193-212.

Moser, C., Barrett, C., 2006. The complex dynamics of smallholder technology adoption: The case of SRI in Madagascar. Agricultural Economics 35, 373-388.

Noltze, M., Schwarze, S., Qaim, M., 2012. Understanding the adoption of system technologies in smallholder agriculture: the system of rice intensification (SRI) in Timor Leste. Agricultural Systems 108, 64-73.

Pandey, S., Byerlee, D., Dawe, D., Dobermann, A., Mohanty, S., Rozelle, S., Hardy, B., 2010. Rice in the Global Economy: Strategic Research and Policy Issues for Food Security. International Rice Research Institute, Los Banos.

Rammel, C., Stagl, S., Wilfing, H., 2007. Managing complex adaptive systems--A co-evolutionary perspective on natural resource management. Ecological Economics 63, 9-21.

Rao, E.J.O., Qaim, M., 2011. Supermarkets, farm household income, and poverty: Insights from Kenya. World Development 39, 784-796.

Rigby, D., Cáceres, D., 2001. Organic farming and the sustainability of agricultural systems. Agricultural Systems 68, 21-40.

Senthilkumar, K., Bindraban, P., Thiyagarajan, T., De Ridder, N., Giller, K., 2008. Modified rice cultivation in Tamil Nadu, India: Yield gains and farmers' (lack of) acceptance. Agricultural Systems 98, 82-94.

Sheehy, J., Peng, S., Dobermann, A., Mitchell, P., Ferrer, A., Yang, J., Zou, Y., Zhong, X., Huang, J., 2004. Fantastic yields in the system of rice intensification: fact or fallacy? Field Crops Research 88, 1-8.

SRI International Network and Resources Center (SRI-Rice). http://sri.ciifad.cornell.edu/index.html, accessed 15 of March, 2012.

Stoop, W., Uphoff, N., Kassam, A., 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource-poor farmers. Agricultural Systems 71, 249-274.

Stoop, W., 2011. The scientific case of the system of rice intensification and its relevance for sustainable crop intensification. International Journal of Agricultural Sustainability 9, 443-445.

Thakur, A., Rath, S., Roychowdhury, S., Uphoff, N., 2010. Comparative performance of rice with System of Rice Intensification (SRI) and conventional management using different plant spacings. Journal of Agronomy and Crop Science 196, 146-159.

Tsujimoto, Y., Horie, T., Randriamihary, H., Shiraiwa, T., Homma, K., 2009. Soil management: The key factors for higher productivity in the fields utilizing the system of rice intensification (SRI) in the central highland of Madagascar. Agricultural Systems 100, 61-71.

Turner, J., Taylor, M., 1998. Applied Farm Management. Blackwell Science. Oxford.

Uphoff, N., Randriamiharisoa, R., 2002. Reducing water use in irrigated rice production with the Madagascar System of Rice Intensification (SRI), in: Bouman, B., Hengsdijk, H., Hardy, B., Bindraban, P., Tuong, T., Ladha, J. (Eds.), Water-Wise Rice Production Workshop. International Rice Research Institute,, IRRI, Los Banos, pp. 71-87.

WFP, World Food Program, 2005. Food Insecurity and Vulnerability Timor Leste. April 2005

Wollni, M., Brümmer, B., 2012. Productive efficiency of specialty and conventional coffee farmers in Costa Rica: Accounting for technological heterogeneity and self-selection. Food Policy 37, 67-76.

World Bank, 2008. Timor-Leste: Poverty in a Young Nation. Dili.

Zhao, L., Wu, L., Li, Y., Lu, X., Zhu, D., Uphoff, N., 2009. Influence of the system of rice intensification on rice yield and nitrogen and water use efficiency with different N application rates. Experimental Agriculture 45, 275-286.