Adoption and impacts of system technologies in smallholder agriculture – the System of Rice Intensification in Timor Leste

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To my family

Summary

The latest turmoil of production and price volatility in the global food sector has put agriculture back to the top of the development agenda. Population growth, changing consumer preferences, bioenergy demand and climate change are some of the huge challenges for agricultural production today and in the future. In the last decades, productivity has been constantly improved through the introduction of improved crop varieties and the greater use of mechanization, irrigation, chemical fertilizer and pesticides. However, such input-intensive strategies do not always correspond to the livelihoods and capacities of millions of smallholders, who contribute substantially to global agricultural output, but are also strongly affected by persistent poverty and growing agro-environmental challenges. Moreover, recently farmers have experienced a downturn of productivity growth which in some cases is associated with environmental degradation and depletion of natural resources. This holds true in particular for rice, one of the world's most important food crops.

In the course of growing agricultural challenges, it is widely recognized that innovative strategies are needed to improve human well-being and future food security. Natural resource management (NRM) practices are one stream of innovations that have been proposed to improve the efficiency of cropping systems in a systemic way. Prominent approaches are conservation agriculture, agroforestry and organic farming, which raised considerable attention within the last decades. Such NRM technologies are integrated innovations to improve agricultural productivity and agroecosystem resilience, involving different agronomic and management components with often synergistic relationships. Therefore, the term system technologies is also used here. Studies found that smallholder farmers often face difficulties with the adoption of complex system technologies. Some of the benefits also remain highly debated.

In the rice sector, the so-called System of Rice Intensification (SRI) has been proposed as a promising technology to increase productivity at affordable costs for resource-poor producers. The principles of SRI focus on neglected potentials to raise yields by changing farmers' agronomic practices towards a more efficient use of natural resources. The innovativeness is based on a set of modified management practices concerning irrigation, plot preparation, transplanting, nursery and fertilization. Even though SRI has been widely promoted in some countries, partial adoption and discontinuance are common and the impacts are often found to be context-specific. However, most of the available literature is based on agronomic studies. There is limited evidence in terms of socioeconomic aspects, which is considered a drawback, as system technologies such as SRI may affect farming systems as a whole. In order to explore opportunities and constraints of technological innovations in smallholder farming, studies have to account for the observed variability of resource endowments and farm management options. This study aims to contribute to this research direction by analyzing the linkages between SRI adoption, rice yields, household income and poverty. Investigating the case of SRI may allow us to draw wider conclusions towards the nature of system technologies in general. The results may help researchers and policy makers to understand socioeconomic constraints to farmer technology adoption and integrate this knowledge into the formulation of rural development strategies.

This study uses household and plot level data from small-scale rice farmers in Timor Leste. Assessing the role of improved rice management practices in Timor Leste is highly relevant from a development perspective. First, this young nation state remains one of Asia's poorest countries in terms of income and food security measures. Second, rice is the main staple food for the majority of the population, but domestic production faces severe technical and environmental challenges such as low levels of mechanization, water scarcity and limited access to agricultural technologies. Since 2007, SRI has been introduced by the Second Rural Development Programme (RDPII). Jointly implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Timorese Ministry of Agriculture and Fisheries (MAF), the extension program aims to improve the productivity of rice production systems in the research area. As part of this study, a farm survey was conducted between August and December 2009. Stratified random sampling was used to select 400 households from participants and non-participants of SRI training programs. These households were interviewed. In addition, plot level data from 475 paddy fields owned by these sample households were collected.

We begin our analysis by identifying SRI adoption patterns and differences between SRI and non-SRI farmers. We show that adoption patterns vary substantially, and partial adoption is commonplace. Whereas some technology components are widely applied by households in the research area, others lack widespread acceptance. The highest SRI adoption rates are recorded for the group of training participants. However, the descriptive analysis also reveals that land and household characteristics seem to play a role in the adoption decision. For example, owners of larger farms are more likely to adopt SRI. The outcomes point at substantial heterogeneity among and between adopters and non-adopters, which has to be considered in the econometric analysis of adoption determinants and impacts.

For the econometric analysis of adoption determinants, different decisions points are identified. A double-hurdle adoption model at the household level shows that variables such as farm size, availability of family labor and participation in extension training determine the initial adoption decision and the share of rice acreage under SRI. However, household level characteristics alone are insufficient to explain adoption. Therefore, an additional double-hurdle model is estimated at the plot level. Several plot level determinants have a significant effect on SRI adoption and the number of technology components used. For example, the availability of an irrigation system, which can be individually controlled by the farmer, is an important determinant for SRI adoption on a particular plot.

However, understanding the adoption determinants alone is insufficient to determine whether or not wider adoption is actually desirable. To analyze this, the third part of the analysis explores the impacts of SRI in terms of yields, household income and poverty. In order to account for the differences and variability among household and plot level parameters, the study accounts for differential technology impacts between the adopters and non-adopters of SRI, using an endogenous switching regression approach. Simple comparison of yield and incomes between adopters and non-adopters does not reveal significant differences, however, we find negative selection bias, meaning that SRI is adopted on plots and by farmers that would have below average yields without adoption. Controlling for external factors and selection bias, it is estimated that SRI is increasing yields by 46% against the counterfactual outcome of non-adoption. We also find a small but significant positive household income effect. Both poor and non-poor households benefit from SRI adoption. Especially smaller and more specialized farms realize high returns from adoption due to lower opportunity costs of investment.

Moreover, SRI farmers also use lower amounts of inputs such as water, seeds and pesticides. Yet, we also find that the gains from adoption depend on plot and farmer heterogeneity. That is, assuming that the same gains were to occur for the non-adopters would they decide to adopt is too simplistic.

To conclude, we have shown that farmers can benefit from the introduction of the system technology SRI. Therefore, SRI adoption presents a potential pathway towards food security, poverty reduction and rural development. However, we have also identified several constraints that hinder the adoption of SRI. Not all farmers can easily implement each component at any given plot, and the gains of adoption depend on the reference system. This is an important outcome with regard to extension services and development agencies highlighting that location-specific factors are relevant with regard to adoption and impacts of system technologies. Moreover, improved rural infrastructure and irrigation systems can further increase adoption rates and adaptation capacity. These challenges need to be overcome, in order to fully harness the potential of promising system technologies in smallholder agriculture.

Zusammenfassung

Die internationalen Agrarmärkte sind in jüngster Zeit von hoher Dynamik und Volatilität der landwirtschaftlichen Produktion und Preisentwicklung geprägt. Die Turbulenzen haben die Rolle der Landwirtschaft als eine der tragenden Säulen innerhalb der internationalen Entwicklungsagenda betont. Dabei steht der weltweite Agrarsektor vor großen Herausforderungen. Eine wachsende Weltbevölkerung, neue Konsumgewohnheiten, die Nachfrage nach Bioenergie und der Klimawandel werden auch in Zukunft die Welternährung beeinflussen. In den vergangenen Jahrzehnten konnte die Landwirtschaft beachtliche Produktionssteigerungen verzeichnen. Diese Entwicklung führte zu einer Verbesserung der Ernährungssituation und wirksamer Armutsreduzierung in weiten Teilen der Welt. Der bemerkenswerte Erfolg wurde vor allem durch die voranschreitende Mechanisierung, Ausweitung der weltweit verfügbaren Bewässerungsfläche und den Einsatz von neuen Sorten, Düngemitteln und Pestiziden erreicht. Dieser intensive Einsatz von Produktionsmitteln entspricht in vielen Fällen jedoch nicht der Lebenssituation und den Möglichkeiten der Kleinbauern in Entwicklungsländern. Die kleinbäuerliche Landwirtschaft trägt jedoch zu einem erheblichen Anteil zur weltweiten Agrarproduktion bei. Gleichzeitig sehen sich aber viele Kleinbauern anhaltender Armut und wachsenden Umweltproblemen ausgesetzt. Zudem verzeichnen viele Betriebe eine Verringerung der Produktionssteigerungsraten, welche zunehmend von Flächendegradierung und dem überhöhten Verbrauch natürlicher Ressourcen begleitet werden. Neben anderen Agrarprodukten ist der Anbau von Reis von dieser Entwicklung besonders betroffen. Reis ist eines der weltweit wichtigsten Grundnahrungsmittel.

Im Zuge wachsender Herausforderungen hängen das Wohlergehen und die Ernährungssicherheit einer wachsenden Weltbevölkerung zunehmend von innovativen Strategien in der Landwirtschaft ab. Eine Gruppe von Innovationen, die sich auf systematische Effizienzsteigerungen landwirtschaftlicher Anbausysteme bezieht, ist das natürliche Ressourcenmanagement (NRM). Praktische Ansätze dieser Entwicklung sind die konservierende Bodenbearbeitung, Agrarforstwirtschaft oder organische Landwirtschaft, welche in den vergangenen Jahren erhebliche Aufmerksamkeit erfahren haben. Natürliches Ressourcenmanagement versucht mittels integrierter Anbausysteme, agrarwirtschaftliche Produktionssteigerungen durch eine verbesserte Nutzung agrarökologischer Potentiale zu erreichen. Viele dieser Praktiken beinhalten verschiedene agronomische Komponenten, die

durch gemeinsame Nutzung häufig Synergien erzeugen. Diese Studie verwendet daher den Begriff der Systemtechnologien. Es gibt jedoch eine Vielzahl von Studien die belegen, dass gerade Kleinbauern Schwierigkeiten haben, diese oftmals sehr komplexen Technologien nachhaltig anzunehmen. Darüber hinaus sind einige der Wirkungen in der Literatur hoch umstritten.

Im Reisanbau gilt das sogenannte System der Reis Intensivierung (SRI) als eine vielversprechende Technologie in der kleinbäuerlichen Landwirtschaft. SRI verspricht erhebliche Produktionssteigerungen zu geringen ökonomischen und ökologischen Kosten. Die Prinzipien dieser neuen Anbausystems basieren auf modifizierten Anbaupraktiken im Rahmen einer effizienteren Ressourcennutzung. Bestandteile dieser innovativen Maßnahmen sind Veränderungen geläufiger Bewässerungspraktiken, Behandlung von Setzlingen, Verpflanzungstechnik und Feldbewirtschaftung. Heute findet SRI in vielen Teilen der Welt Anwendung. Es kann allerdings zunehmend festgestellt werden, dass viele Bauern SRI nur teilweise annehmen oder sogar wieder verwerfen. Zudem sind die Wirkungen oftmals kontextabhängig. Jedoch basieren viele Erkenntnisse auf rein agronomischen Studien, sozioökonomische Analysen sind bisher nur unzureichend erarbeitet. Dies erscheint vor dem Hintergrund, dass gerade die Annahme von komplexen Systemtechnologien wie SRI Auswirkungen auf den Landwirtschaftsbetrieb als Ganzes haben, unzureichend. Eine Analyse der Möglichkeiten und Herausforderungen von neuen Technologien in der kleinbäuerlichen Landwirtschaft erfordert die Berücksichtigung hoher Variabilität der Ressourcenverfügbarkeit und betriebswirtschaftlichen Optionen in den landwirtschaftlichen Produktionssystemen. Die folgende Studie widmet sich dem besagten Forschungsgegenstand und analysiert den kausalen Zusammenhang zwischen der Adoption von SRI und deren Wirkung auf die Flächenerträge, Haushaltseinkommen und Armutssituation von Reisbauern in Timor Leste. Die Ergebnisse sollen dazu beitragen, die Herausforderungen und Wirkungen von Systemtechnologien besser verstehen zu können. Erkenntnisse dieser Art helfen bei der Formulierung zukünftiger Entwicklungsstrategien.

Grundlage der vorliegenden Studie sind Daten einer Auswahl von Reisbetrieben in Timor Leste. Im timoresischen Reisanbau kommt neuen Technologien eine besondere Bedeutung zu. Zum einen ist dieser noch junge und fragile Staat in Bezug auf Einkommen und Ernährungssicherheit eines der ärmsten Länder Südostasiens. Zum anderen ist Reis das Hauptgrundnahrungsmittel für weite Teile der timoresischen Bevölkerung. Die jährliche Produktion kann der Nachfrage jedoch nicht entsprechen und sieht sich erheblichen technischen und ökologischen Herausforderungen ausgesetzt. Zu den Hauptursachen gehören geringe Mechanisierung, saisonale Wasserknappheit und ein unzureichender Zugang zu neuen Technologien. Seit 2007 versucht das Second Rural Development Programme for Timor Leste (RDPII) diesen Herausforderungen durch die Einführung von SRI zu begegnen. Das Programm wurde unter der Federführung der Deutschen Internationalen Zusammenarbeit (GIZ) und dem Timoresischen Landwirtschafts-ministerium (MAF) durchgeführt. Ziel ist die Erhöhung der Produktivität des timoresischen Reisanbaus. Von August bis Dezember 2009 wurde im Rahmen der vorliegenden Studie eine umfangreiche Haushaltsbefragung erhoben. Dafür wurden 400 Reisanbaubetriebe durch eine stratifizierte Zufallsstichprobe ausgewählt. Die Stratifizierung basiert auf der Teilnahme und Nicht-Teilnahme am SRI Trainingsprogramm. Zusätzlichen wurden detaillierte Felddaten und Bodenproben von 475 Reisfeldern aller befragten Haushalte aufgezeichnet und analysiert.

Als Ausgangslage werden im Rahmen der Studie unterschiedliche Adoptionsmuster und Unterschiede zwischen SRI und Nicht-SRI Bauern erarbeitet. Die Analyse zeigt, dass sich die beobachteten Adoptionsmuster, das heißt die Kombinationen von unterschiedlichen SRI Komponenten, teilweise erheblich unterscheiden. Viele Landwirte nehmen die Technologie nur teilweise an. Während einige Komponenten vermehrt Anwendung finden, werden andere kaum berücksichtigt. Die höchsten Adoptionsraten verzeichnet die Gruppe der Trainingsteilnehmer. Jedoch verweist die deskriptive Analyse auch auf weitere Betriebs- und Haushaltsfaktoren, welche die Adoptionsentscheidung beeinflussen. Zum Beispiel verzeichnen größere Reisbauern eine höhere Wahrscheinlichkeit, SRI zu adoptieren. Diese Ergebnisse deuten auf eine beachtenswerte Heterogenität zwischen den unterschiedlichen Haushaltstypen hin. Die erarbeiteten Differenzen werden in der weiteren ökonometrischen Analyse der Adoptionsentscheidungen und Technologiewirkungen eine bedeutende Rolle spielen.

Für die ökonometrische Analyse der Adoptionsfaktoren werden unterschiedliche Entscheidungsebenen identifiziert. Ein zweistufiges Entscheidungsmodell (double-hurdle model) zeigt, dass Haushaltsfaktoren wie Betriebsgröße, Arbeitsverfügbarkeit und Trainingsteilnahme die grundsätzliche Adoptionsentscheidung, aber auch die Anbaufläche der neuen Technologie bestimmen. Jedoch können Haushaltsvariablen die Adoption von SRI nur teilweise erklären. Ein weiteres Modell analysiert die Adoptionsentscheidungen auf Feldebene. Die Analyse zeigt einen signifikanten Einfluss unterschiedlicher Feldparameter auf. So bestimmt die Verfügbarkeit eines Bewässerungssystems die Adoption von SRI auf einem bestimmten Reisfeld, erklärt aber auch partiell die Anzahl der angenommenen Komponenten.

Allerdings gibt die Untersuchung der Adoptionsentscheidungen nur geringen Aufschluss darüber, ob die Annahme von SRI überhaupt wünschenswert ist. Vor diesem Hintergrund betrachtet der dritte Teil der Studie die Wirkungen von SRI im Bezug auf Erträge, Haushaltseinkommen und Armut. Die Analyse geht dabei auf die unterschiedlichen Haushalts- und Feldparameter zwischen SRI und Nicht-SRI Betrieben ein und kontrolliert unterschiedliche Technologieeffekte unter Verwendung eines speziellen zweiteiligen Regressionsmodells (switching regression model). Dabei lässt sich feststellen, dass SRI vor allem auf Feldern und von Landwirten angenommen wird, die sonst unterdurchschnittliche Erträge erzielen. Die Annahme von SRI wird daher durch eine negative Selektion beeinflusst. Unter Berücksichtigung externer Faktoren und selektiver Auswahl wird allerdings geschätzt, dass sich die Erträge auf SRI Feldern gegenüber einer Nicht-Annahme um deutliche 46% erhöhen. Dies führt zu einer signifikanten, wenn auch geringen Verbesserung des Haushaltseinkommens. Haushalte ober- und unterhalb der Armutslinie können somit von SRI gleichermaßen profitieren. Besonders kleinere und spezialisierte Betriebe verzeichnen die größten Einkommenszuwächse. Zudem profitieren SRI Betriebe von niedrigerem Wasserbedarf sowie geringerem Saatgut- und Pestizideinsatz. Dennoch basieren diese Wirkungen auf lokalen und kontextbezogenen Faktoren, welche bei unterschiedlichen Haushaltstypen und Anbauflächen teils sehr unterschiedlich ausfallen. Dies bedeutet, dass die geschätzten Ertrags- und Einkommenszuwächse nicht ohne Weiteres von allen Betrieben zu verwirklichen sind. Gemäß Schätzungen sind auf konventionellen Feldern weitaus geringere Ertragszuwächse zu erwarten.

Abschließend kann festgestellt werden, dass die Einführung von SRI zu einer positiven Entwicklung des timoresischen Reissektors beiträgt. Eine erfolgreiche Adoption der Technologie bereitet den Weg in Richtung Armutsreduzierung, Ernährungssicherheit und ländlicher Entwicklung bei gleichzeitiger Berücksichtigung einer schonenden Nutzung der natürlichen Ressourcen. Jedoch wurden auch Herausforderungen und Grenzen der Adoption aufgezeigt. Nicht alle Bauern können ohne Weiteres alle Komponenten auf jedem beliebigen Feld umsetzen. Das ist eine wichtige Erkenntnis im Hinblick auf die Rolle von Landwirtschaftsprogrammen. Die vorliegenden Ergebnisse zeigen, dass erfolgreiche Strategien auf die Bedeutung lokaler und kontextspezifischer Faktoren eingehen und diese für die nachhaltige Verbreitung von Systemtechnologien berücksichtigen sollten. Weiterhin können eine verbesserte ländliche Infrastruktur und technische Bewässerungssysteme die Adoption erhöhen. Die Erschließung der Potentiale von Systemtechnologien für Kleinbauern basiert daher auf der Überwindung der genannten Herausforderungen durch die Unterstützung landwirtschaftlicher Entwicklungsprogramme.

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Abbreviations

ATU	Average treatment effect of the untreated
ATT	Average treatment effect of the treated
AWD	Alternate wetting and drying
BMZ	German Federal Ministry for Economic Cooperation and Development
CAPE	Conditional average partial effect
EC	European Commission
FIML	Full information maximum likelihood
GDP	Gross domestic product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ICM	Integrated crop managemenat
IMR	Inverse Mills ratio
IPAD	Instituto Português de Apoio ao Desenvolvimento
IV	Instrumental variable
MAF	Ministry of Agriculture and Fisheries
NRM	Natural resource management
PCA	Principal component analysis
RDPII	Second Rural Development Programme for Timor Leste
SRI	System of Rice Intensification
UAPE	Unconditional average partial effect
UTAD	Universidade Trás-os-Montes e Alto Douro

1. General introduction

1.1 The role of agriculture as an avenue for growth and poverty reduction

An overwhelming 75% of the world's poor live in rural areas, most of them in developing countries (World Bank, 2007). The vast majority depends directly or indirectly on agriculture. It is estimated that 85% of farmers in the developing world occupy farm land of less than 2 hectares and are strongly engaged in subsistence farming (European Technology Assessment Group, 2009). In total, small farms manage about 60% of global arable land and contribute immensely to the world's agricultural production (McIntyre et al., 2009). However, smallholders are extremely vulnerable to economic or environmental shocks, because negative externalities do equally affect economic activities, livelihoods and food security (McIntyre et al., 2009). Moreover, climate change will disproportionately affect the poor in risk-prone, marginal environments of developing countries, calling for the adaptation of local agricultural production systems (International Panel of Climate Change, 2007; Nelson et al., 2010). These points reveal the persistent importance of the small-farm sector as an avenue for growth, employment and poverty reduction (Mellor, 1976; World Bank, 2007). But what strategies can best serve resource poor farmers? This research aims to contribute to this question by highlighting the role of technological innovations in smallholder production systems. In particular, we investigate the case of the System of Rice Intensification (SRI) in Timor Leste.

1.2 The emergence of system technologies in smallholder agriculture

Agricultural productivity has been impressively increased in the course of the Green Revolution and contributed significantly to a decrease of poverty in large parts of the developing world (World Bank, 2007). However, millions of smallholders remain widely untouched by modern technologies, which are primarily based on the greater use of inputs such as chemical fertilizer, pesticides, irrigation and mechanization (Foresight, 2011; Pretty, 1995). This high-external-input strategy did not always correspond to the livelihoods and capacities of small-scale producers who are often excluded from access to credit, information and other rural markets and services (Altieri, 2002). To overcome market access constraints, input subsidies were sometimes implemented. However, such subsidy programs did often not properly address the underlying constraints, while sometimes created new problems, including negative environmental externalities (European Technology Assessment Group, 2009; Fan et al., 2008; Kumar and Mittal, 2006; McIntyre et al., 2009).

Today, agriculture faces several emerging challenges, including population growth, changing consumer preferences, demand for bioenergy, climate change and extreme weather events, land degradation and resource scarcity (World Bank, 2007). Meeting these challenges requires comprehensive and innovative strategies to improve human well-being and future food security (McIntyre et al., 2009). Natural resource management (NRM) practices, which can be perceived as complex adaptive systems, have been proposed to improve the efficiency of agricultural production in a systemic manner (European Technology Assessment Group, 2009; Marenya and Barrett, 2007; Rammel et al., 2007). This study understands NRM technologies as integrated innovations to improve agricultural productivity and agroecosystem resilience. As usually several agronomic and management components with synergistic interactions are involved, we also use the term "system technologies". This is in contrast to other modern technologies such as new high-yielding crop varieties, where the innovation is packaged into a particular input. In the last decades, system technologies have raised considerable attention by governments, development agencies and farmers. Prominent approaches are conservation agriculture (Giller et al., 2009; Jansen et al., 2006; Kassam et al., 2009), agroforestry (Molua, 2005; Muschler and Bonnemann, 1997; Neupane and Thapa, 2001) and organic farming (Hole et al., 2005; Kristiansen and Merfield, 2006; Rigby and Cáceres, 2001), most of which rely more generally on agroecological principles rather than standardized practices or specific input recommendations.

Principle-based system technologies allow the adaptation of practices to different agronomic and socioeconomic conditions (Lee, 2005). On the other hand, context-specific best management practices cannot easily be generalized, complicating their dissemination (Lee, 2005; Rigby and Cáceres, 2001). This is especially true in smallholder agriculture due to highly diverse resource endowments and farm management options. If adaptation results in diverse adoption patterns and therefore in varying technological change, the impacts of innovations are likely to vary, too. Indeed, the impacts of non-standardized system technologies are subject to controversy (Alary et al., 2007; Glover, 2011a; Knowler and Bradshaw, 2007) and are often found to be context-specific (Giller et al., 2009; Kassam et al., 2009; Lee, 2005). The ongoing debate reveals that there are important knowledge gaps, both with regard to adoption and impacts of system technologies.

1.3 The System of Rice Intensification

Rice is the most important staple food for about half of the world's population and an important food crop for farmers in developing countries (Food and Agriculture Organization, 2010; Seck et al., 2012). It is estimated that about 900 million of the world's poor depend on rice production either as a consumer or a producer, accounting for nearly half of their daily food expenditures (Pandey et al., 2010). In the course of the Green Revolution, global rice production had increased remarkably, largely due to the introduction of high-yielding varieties and input intensification. Especially in Asia, which incorporates the world's most important rice producing regions, this development has contributed to a substantial reduction of poverty over some decades. However, more recently farmers have experienced a downturn of productivity growth, which is often associated with increasing environmental concerns (International Food Policy Research Institute, 2009). Rice yield growth has already failed to hold pace with population growth and consumer demand, leading to supply shortages and higher prices, which disproportionately affect the poor (Pandey et al., 2010). This became obvious in the latest food crisis, when rice prices increased by about 50% between 2007 and 2010 (Food and Agriculture Organization, 2010). Since then, prices have remained high and volatile (Seck et al., 2012). Moreover, climate change is expected to further affect global rice production by increasing yield instability, water shortages or the loss of agricultural land in delta regions where commercial rice production is concentrated (Food and Agriculture Orgaization, 2010; Palis et al., 2010; Pandey et al., 2010). Improving global food security will, therefore, depend on new opportunities to increase rice productivity per unit of land, labor and water in an economically and environmentally acceptable way.

The System of Rice Intensification could be a promising approach to meet currently untapped production potentials of rice at affordable costs for small-scale farmers (Mishra et al., 2007; Stoop et al., 2002). SRI focuses on farmers' agronomic practices towards a more efficient use of natural resources (Barah, 2009; Uphoff and Randriamiharisoa, 2002; Zhao et al., 2009). In the mid 1980s, the technology originated in Madagascar developed inductively by farmers around a French missionary, Henri de Laulanìe. The reported results were remarkable and promising. Studies found that yields of Malagasy SRI farmers doubled and even quadrupled without new varieties or the use of other additional inputs (Sato and Uphoff, 2007; Uphoff, 1999). Since then, SRI has been promoted in several countries in Asia, Africa and Latin America by governmental and non-governmental organizations. Today, it is estimated that more than 1 million farmers are following SRI practices on more than 1 million hectares of farm land (European Technology Assessment Group, 2009). The technology is believed to be appropriate for smallholders in particular, because it addresses some major constraints such as limited resources of land, labor, water and cash as well as losses from pest, diseases and adverse climatic conditions.

The concept of SRI comprises a set of modified management practices concerning irrigation, plot preparation, transplanting, nursery and fertilization (McDonald et al., 2006; Stoop, 2011; Uphoff and Randriamiharisoa, 2002). Based on the experiences from Madagascar, a package of distinctive components has been developed by farmers, trainers and researchers. To date, there is no universal definition of what SRI consists of; studies find it difficult to attribute the observed outcomes to a given technological change. However, in accordance with the existing literature, some core practices can be distinguished from other rather optional practices.

In chapter 2, a technical understanding of SRI is developed. The definition used there accounts for all SRI practices adopted by a household. In chapters 3 and 4, SRI is defined slightly differently; to make it more suitable for the econometric analysis, we define a rice plot as an SRI plot only when certain core SRI components have been adopted on that plot. Details of the definitions used are given further below. At this stage, it should be mentioned that mean values of the sub-samples of SRI adopters and non-adopters can vary slightly, depending on the concrete definition used. However, the main findings are robust and largely independent of the definition.

Even though SRI has been widely promoted in some countries, non-adoption, partial adoption and discontinuance are commonplace (Moser and Barrett, 2006; Senthilkumar et al., 2008). Moreover, the impacts of the technology are heavily debated (Anitha and Chellappan, 2011; Barrett et al., 2004; Dobermann, 2004; Latif et al., 2005; McDonald et al., 2006; Moser and Barrett, 2006; Sheehy et al., 2004; Stoop et al., 2002; Surridge, 2004; Tsujimoto et al., 2009).

1.4 Problem statement

The introduction of resource-conserving technologies to smallholder farming systems offers new opportunities to meet future challenges of crop production (European Technology Assessment Group, 2009; Food and Agriculture Organization, 2009). But it is also shown that farmers are facing difficulties with adoption and that the benefits do not equally occur across different types of farms (Alary et al., 2007; Kassam et al., 2009; Knowler and Bradshaw, 2007; Lee, 2005). To date, there is only limited understanding about the opportunities and constraints related to the adoption of system technologies such as SRI. Investigating these issues supports agricultural planning and the formulation of rural development strategies.

As system technologies offer opportunities for the adaptation of practices to specific environments, practical implementation varies, which makes it more difficult for researchers to attribute observed outcomes to a given technological change. This holds in particular for complex technology packages. Due to its optional principles and adaptive capacity, SRI is likely to be practiced in a number of different ways. We hypothesize that not all farmers fully adopt all SRI components, thus partial adoption can be expected. The identification of diverse adoption patterns is crucial in order to understand adoption and impacts of the technology of interest.

Even though SRI has been widely promoted, worldwide adoption rates are still limited. Partial adoption and discontinuance may be associated with a mixed yield experience of farmers. Moreover, it is shown that additional labor requirements hinder SRI adoption by smallholders, who sometimes face seasonal labor constrains (Moser and Barrett, 2003). However, as the adoption of system technologies is context-specific, we hypothesize that there may be additional micro level parameters which may influence adoption, including the characteristics of individual plots. Understanding the parameters that affect adoption is important to design appropriate technology delivery strategies. Farmers do not only need to acquire a general understanding of the technology, but they also have to know details of each component to be able to adapt it to farm and plot specific conditions. Such knowledge is often not easily available, which makes widespread adoption more complicated than for less knowledge-intensive and standardized technologies.

The impacts of SRI are discussed on the basis of various empirical studies using different designs including field trials, experiments and research stations (McDonald et al., 2006). Previous studies have largely ignored to address wider socioeconomic implications at farm level. This might be insufficient in the case of complex system technologies which may substantially affect farming systems as a whole. A few exceptions are studies from Madagascar which took socioeconomic data into account (Barrett et al., 2004; Moser and Barrett, 2006). In order to address the improvement of smallholder farming systems to a given technological change, causal analysis has to refer to the impact of technologies on yield, household income and poverty. Such an analysis depends on detailed farm, farmer and plot level data which are often not easily available (Doss, 2006). Therefore we conducted a standardized household survey and additionally collected detailed plot level data and soil sample analysis which will be described in the following.

We suppose that due to its low external input requirements SRI can potentially contribute to the improvement of smallholder farming systems. However, this may not hold for all farmers and all plots, because we expect context- and location-specific factors to influence adoption and impacts. We hypothesize that both adoption and impacts of system technologies depend on the heterogeneity of smallholder farming systems which are characterized by a high variability of farm management options and resource endowments in different agroecological and socioeconomic environments.

1.5 Objectives of the study

Knowing the respective opportunities and constraints associated with the adoption and impact of agricultural technologies allows rural development strategies to assist or overcome them. In view of the identified research gaps in the literature, this study aims to analyze adoption and impacts of system technologies in smallholder agriculture. We do so by investigating the System of Rice Intensification (SRI) in Timor Leste, evaluating farm, farmer and plot level data. The specific objectives are as follows:

- To identify SRI adoption patterns and to explore differences between SRI and non-SRI farmers.
- To understand the factors that influence farmers' adoption decisions.
- To assess the impacts of SRI in terms of yield, household income and poverty.

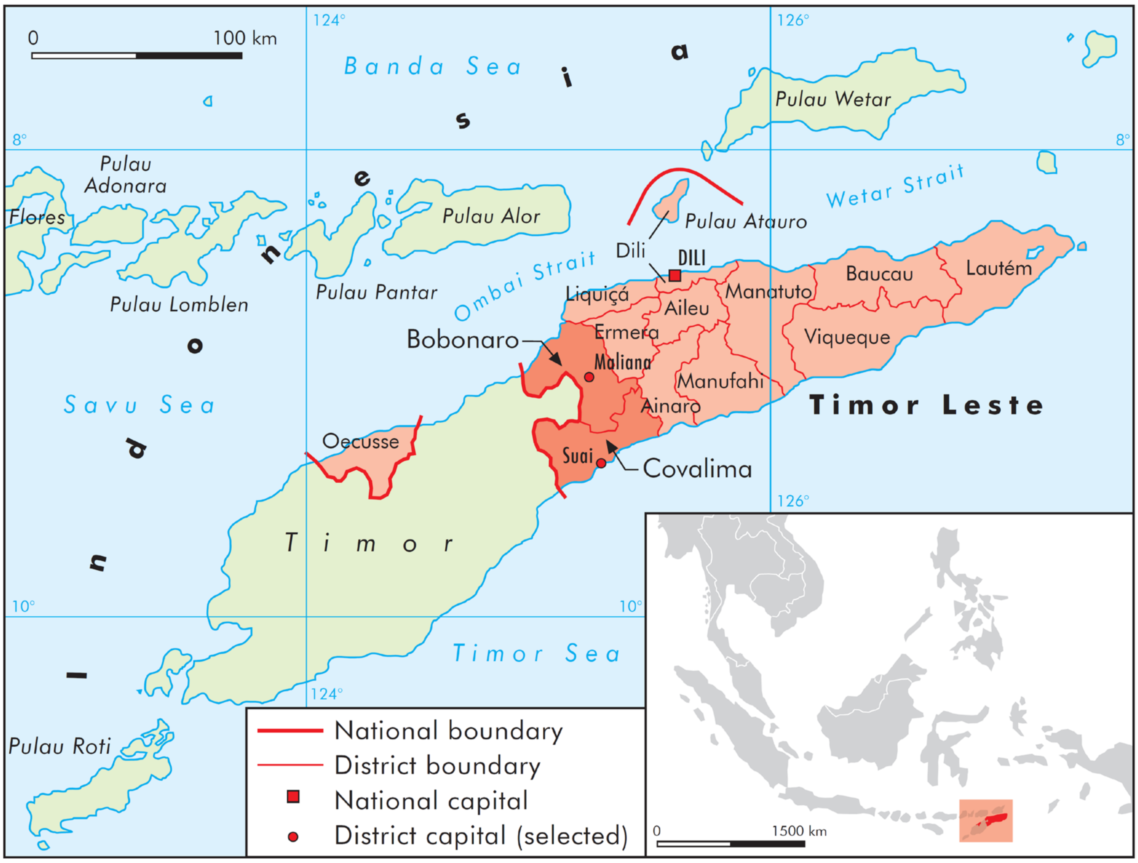
1.6 Data collection

This research is based on primary data from Timor Leste. Assessing the role of improved rice management practices in the Timorese context is highly relevant from a development perspective. First, this young nation state remains one of Asia's poorest countries in terms of income and food security measures (World Bank, 2008, 2012). Second, rice is the main staple food for the majority of the people, but domestic production is far from meeting the demand of the country's fast growing population and faces severe technical and environmental challenges such as low levels of mechanization, water scarcity and limited access to agricultural technologies (Deichert et al., 2009; Noltze et al., 2011, 2012; World Food Program, 2005).

The data used in this study is derived from a comprehensive farm survey that was conducted in the west of Timor Leste (Figure 1). The research area covers the two national districts Covalima and Bobonaro which include some of the country's most important rice lands (Ministry of Agriculture and Fisheries, 2008). In the two districts, SRI has been introduced on behalf of the Second Rural Development Programme for Timor Leste (RDPII), jointly implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Timorese Ministry of Agriculture and Fisheries (MAF). The geographical location of the region falls on the latitude 8°44' to the North and 9°27' to the South, marked be the longitude 124°56' to the West and 125°32' to the East. The area covers about 2,579 km² which is approximately 17% of Timor Leste's total land mass. The region is characterized by very diverse agro-climatic conditions ranging from coastal plain lands to mountainous zones. The total population of the two districts sums up to about 152,000 which accounts for about 14% of the Timorese population (National Statistics Directorate and United Nations Population Fund, 2011). The field work of this survey was carried out between June and December 2009.

Together with MAF, complete household lists of all rice farming households in the research area were established. The information collected included the place of residency and the participation of households in agricultural extension services. The lists served as a sampling frame for the household survey and included 1228 SRI participants and 3220 non-participants of the SRI extension training. Stratified random sampling was used to select 400 households from both groups. A total of 397 households were finally visited and interviewed, including 199 participants and 198 non-participants.

Figure 1. Location of research area in Timor Leste



Note: Survey areas Bobonaro and Covalima are highlighted. Source: Noltze et al. (2011).

The farm survey consists of two main parts. First, a household survey was conducted from August to October. For the interviews, a structured questionnaire was used to collect information from all household members, including wealth indices, agricultural and non-agricultural economic activities, social capital with respect to exposure to institutions and detailed information concerning rice cultivation practices (an English version of the questionnaire used is appended in section B of the appendix). The questionnaire was translated and interviews were hold in the national language Tetun. Seven university students were recruited as enumerators, who conducted two interviews per person per day. The interview partners were the head of the household or the most informed household member. In the household survey 475 rice plots had been identified. Second, between October and December all rice fields recorded were visited together with farmers. At the field, detailed plot level information such as location, slope and irrigation system were collected. Moreover, soil samples were collected from one randomly drawn point on each plot and analyzed by easy-to-use testing procedures in field laboratories, including the analysis of soil texture, saturation, pH value and electrical conductivity. Whereas some tests were examined by electronic instruments such as pH and conductivity meters, others were conducted by using simple materials such as plastic film, bottles and bowls. The tests applied do not provide absolute figures under laboratory conditions, but are used to control for relative differences among plots.

1.7 Outline of the study

The remainder of this study is organized in three main chapters addressing the three specific objectives listed above. Chapter 2 reviews the introduction of SRI in Timor Leste and identifies adoption patterns among Timorese rice producers. A technical definition of SRI is developed and differences between adopters and non-adopters are highlighted.

Chapter 3 is devoted to the factors that influence farmers' adoption decisions. It is structured according to the main decision stages of farmers: first, the initial decision to adopt SRI and second, the intensity of adoption. In addition, the depth of adoption, especially the factors that drive partial adoption, are examined, taking plot level data into account.

Chapter 4 investigates the impacts of SRI adoption on yield, household income and poverty. In particular, we are interested in differential technology effects between adopters and non-adopters. We account for structural differences between groups and account for potential selection bias.

Finally, chapter 5 summarizes and provides conclusions and policy implications. Moreover, some limitations and directions for further research are discussed.

2. Knowledge-based agricultural innovations in Asia: The System of Rice Intensification (SRI) in Timor Leste[1]

Growing concerns about the downturn of productivity growth and environmental problems associated with intensive paddy systems call for innovative strategies in rice cultivation. Improved technologies have to increase productivity by simultaneously addressing land, labor and capital constraints. Natural resource management practices, such as the System of Rice Intensification, have been proposed to increase production sustainably. However, complex system technologies offer opportunities for the adaptation of practices to specific environments and are therefore likely to be practiced in a number of different ways. Not all farmers may fully adopt the technology, thus partial adoption can be expected. Previous studies did often neglect a potential variability of technological change, which may be insufficient with regard to subsequent adoption and impact analysis. This chapter identifies adoption patterns of SRI farmers in Timor Leste and explores differences between SRI and non-SRI households.

2.1 Introduction

In the aftermath of the recent economic turmoil, the Food and Agriculture Organization (2010) estimates that more than one billion people are food insecure and undernourished worldwide. Many of the poor and vulnerable depend largely on the production of rice as the main staple food, but also as an opportunity for employment and an income source. It is estimated that current paddy production needs to be increased by more than 50% to meet the rising food demand over the next few decades (Mishra and Salokhe, 2010). Although rice production has increased substantially since the Green Revolution, annual growth rates are now facing a remarkable downturn (International Food Policy Research Institute, 2009). In some regions, stagnating yields can be observed. High-input rice farming often involves mono-cropping, modern

[1] This chapter is published as an article in 'Pacific News 35 (2011) 4-9'. The co-authors of this paper are Stefan Schwarze, Assistant Professor; and Matin Qaim, Professor at the Department of Agricultural Economics and Rural Development, Georg-August-University of Göttingen, Germany.

varieties, fertilizer, and pesticide use. There are concerns that the stagnating yields reflect the deterioration of the crop-growing environment as a result of soil degradation in intensive paddy systems. While in some regions overuse of chemical inputs has caused negative externalities, in many low-income countries limited resources still hinder the implementation of high-input systems. Accordingly, post-Green Revolution perspectives call for innovative strategies that are resource conserving and technically feasible, addressing livelihoods in an economically and socially acceptable way. The System of Rice Intensification (SRI), a knowledge-based low-external input technology, promises higher yields with no deleterious impact on natural resources at affordable costs for poor smallholder farmers.

2.2 Motivation of the study

SRI is already raising factor productivity and incomes for more than one million smallholders around the world on more than one million hectares (European Technology Assessment Group, 2009). Today it is applied in various agroecosystems in Africa and Asia: from tropical and coastal to semi-arid and mountainous regions. Experiences suggest that crop yields under SRI can be doubled, and even in some cases, quadrupled (Anthofer, 2004; Sato and Uphoff, 2007). Furthermore, several studies found a significant reduction in the total amount of water needed (Ceesay et al., 2006; Uphoff, 2001). Poor water management often leads to land degradation through salinization or water logging. Additionally, inappropriate use of pesticides causes groundwater pollution and loss of biodiversity. Low external input use (water and fertilizer, etc.) marks SRI as an environmentally friendly technology for small-scale farmers in developing countries. However, Alagesan and Budhar (2009) found that farmers faced difficulties in the large-scale adoption of SRI in Tamil Nadul, India, due to knowledge deficits and labor shortages. Non-adoption and disadoption was examined by Moser and Barrett (2002) in Madagascar; they also cited problems relating to the higher labor needs of SRI. A study by Barrett et al. (2004) found that half of the gains from SRI adoption are based on farm and farmer characteristics rather than the technology itself.

Obviously, SRI is the subject of considerable controversy in the agricultural development debate. Concrete empirical evidence about the adoption performance of SRI under different agroecological and socioeconomic conditions remains limited. This chapter aims to contribute to the ongoing discussion by describing SRI adoption patterns among smallholder rice producers in Timor Leste and to explore differences between adopters and non-adopters. The research builds on primary farm survey data. Adequate definitions of knowledge-based land management practices need to consider the complexity of non-fixed technology packages. We do so by specifically accounting for partial adoption, that is, farmers adopting only certain components of the package but not others. The chapter is structured as follows. Firstly, a general overview of SRI will be provided. Secondly, the introduction of SRI in Timor Leste will be outlined. SRI adoption is defined at the farm household level using a two-group cluster approach, differences between adopters and non-adopters in terms of farm and household characteristics will be presented. In order to assure that key components of the technology are relevant among the derived group of adopters, principal component analysis (PCA) identifies defining factors determining SRI adoption in the given context. Finally, some conclusions will be discussed.

2.3 The System of Rice Intensification in practise

SRI relies mainly on changing farmers' agronomic practices for managing rice plants, soil, water, and nutrients. In the context of sustainable land management practices, SRI can be described as a complex agricultural production system, leading to higher agroecological and biological productivity without necessarily increasing external key inputs such as mineral fertilizer and pesticides, labor or capital (European Technology Assessment Group, 2009). The concept of SRI was developed by a French priest, Fr. Henri de Laulanié, in the mid 1980s in Madagascar, to enable small-scale farmers increase rice yields using less water and seeds.

The main practices in the field include (i) carefully managed nurseries, (ii) application of compost, (iii) transplanting of young seedlings (10-15 days old), (iv) row planting (v) cultivation of single seedlings (vi) using a planting distance of at least 20x20 cm, (vii) intermittent flooding and (viii) regular weeding of plots (Table 1). Early transplanting of single seedlings and modified water management are the most prominent characteristics of SRI (European Technology Assessment Group, 2009). Together with row planting in high distance square patterns these principles support roots growth and tillering. A strong root system has positive impacts on plants' vegetative and reproductive phases via advanced nutrient uptake. The raising and selection of strong seedlings can be supported by carefully managed nurseries. Additionally, improved water management supports soil aeration and reduces overall water input. Uphoff and Randriamiharisoa (2002) found that continuously flooded soils constrain root growth and limit anaerobic microbial populations. Advantageously, SRI is able to reduce the total amount of water needed where water shortages occur. The water management practises are not primarily meant to be recommendations for rice cultivation in permanent flooded locations. However, if water levels are reduced to moist soil conditions, weeds are likely to grow. Thus, weeding is seen as another important SRI element to control for pests. Furthermore, organic input is added to enhance soil fertility by simultaneously facilitating soil aeration. Square pattern planting in high distances enables the use of mechanical weeders to reduce labor inputs. And finally, the incorporation of organic manure into the soil supports root activities by stimulating growth-promoting bacteria (Mishra et al., 2007).

Table 1. Adoption of components per household

Components		Description	Adopted (%)	Factor loadings
i	Nursery	carefully managed mat or tray nurseries	39.8	0.7319
ii	Compost	application of compost at nurseries and plots	12.3	0.3918
iii	Transplanting	planting young seedlings < 15 days	57.9	0.7400
iv	Row planting	square pattern row planting on plot	65.7	0.9023
v	Single seedlings	only one seedling per hill	54.2	0.8917
vi	Distance	distance of seedlings from 20x20 to 50x50cm	63.5	0.8964
vii	Re-irrigation	alternate flooding and drying on plots	54.2	0.3637
viii	Weeding	Weedings, manually or with hand weeders	91.9	0.3578

Source: Own survey data. N=397.

Globally, the introduction of SRI differs slightly according to location-specific, agronomic and socioeconomic characteristics of target groups and program objectives. Accordingly, there is no common definition available capturing the complexity of this novel rice production management system. Finally, SRI was never meant to be a fixed technology package; it can rather be described as an expandable menu which is constantly modified through researchers' and farmers' experimentation. Farmers are encouraged to participate in the adaptation of SRI to specific socioeconomic and agroecological conditions (European Technology Assessment Group, 2009). Therefore the adoption decision is strongly based on knowledge. Firstly, farmers have to collect information about the different components before deciding for each component separately to adopt or not to adopt, and if yes, how to adapt each technique to local conditions: the number of weedings per season, the quantity and quality of compost or the optimum distance between seedlings, and so on. Thus the knowledge character of SRI is simply not defined by 'knowledge on how to use the technology'; rather, it is the incorporation of a comprehensive 'knowledge of the effects of all eight components and the interactions among them'.

2.4 The System of Rice Intensification in Timor Leste

The young nation-state of Timor Leste, which is located in the Southeast of the Indonesian archipelago, is among the poorest countries in Southeast Asia. The country's economy depends largely on agricultural production, which sums up to one third of the national GDP, providing income to more than 80% of the population (Correia et al., 2009). Rice is one of the main crops grown by Timorese farmers both as a staple food for home-consumption and as a source of cash income. However, average production levels of 2 tons per ha cannot meet local demand, so the country relies on rice imports which costs an estimated average of US$ 58.5 million annually (Ministry of Agriculture and Fisheries, 2008). The domestic production is subsidized as the government is buying rice at a guaranteed price of US$ 0.30 per kg of paddy, which is usually higher than the price of imported rice. This import substitution strategy aims to cover higher production costs of relatively inefficient Timorese rice producers of today. Nevertheless, rising food prices and export limitations of important rice producing countries have intensified the risks of import dependencies. Hence, the government emphasizes strategies to increase levels of domestic rice production.

Since 2007, the Second Rural Development Programme for Timor Leste (RDPII), jointly implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit

(GIZ) and the Timorese Ministry of Agriculture and Fisheries (MAF), promotes SRI for an increase in domestic rice production so as to meet the rising food demands of the fast growing Timorese population. The agricultural extension component of RDPII works through an advisory service approach with farmer groups. The focus is particularly on knowledge-based technologies, because levels of mechanization are low and farmers' access to external inputs is limited. Especially in the two western boarder districts of Bobonaro and Covalima, SRI has become the main component of extension services.

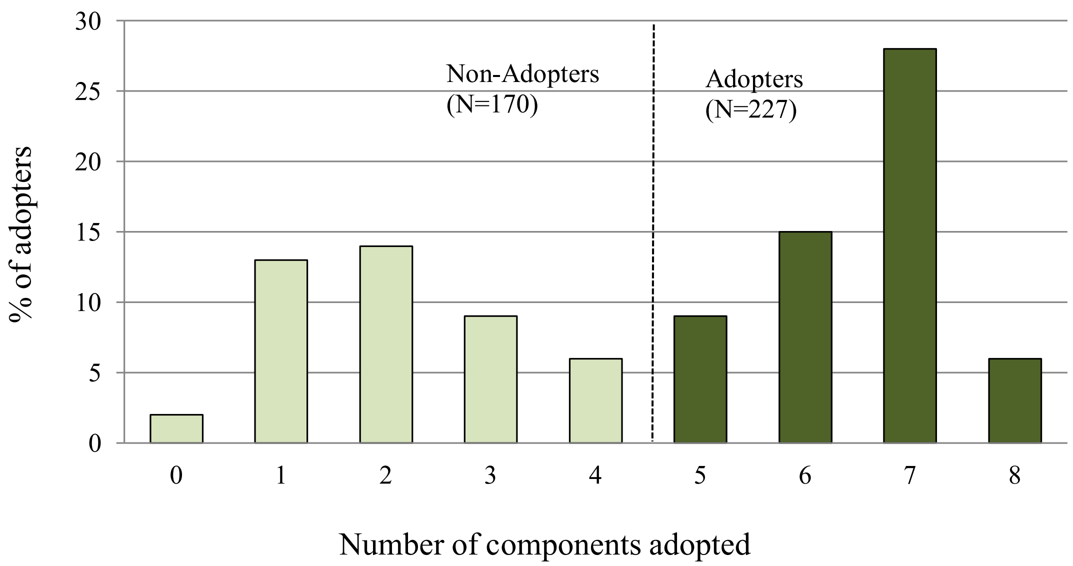
2.5 Empirical approach

In order to examine adoption patterns of SRI among small-scale rice producers in Timor Leste, a farm survey was carried out between August and December 2009. The survey covered the two districts of Bobonaro and Covalima. Complete household lists had been generated, after which stratified random sampling was used to select 200 households from both participants (N=1228) and non-participants (N=3220) of SRI extension trainings. This sampling procedure allows for causal conclusions in the impact analysis but has no such implications in this chapter. A total of 397 households were finally visited and interviewed, including 199 training participants and 198 non-participants. All six relevant lowland rice producing sub-districts are represented in the sample. For the interviews, a structured questionnaire was used to collect comprehensive information from all household members, including wealth indices, agricultural and non agricultural income generating activities, social capital with respect to exposure to institutions and detailed information concerning rice cultivation practices.

2.6 Results and discussion

It cannot simply be assumed that participants in SRI training would be SRI adopters and non-participants would be non-adopters. The reason is that some participants may not have adopted, or that some non-participants may have adopted due to information and knowledge spill-overs. Moreover, adoption is not a simple 0-1 decision, because SRI involves different components, of which some may be adopted by farmers and others not. Against this background, an SRI component count system, or so-called 'adoption scores', which provide detailed information on the number of SRI components applied by each household was developed. The adoption of each component counts as one adoption score. High adoption rates of more than 50% for individual components suggest that these components are applied also beyond the group of training program participants (Table 1). Adoption rates of more than 60% are observed for weeding, row planting, and distance recommendations. This is not surprising as these components were already part of a former rice extension service known as Integrated Crop Management (ICM) and were seen as a stepping stone towards the introduction of SRI in Timor Leste (Deichert et al., 2009). In contrast, newer components such as composting or the use of mat or tray nurseries were only adopted by fewer farmers. The application of carefully managed nurseries is a practice that was particularly unknown to Timorese rice farmers until recently, but adoption rates might potentially increase with more experience becoming available. A lagged uptake can be expected for composting, too, as its controlled production takes months even under subtropical climatic conditions.

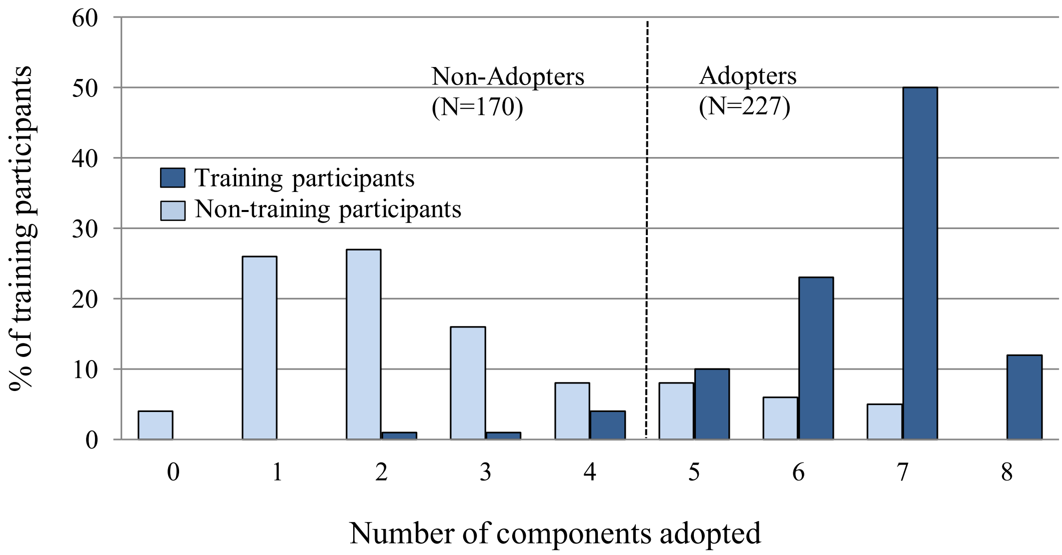
Figure 2. SRI adopters and non-adopters by adoption scores (%)



Source: own survey data. N=397.

In order to classify farmers into SRI adopters and non-adopters, a two-group clustering approach was applied using Stata's partition-clustering method. This method allows group formation based on statistical principles, reducing the dispersion of data within a selected number of clusters to a minimum. Based on this procedure, adoption scores of <5 and >=5 identify non-adopters and adopters, respectively (Figure 2). As a result, 227 farm households were classified as adopters. 22% of these adopter households apply SRI on only some part of their rice areas next to traditional practices on the remaining parts. Highlighting the influence of SRI training indicates that among the training program participants, only 5% had an adoption score of less than 5, meaning that they were non-adopters (Figure 3). On the other hand, 19% of the non-training participants were classified as adopters. Not surprisingly, 79% of the non-training participants who have an adoption score of >=5 take part in the government-promoted hybrid rice program, which has a number of components that are similar to those in SRI. Based on the utilization of hybrid seeds, differences include later transplanting (>15 days), two seedlings per hill instead of one, flooded water conditions and specific recommendations on fertilizer use. In contrast to other rice intensification technologies, varieties are not part of SRI technology; as such, SRI can be fully applied taking hybrid seeds or other improved varieties.

Figure 3. SRI training participants and non-training participants by adoption scores (%)



Source: Own survey data. N=397.

Even though the introduced adoption scores give insights towards the depth of the technology package adopted, it remains unclear which components determine SRI adoption in the given study. As each component is at first assumed to be relevant for SRI in the Timorese context, principal component analysis (factor analysis) allows for the establishment of an index representing the dimensionality of SRI in the Timorese context. Factor loadings are the correlations among the variable and the factor (Table 1). The higher the loading the more powerful is the variable in defining the factor's dimensionality. Results indicate that row planting, distance and single seedlings are the main defining factors for this SRI index, followed by transplanting young seedlings and the use of nurseries. Accordingly, weeding seems to be less specific to SRI as it is applied by most of the households (92%). However, the total number of weedings in one season is significantly different and 1.25 times higher compared to non-SRI plots. Circular re-irrigation and compost application do not have high impacts on defining the index. The components row planting, distance and single seedlings are applied by 100%, 98% and 93% of all adopter households, respectively. 92% of adopter households practise these three components in combination. 81% apply additionally transplanting of young seedlings. 78% of the adopters follow row planting, distance and single seedlings together with weeding and re-irrigation recommendations.

Most farmers in the sample are primarily rice farmers who cultivate additional crops for home-consumption such as cassava, sweet potatoes, and vegetables. Maize is the main secondary cash crop cultivated on the harvested paddy fields which is done by 51% of all interviewed households. Few households cultivate also cash crops like mung beans, soy beans or peanuts. Additionally, nearly all households keep livestock, mainly pigs (89%) and chicken (81%), but also buffaloes and cows (67%) or goats (38%). Except for chicken, livestock is seldom sold but it rather represents an asset which is used for festivities, ceremonies and dowry. Moreover, 46% of the households are at least seasonally involved in non-farm income activities such as construction work, home production, small-scale trading or work as off-farm hired laborers.

Table 2. Summary statistics by households' adoption status

	Means (SD)						
	All		SRI households		Non-SRI households		
Household variables	n=397		n=227		n=170		
Farm and location characteristics							
Total land area (hectare)	1.88	(1.78)	2.05	(1.29)	1.66	(0.95)	**
Total rice area (hectare)	1.27	(0.83)	1.38	(0.89)	1.13	(0.71)	**
HH living in Bobonaro (%)	48.86	(50.05)	59.47	(49.20)	34.71	(48.74)	**
Household and contextual characteristics							
HH size (number of HH members)	6.64	(2.27)	6.73	(2.27)	6.52	(2.29)	
HH head years of schooling (years)	4.09	(4.56)	4.12	(4.52)	4.05	(4.63)	
HH having nonfarm income (yes/no)	46.09	(49.91)	50.66	(50.10)	40.00	(49.13)	*
Access to formal credit sources (%)	11.33	(31.74)	14.09	(34.87)	7.64	(26.65)	*
Participation in SRI training (%)	50.12	(50.06)	83.25	(37.41)	5.88	(23.59)	**
Participation in hybrid programme (%)	16.12	(36.81)	25.11	(43.46)	4.11	(19.92)	**
SRI training participants in village (%)	36.55	(29.42)	46.50	(29.64)	23.27	(23.31)	**

Notes: ** and * denote statistical significance at the 1% and 5% level respectively. Source: Own survey data.

Adopting and non-adopting households differ by farm, household, and contextual characteristics (Table 2). On average, households own 1.88 hectares of land, of which 1.27 hectares are cultivated with rice. SRI adopters own significantly more land and cultivate significantly more rice. It can be assumed that larger farms tend to concentrate more than small farms on lucrative wet rice production, so that they are more eager to adopt innovative intensification strategies. SRI farmers are likely to be located in the district of Bobonaro (59%) as SRI was first introduced in the Maliana valley before extension recently spilled over to the southern district of Covalima. With regard to SRI adoption, besides the starting time of large-scale promotion of SRI and the fact that SRI farms in Bobonaro tend to be slightly larger in Bobonaro compared to Covalima, no fundamental differences can be detected among the two target districts and the target populations accordingly. Even though no significant differences can be found between the groups, overall, low levels of schooling can be considered as a challenge for the diffusion of knowledge-based technologies. On average, the household heads went to school for just about four years, only 36% completed primary school.

The share of SRI adopters, who have nonfarm income and access to formal credit sources such as banks, government programs or credit groups, is also significantly larger than the share of non-adopters. SRI as a low-input system promises to reduce input costs compared to conventional practices. However, SRI components are labor intensive and the costs of hired labor needed on top of the family labor could be an obstacle for adoption. Furthermore, adopters have significantly higher rates of participation in extension programs such as SRI or the hybrid rice training program. The percentage of adopters is also higher in villages with a larger share of SRI training participants, suggesting that there are spill-over effects, for instance through indirect farmer-to-farmer extension.

2.7 Conclusion

SRI is a knowledge-based technology, which consists of different components. In the case considered here it consists of eight components, not all of which are widely adopted yet. Whereas well-known techniques such as row planting and weeding are widely applied in the research area, components that have previously been unknown to farmers, like the use of compost and nurseries, lack widespread implementation. However, compost enriched soils combined with carefully managed seedlings are two key elements for the success of SRI as an integrated sustainable agricultural system. Accordingly, extension training should concentrate especially on these newer components.

Taking empirical data from two districts of Timor Leste the study found high adoption rates among SRI training participants in the selected sample. This supports the assumption that – with proper extension – knowledge-intensive agricultural production systems can be implemented in the Timorese context, which is characterized by low productivity levels and limited availability of high-input technologies. However, land and household characteristics seem to play a role in the adoption decision and thus can be assumed as important influencing factors for large-scale promotion. Owners of larger farms, located in villages where training participation is high, are more likely to adopt the new system. Accordingly, extension services have to find mechanisms on how to encourage small farmers in remote areas to adopt the innovative technology. It can be expected that a successful introduction of knowledge-intensive technologies needs several years until its full implementation.

Further research should focus on the influence of farm and farmer characteristics on the adoption of SRI components. The analysis presented here will be extended by multivariate regression analysis in the following chapters.

3. Understanding the adoption of system technologies in smallholder agriculture: the System of Rice Intensification (SRI) in Timor Leste[2]

Against the background of rising food demand, decreasing productivity growth, and environmental degradation, natural resource management practices have been propagated, especially in a smallholder farm context. However, system technologies, such as the System of Rice Intensification, are often location-specific and characterized by partial adoption and disadoption. Previous studies were often not able to fully explain this, because they mostly relied on farm and household level data, neglecting plot level differences that may be important. We address this limitation, using SRI adoption in Timor Leste as an example. Regression models are specified and estimated to explain farmers' decision-making process.

3.1 Introduction

The rise in global food grain prices continues to threaten food security in many low income countries. Besides wheat and maize, rice is the main affected cereal, which has faced an average price increase of 50% between 2007 and 2010 (Food and Agriculture Organization, 2010). In the Green Revolution period, global rice production had increased remarkably, largely due to the widespread adoption of high-yielding varieties and high-input packages in Asia. While rice production is still increasing, more recently farmers have experienced a downturn in productivity growth, which is partly associated with a loss of soil fertility, salinization, and other forms of land degradation (Foresight, 2011; International Food Policy Research Institute, 2009). Moreover, climate change is expected to lead to higher temperatures, greater water demand by crops, more variable rainfall, and extreme weather events, causing negative effects for agriculture in many regions (International Panel of Climate Change, 2007). Sustainable agricultural

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innovations are needed to meet rising food demand in an environmentally and socially acceptable way.

The system of rice intensification (SRI) could potentially be an approach to increase rice production at affordable costs for small-scale farmers, without harming the environment (Mishra et al., 2007; Stoop et al., 2002). SRI principles focus on neglected potentials to raise yields by changing farmers' agronomic practices towards more efficient use of natural resources (Barah, 2009; Uphoff and Randriamiharisoa, 2002; Zhao et al., 2009). SRI was initially developed in Madagascar, but recently it has been widely promoted also in several Asian countries by governmental and non-governmental organizations (European Technology Assessment Group, 2009). Existing impact studies show mixed results. In some cases, SRI was associated with high rice yields (Anthofer, 2004; Barrett et al., 2004; Senthilkumar et al., 2008), whereas other studies detected no significant yield gains or even negative effects (Dobermann, 2004; McDonald et al., 2006; Tsujimoto et al., 2009). The yield effect seems to depend crucially on the reference system. While SRI may outperform average conventional practices with sub-optimal conditions, McDonald et al. (2006) showed that it is yield reducing compared to conventional best management practices for rice in many regions. Hence, impacts are context specific. Yet, almost all studies on SRI point at positive environmental and resource conserving effects due to reduced use of external inputs. Thus SRI may be suitable for small-scale farmers, who often have limited access to inputs and credit markets.

In this chapter, the focus is not on analyzing impacts of SRI, but on better understanding the factors that influence farmers' adoption decisions. Even though SRI has been widely promoted, partial adoption and discontinuance are commonplace (Moser and Barrett, 2006; Senthilkumar et al., 2008). This may be related to the mixed yield experience. Furthermore, Moser and Barrett (2003) showed that the additional labor requirement associated with SRI may represent a constraint for smallholders facing seasonal labor shortages. As the suitability of SRI is context specific, we hypothesize that additional micro level factors may influence adoption, including the characteristics of individual plots. Understanding these micro level factors is important to design appropriate technology delivery strategies. Beyond SRI, our hypothesis may hold more generally for system technologies. We define a system technology as an integrated innovation to improve agricultural productivity and agroecosystem resilience, involving different agronomic and management components with synergistic relationships, as opposed to a single new high-yielding crop variety for instance. System technologies often focus on general principles rather than standardized practices or specific inputs. Prominent system approaches other than SRI are conservation agriculture, agroforestry, or organic farming. Such technologies have received considerable attention, but many of them have not seen widespread adoption (Knowler and Bradshaw, 2007). Often, system technologies are not only labor intensive, but also knowledge intensive, as synergies between different components have to be understood; this may also require experimentation and adaptation by farmers themselves. Suitable adaptations are location-specific, which complicates farmer-to-farmer transfer of concrete practices and experiences (Giller et al., 2009; Lee, 2005). To control for heterogeneity of agroecological conditions, regional proxy variables are commonly used in adoption research (Doss, 2006). This is insufficient, however, as regional proxies cannot properly capture micro level variation across and also within individual farms.

Here, we address this limitation by using detailed household and plot level data to explain the adoption of SRI among smallholders in Timor Leste. The rest of this chapter is organized as follows. The next section describes SRI and its role in Timor Leste. Section 3.3 presents the analytical framework and describes the data and descriptive statistics. Section 3.4 presents and discusses results from the econometric models, while section 3.5 concludes.

3.2 The System of Rice Intensification in Timor Leste

Agriculture accounts for one-third of gross domestic product in Timor Leste; about 80% of the population are engaged in agricultural activities (Correia et al., 2009). Rice is the main staple food in the country and a widely grown field crop. However, domestic rice production is not sufficient to meet the demand of the fast growing population. The absence of irrigation facilities is one major constraint for increasing productivity beyond the subsistence level (World Food Program, 2005). Timor Leste is a net importer of rice, and these imports are subsidized, entailing a big and rising burden on the government's budget (Ministry of Agriculture and Fisheries, 2008). Against this background, the country is emphasizing strategies to increase domestic rice production and to reduce import dependency, including the promotion of new technologies.

In 2007, SRI was jointly introduced in Timor Leste by the Ministry of Agriculture and Fisheries (MAF) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in two major rice producing districts, namely Bobonaro and Covalima. SRI was chosen for promotion by these organizations, because it may increase yields while addressing constraints of limited water availability. The SRI program was introduced by the national extension service through farmer groups; it covered 35 farmers in 2007, 450 in 2008, and 1,228 in 2009, which is equivalent to 28% of all rice farmers in the two target districts (Deichert et al., 2009). In 2008, SRI was declared a national extension strategy in Timor Leste.

In general, SRI is understood as a set of agronomic and natural resource management principles, without prescribing a standardized toolkit (Stoop et al., 2002). On the one hand, this might seem risky for farmers for whom a fixed technology package may be easier to understand and implement. On the other hand, on-farm participatory experimentation offers opportunities for better adaptation to local conditions, which may reduce adoption risks in the long run. Nonetheless, SRI involves a set of core components, which may be flexibly extended by additional practices. In accordance with the SRI International Network and Resources Center (2011) of the Cornell International Institute for Food, Agriculture and Development, we define the following four components as core SRI components in our context:

- *Intermittent irrigation*. Rice fields should be kept moist but not continuously flooded, in order to minimize anaerobic conditions that hamper the growth of roots and soil organisms.
- *Early transplanting.* Rice seedlings should be transplanted at an age of younger than 15 days, to minimize the transplant shock.
- *Single seedlings.* Rice seedlings should be planted singly to permit better root growth and tillering.
- *Wide spacing.* Rice plants should be planted in square patterns of a minimum distance of 20 x 20 cm, in order to keep all leaves photosynthetically active.

We define farmers as SRI adopters only when they have adopted all four core components. SRI-Rice also defines organic fertilization as an essential SRI component. The use of compost or manure stimulates growth-promoting bacteria in the soil (Mishra et al., 2007). However, this has not yet been an important element in the Timorese program, so that we do not consider organic fertilization as a core component in this analysis. Additional recommended practices include the establishment of carefully managed mat or tray nurseries and regular weeding (Glover, 2011a; McDonald et al., 2006). Weeding is more important in SRI than in traditional rice, because weeds spread more rapidly under non-flooded conditions. Hence, weeding is strongly related to intermittent irrigation, but it is not defined as a core component itself by SRI-Rice.

All different components involve synergistic effects, which may vary from one place to another (Glover, 2011a). Therefore, it is necessary for farmers to adapt the general principles to local conditions, which requires detailed knowledge not only on 'how to do it' but also on 'why to do so'. Understanding this enables farmers to make important decisions on aspects such as optimal water levels, planting distance, or timing of transplanting. Good extension and training programs are likely to increase farmers' ability to adopt SRI successfully.

3.3 Materials and Methods

3.3.1 Analytical Framework

For our analysis of farmers' adoption behavior we assume that the farm household is maximizing utility. For the decision whether or not to adopt, the expected utility of SRI is compared to the expected utility of conventional practices subject to individual resource endowments and other constraints (Feder et al., 1985). Agricultural technology adoption has been studied extensively in the literature (Byerlee and de Polanco, 1986; Feder et al., 1985). Often, adoption is not simply a yes/no decision. For instance, farmers may decide to adopt a certain innovation but only apply it on a part of their land, or, when several components are involved, they may decide to use only certain components but not others (Leathers and Smale, 1991; Smale et al., 1995). While most adoption studies have used binary adoption models (Doss, 2006), there are also some that have analyzed adoption intensity with continuous models (Just and Zilberman, 1983; Sall et al., 2000) or the adoption of package components with count data approaches (Lohr and Park, 2002; Sharma et al., 2011).

The adoption decision is a process that extends over a certain period of time, from hearing about the technology for the first time to actual uptake. This holds true in particular for knowledge-intensive system technologies such as SRI. In our modeling approach, we assume that this adoption process involves different decision stages. For SRI adoption, there are two decision stages: first, the farmer decides whether or not to adopt the technology with all its four core components (status of adoption); second, the acreage on which SRI shall be used is determined (intensity of adoption). In addition, we want to understand what drives partial adoption, involving the decision about how many of the four core components to use on a given plot (depth of adoption).

Studies about SRI in Madagascar have focused primarily on the status and intensity of adoption (Moser and Barrett, 2003, 2006), while the depth of adoption has been disregarded. This is considered a drawback, because the SRI components are assumed to have synergistic effects (Stoop et al., 2002). Even though empirical evidence about the concrete relationships between different components is limited, several studies showed that non-adoption of some of the core components may change the outcome significantly (Ceesay et al., 2006; Mishra and Salokhe, 2008, 2010). In our study in Timor Leste, we analyze all three decision stages – status, intensity, and depth of adoption – using two different specifications of a double-hurdle model. The first model considers the household level, where farmers decide about the status and intensity of SRI adoption. The depth of adoption cannot be modeled at the household level, because the number of SRI components applied may vary from one plot to another on the same farm, depending on plot characteristics. Therefore, the second model considers the plot level, where farmers decide about the number of core components to apply, if any.

At the household level, two decision stages (hurdles) have to be passed, namely adoption status and intensity. Oftentimes, the two hurdles are estimated separately using a binary outcome model for the first and a Tobit model for the second stage. However, a Tobit specification implicitly assumes that the value of the dependent outcome variable y (adoption acreage), given that $y > 0$, and the choice of $y > 0$ are determined by the same underlying process, which may or may not be true. The double-hurdle model, a generalized Tobit specification, is able to overcome this potential restriction by accounting more flexibly for the two sequential decisions (Cragg, 1971). A probit model estimates the probability that a household will adopt SRI, while a truncated normal model estimates the intensity of adoption. A double-hurdle model has recently been used by Langyintuo and Mungoma (2008) in an agricultural technology adoption context.

Let $y_{i1}^{*} = x_i'\alpha + u_i$ represent the binary decision to adopt SRI, whereas the decision on how much land to allocate to SRI can be described as $y_{i2}^{*} = z_i'\beta + v_i$. In these specifications, y_{i1}^{*} and y_{i2}^{*} are the two latent variables of status and intensity, x_i and z_i are vectors of household variables determining the decisions, and α and β are coefficients to be estimated. u_i and v_i represent the respective error terms, which are assumed to be independent and distributed as $u_i \sim N(0,1)$ and $v_i \sim N(0, \sigma^2)$. The likelihood function for this double-hurdle model can then be written as (Jones, 1989):

$$L(y_i|x_i,\theta) = \prod_{y_i=0}[1 - \Phi\left(\frac{x_i\alpha}{\sigma_u}\right)]\Phi\left(\frac{z_i\beta}{\sigma_v}\right)$$

$$\times \prod_{y_i>0}\Phi\left(\frac{x_i\alpha}{\sigma_u}\right)\Phi(\frac{z_i\beta}{\sigma_v})\frac{\phi[(y_i - z_i\beta)/\sigma_v]}{\sigma_v\Phi(z_i\beta/\sigma_v)} \tag{1}$$

where ϕ and Φ are the probability density and cumulative distribution functions of the normal distribution, and σ_u and σ_v are the standard deviations of u_i and v_i, respectively. The first term estimates the status of y_i, whether $y_i = 0$ or $y_i > 0$. The second term estimates the intensity, that is, the exact value of y_i if $y_i > 0$. In order to assess the impact of the independent variables towards adoption, marginal effects are estimated following Burke (2009). They refer to the main outcome scenarios if one or both hurdles are passed by the farmer: the decision to adopt, the conditional average partial effect (CAPE) if the initial adoption decision is positive, and the unconditional average partial effect (UAPE) as the combined effect of both decision stages.

At the plot level, the study focuses on the depth of adoption, explaining the number of SRI core components applied. This is a count variable, so that some model adjustments are necessary for reliable estimates (Holmes and Englin, 2010; Martínez-Espieira and Amoako-Tuffour, 2008). We use a count data framework developed by Mullahy (1986) for the double-hurdle specification. Similar to the approach above it is assumed that the two decisions involved – whether to adopt any and, if so, how many SRI components – are not necessarily determined by the same process (Cameron and Trivedi, 2005). For crossing the first hurdle of $y > 0$, farmers have to report at least one adopted core component. This can be estimated by a binomial probability model. In the second hurdle, a conditional distribution refers to actual positive outcomes between 1 and 4 through a truncated count data specification, given that $y > 0$ (Greene, 2005). Apart from this change, the count data double-hurdle model can be estimated with a two-part likelihood function, as shown in equation (1) (Burke, 2009; Jones, 1989; Mullahy, 1986).

3.3.2 Data and descriptive statistics

Data for this study were collected through a comprehensive household survey conducted in Timor Leste in late 2009. Households were selected using a stratified random sampling procedure. First, all rice-farming households in Bobonaro and Covalima, the two districts where SRI was initially introduced, were listed and stratified into participants and non-participants of SRI training. This led to lists with 1228 training participants and 3220 non-participants. Second, from each group, 200 households were randomly selected. We purposively over-sampled training participants in order to improve estimation efficiency. Out of the total of 400 selected households, 397 could be interviewed. Additionally, detailed plot level data were collected. Because many farmers had more than one rice plot, we collected data for a total of 475 plots. Together with the farmers, we visited all plots to collect data on location, slope, and irrigation conditions and to draw soil samples.

In this chapter we classify rice plots as SRI plots when farmers have adopted all four core components, namely (1) intermittent irrigation, (2) early transplanting, (3) single seedlings, and (4) wide spacing (Table 3). Whereas intermittent irrigation has been adopted on 75% of all sampled plots, the other three core components have sample adoption rates of around 50%. The more widespread adoption of intermittent irrigation is not surprising, as this practice saves water, and water shortage is a critical constraint in Timor Leste. Even before SRI training started, water scarcity had forced some farmers to grow rice under non-flooded conditions, which has probably facilitated SRI acceptance in the study region. The adoption of additional recommended practices, such as nursery management, compost application, and regular weeding, is also shown in Table 3, but these are not considered further in the subsequent analysis.

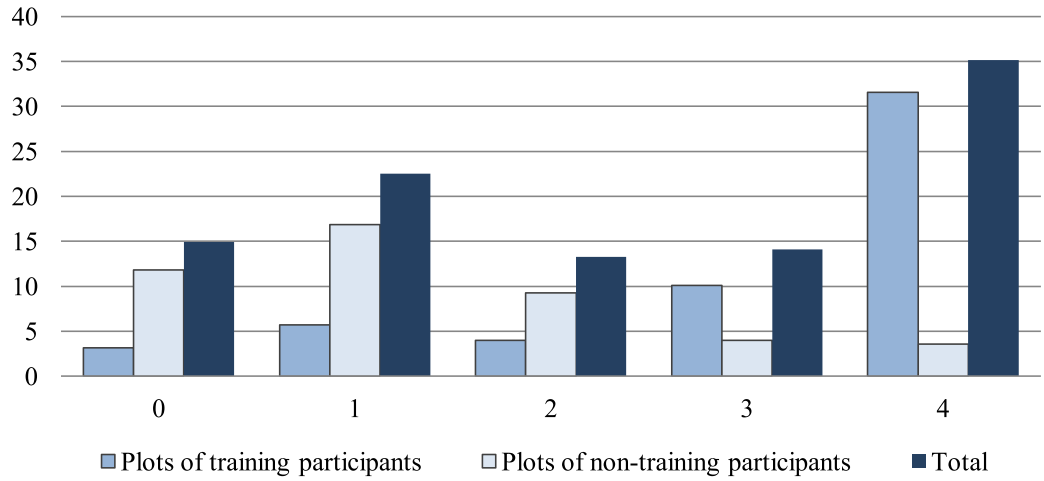
Table 3. Adoption of SRI components per plot (%)

Components		Description	%
Core components			
1	Intermittent irrigation	Fields kept moist but not continuously flooded	74.89
2	Early transplanting	Transplanting rice seedlings younger than 15 days	52.00
3	Single seedlings	Only one seedling is planted per hill	48.42
4	Wide spacing	Minimum planting distance of 20 x 20 cm	57.68
Additional components			
5	Nursery	Carefully managed mat or tray nurseries	34.52
6	Compost	Applications of organic material on plots	11.15
7	Weeding	Regular weeding, manually or with hand weeders	89.26

Source: Own survey data. N=475.

Around 20% of all sample households cultivate more than one rice plot. For the analysis, all households with at least one SRI plot are defined as SRI farmers. This leads to 159 (40%) households that practice SRI on 167 (35%) plots, indicating that some SRI farmers have more than one SRI plot. Moreover, 18% of all SRI households have at least one additional non-SRI plot, underlining that the analysis of plot level characteristics may be of particular interest. The sample adoption rates also reveal that we cannot simply assume training participants to be SRI adopters and non-participants to be non-adopters. Obviously, some training participants have not adopted, or have adopted only partially, while some non-participants have fully adopted SRI (Figure 4).

Figure 4. Number of SRI components adopted on plots (in %)



Source: Own survey data.

In terms of socioeconomic characteristics, Table 4 shows that sample farmers are primarily small-scale rice growers with a total average farm size of less than two hectares. Farm size refers to the area owned by the household, which is slightly larger than the area cultivated, because the housing area and uncultivable patches are also included. A land rental market or sharecropping arrangements hardly exist in the study area. In addition to rice, secondary field crops such as cassava, maize, mung beans, soybeans, and vegetables are grown. Other farm activities include livestock and agroforestry-type systems. A comparison between SRI adopters and non-adopters reveals significant differences in some of the farm and household characteristics. On average, adopters own larger farms, cultivate a bigger rice area, and have a higher participation rate in extension training. Participation in SRI training involves the attendance of farmers in regular group meetings. Even though some farmers may attend training only until they are fully able to implement the technology on their own, participants are generally encouraged to periodically return to the group meetings in order to share their experience. Table 4 also shows that SRI adopters are found more commonly in villages where the overall participation rate in training programs is higher. This is related to the fact that extension services started SRI training in a few pilot villages. Most of these villages are located in Bobonaro, where SRI was introduced first.

For other household variables, no significant differences between SRI adopters and non-adopters are observed, although they may still play a role in the adoption model. Table 2 shows average household size in terms of the number of household members, defined as all people who usually eat from the same pot and sleep under the same roof. However, more important for SRI adoption may be the number of household members of working age (18-65 years), as this is an indicator of family labor availability. Labor is sometimes hired in for plowing, harvesting, and threshing, but not for farm operations specifically related to SRI. The distance to the nearest agricultural input market, where farmers can purchase seeds, equipment, and fertilizer, might affect the adoption of low-input technologies like SRI positively. Access to formal credit may also play a role; this was elicited during the interviews by asking farmers whether they can obtain credit from banks, cooperatives, or state agencies, when they need. We also asked for non-farm income, which was shown to influence innovation adoption in other studies. Non-farm income here includes all non-farm activities such as non-agricultural self-employment, wage labor, or transfers.

The lower part of Table 4 shows plot level characteristics. SRI is adopted more on plots located near to the homestead, measured as the time it takes farmers to reach the plot. SRI is also practiced more on plots with a technical irrigation system. Technical irrigation systems in the research area are characterized by permanent irrigation infrastructure with tertiary water supply channels, locks, and separate drainpipes. These systems were established and are maintained by government agencies. Water application to rice plots is sometimes dependent 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. Hence, we also asked farmers whether individual control over water management is possible for them, which appears to matter for SRI adoption.

All plots without a technical irrigation system are rain-fed. The rainy season in Timor Leste occurs mainly from November to April. On average, water for irrigation is available during five months, so that there is only one wet rice season per year. As can be seen, SRI tends to be adopted more on plots that have shorter than average water availability, as the technology is expected to require less water than the traditional method of continuous flooding. Plot slope is another attribute relevant for water control.

There are no rice plots with steep slopes in the sample, but we distinguish between plots which are fully leveled (flat) and plots with slight slopes. This classification is based on farmers' own statements combined with a visual plot inspection during the survey. The share of plots with slight slopes is significantly larger for SRI than for conventional rice.

Concerning soil quality, existing adoption studies often use variables based on farmer-reported categories (Marenya and Barrett, 2009). However, since different dimensions of soil properties may potentially matter for SRI adoption, we decided to draw soil samples for more detailed analysis. Soil samples were collected from one randomly drawn point on each plot. As plot sizes are small, we do not expect large variations in soil properties within plots. While farmer perceptions about soil characteristics may sometimes differ from laboratory measurements, we expect a good correlation, because we only used very simple testing procedures in field laboratories, such as structure and saturation tests as well as pH and electric conductivity tests. Electrical conductivity, which is affected by a wide range of soil attributes, such as clay content, temperature, organic materials, and salinity (Ezrin et al., 2009), ranges from 0.36 to 6.87 mS/cm, with an average value of 2.31mS/cm.

Table 4. Descriptive statistics – household and plot level characteristics

	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)	**
Share of rice in total cultivated land (%)	71.79	(23.80)	72.66	(24.81)	71.21	(23.14)	
Number of buffaloes owned	1.34	(4.09)	1.30	(3.73)	1.35	(4.32)	
HH living in Bobonaro (%)	48.86	(50.05)	56.60	(43.92)	43.69	(49.70)	**
Distance to nearest input market (km)	3.87	(4.25)	3.21	(4.26)	4.00	(4.26)	
Household characteristics							
HH head age (years)	45.89	(12.81)	46.81	(11.89)	45.27	(13.37)	
HH head years of schooling (years)	4.09	(4.56)	4.03	(4.52)	4.13	(4.59)	
HH size (number of HH members)	6.64	(2.27)	6.73	(2.23)	6.58	(2.31)	
HH members of working age (number)	3.21	(1,52)	3.20	(1.53)	3.21	(1.51)	
Financial capital							
HH having nonfarm income (%)	46.09	(49.01)	47.79	(50.10)	44.95	(49.84)	
HH nonfarm income (in thousand US$)	0.77	(3.27)	1.12	(4.91)	0.52	(1.23)	
Access to formal credit (%)	11.33	(31.74)	11.94	(32.53)	10.92	(31.26)	
Social capital and contextual variables							
Participation in SRI training (%)	50.12	(50.06)	88.67	(31.78)	24.36	(43.02)	***
SRI training participants in the village (%)	36.55	(29.42)	45.13	(28.45)	30.82	(28.71)	***
Natural disaster caused rice yield failure of more than 50% (in the last 5 years) (%)	70.27	(45.76)	71.69	(45.19)	69.32	(46.21)	
Accident/illness caused labor inability of an adult member of HH (in the last 5 years) (%)	13.35	(34.05)	10.06	(30.17)	15.54	(36.31)	
Plot level characteristics	n=475		n=167		n=308		
Technical							
Plot slope (0=flat, 1=slight slope)	0.10	(0.30)	0.14	(0.35)	0.08	(0.27)	**
Technical irrigation system (%)	87.37	(33.26)	98.20	(13.32)	81.33	(39.02)	***
Length of irrigation period (months)	5.09	(3.24)	4.57	(3.07)	5.40	(3.29)	***
Time to plot from house (hours)	0.57	(0.62)	0.50	(0.54)	0.60	(0.66)	*
Control over water management possible (%)	88.34	(32.13)	98.00	(15.38)	83.16	(37.48)	***
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)	
Loam (%)	67.81	(16.24)	66.67	(16.37)	68.43	(16.14)	
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)	

*,**,*** The difference between SRI and non SRI is statistically significant at the 10%, 5%, and 1% level, respectively. Note: HH means household. Source: Own survey data.

3.4 Results and discussions

This section presents the estimation results from the econometric models introduced in subsection 3.1. At first, the specifications of both double-hurdle models are tested before the determinants of adoption status, intensity, and depth are discussed.

3.4.1 Model specification tests

In order to justify the use of the models as outlined in subsection 3.1, the chosen specifications are tested against their alternatives. As mentioned, the first double-hurdle model is a generalized Tobit specification. This implies that a Tobit model is nested in the double-hurdle model, so that we tested against the Tobit alternative using a likelihood-ratio (LR) test (Greene, 2008). The test results, which are shown in Table 5, reject the null hypothesis that the Tobit model is appropriate and indicate that the estimated double-hurdle model is preferred.

Because count data are highly non-normal, a Poisson hurdle model was specified to estimate adoption depth. In the first step, the Poisson model is compared to the alternative Negative Binomial Regression Model (Cameron and Trivedi, 2001; Long and Freese, 2001). No over-dispersion of the data can be detected, and the estimated coefficient, which reflects unobserved heterogeneity among observations, is not significantly different from zero, suggesting that the Poisson is appropriate. In the second step, the logit-Poisson hurdle model is tested against a single Poisson regression. Using an LR test, the Poisson regression model is rejected, and the double-hurdle model is found appropriate (Table 5).

Table 5. Specification tests

LR statistic ($\chi2$)	Critical value ($\chi2$)	Conclusion
LR test against Tobit specification (H_0=Tobit is appropriate)		
252.94	22.36	H_0 rejected
LR test against Poisson specification (H_0=Poisson is appropriate)		
43.35	26.30	H_0 rejected
Wald test (H_0=restricted model solely based on household level attributes is more appropriate)		
78.45	21.03	H_0 rejected

Source: Own survey data.

3.4.2 Adoption status and intensity at household level

The estimation results on adoption status and intensity are presented in Table 6. The unit of observation is the household. In addition to the estimation coefficients shown in the first two columns, marginal effects are presented in the last three columns. They can be interpreted as the probability of having a non-negative outcome in the first stage and a conditional positive outcome in the second stage.

The number of household members of working age has no significant effect on the first stage decision, whether or not to adopt SRI with its four core components on at least one plot. But it determines the intensity of adoption, measured as the area under SRI. Having more family labor available increases the area under SRI significantly. The UAPE, which is the combined effect of both decision stages, shows that having one additional working age household member increases the SRI area by almost 0.05 hectares. This is due to the higher labor requirement of the new technology. Especially in the initial phase of SRI adoption, farmers depend on family labor, which cannot easily be replaced by hired labor, because of specific knowledge, training, and experience required. In the training sessions, farmers are advised to first gain experience with SRI themselves, before involving hired laborers.

Farm size affects both decision stages positively and significantly. Conditional on a positive outcome of the first decision stage, each additional hectare of land owned increases the SRI area by 0.57 hectares, whereas the UAPE is 0.27. While SRI is scale neutral as such, larger farmers are often found to be among the early adopters of new technologies, because greater endowment with land and other assets tends to reduce risk aversion and increase openness for innovation (Just and Zilberman, 1983). Learning how to properly use a new technology represents a fixed cost, which is more worthwhile to invest in with a larger farm size. The coefficients for share of rice in total cultivated land are also positive and significant; increasing the share by 1% leads to a 0.01 hectare increase in the SRI area, implying that rice farmers with a higher degree of specialization are more eager to adopt the new technology.

Table 6. Maximum likelihood estimates and marginal effects for status and intensity of adoption

Variable	Maximum likelihood estimates		Marginal effects		
	Decision to adopt SRI	Decision on SRI acreage	Decision to adopt SRI	Decision on SRI acreage	
				CAPE[a]	UAPE[a]
HH members of working age (number)	0.0650	0.0700***	0.0237	0.0626	0.0451*
	(0.0559)	(0.0220)	(0.0203)	(0.0503)	(0.0256)
HH head age (years)	-0.0024	-0.0035	-0.0009	-0.0031	-0.0019
	(0.0079)	(0.0032)	(0.0029)	(0.0037)	(0.0027)
HH head years of schooling (years)	-0.0142	-0.0005	-0.0052	-0.0004	-0.0045
	(0.0203)	(0.0083)	(0.0074)	(0.0055)	(0.0066)
Total land area owned (ha)	0.1204*	0.6368***	0.0439*	0.5698***	0.2674***
	(0.0725)	(0.0267)	(0.0264)	(0.0757)	(0.0469)
Share of rice in total cultivated land (%)	0.0063*	0.0233***	0.0023*	0.0208***	0.0104***
	(0.0035)	(0.0014)	(0.0013)	(0.0016)	(0.0015)
Number of buffaloes owned (number)	-0.0243	0.0093	-0.0088	0.0083	-0.0039
	(0.0211)	(0.0083)	(0.0077)	(0.0073)	(0.0060)
HH having nonfarm income (dummy)	-0.2159	-0.0342	-0.0782	-0.0306	-0.0780
	(0.1635)	(0.0679)	(0.0589)	(0.0453)	(0.0535)
Access to formal credit (dummy)	-0.0780	0.0304	-0.0284	0.0272	-0.0126
	(0.1579)	(0.0643)	(0.0573)	(0.0549)	(0.0564)
Distance to nearest input market (km)	0.0189	-0.0049	0.0069	-0.0044	0.0039
	(0.0185)	(0.0073)	(0.0067)	(0.0052)	(0.0061)
Natural disaster (dummy)	-0.0514	-0.0923	-0.0188	-0.0825	-0.0490
	(0.1757)	(0.0729)	(0.0646)	(0.0521)	(0.0572)
Accident/illness (dummy)	-0.2808	0.0789	-0.0972	0.0705	-0.0567
	(0.2366)	(0.1042)	(0.0771)	(0.0733)	(0.0837)
Participation in SRI training (dummy)	2.0012***	0.0048	0.6401***	0.0042	0.6102***
	(0.1712)	(0.0999)	(0.0392)	(0.0876)	(0.0426)
HH living in Bobonaro (dummy)	0.2690*	0.0714	0.0979*	0.0638	0.1076**
	(0.1607)	(0.0673)	(0.0571)	(0.0607)	(0.0540)
Constant	-2.1175***	-1.6822***			
	(0.5307)	(0.2552)			
Sigma		0.3567***			
		(0.0215)			
Observations	397	397	397	397	397
Log-Likelihood		-219.1701			

*,**,*** significant at the 10%, 5%, and 1% level, respectively. Notes: Robust standard errors are shown in parentheses (bootstrapped for marginal effects); HH means household. [a]CAPE=Conditional average partial effect, UAPE=Unconditional average partial effect. Source: Own survey data.

Most of the other household level characteristics do not influence SRI adoption significantly. For education, this may be unexpected, given that SRI is a knowledge-intensive technology. But with an average of only four years of schooling completed, household heads have relatively low educational levels in any case, and the knowledge acquired in local primary schools may not be very relevant for rice farming. For the other variables, the insignificant results are not surprising, because – apart from the higher labor needs – SRI is a low-external input technology, so that it does not necessarily depend on access to credit or market proximity. In order to avoid potential simultaneity bias, we only included variables which are time-invariant or very unlikely to be jointly determined with SRI adoption. For example, instead of non-farm income in monetary terms, which could potentially change through SRI adoption, we use a non-farm income dummy, which is much less likely to be affected.

Another explanatory variable of interest is participation in SRI training. As explained above, group training sessions are organized by the national extension service. Participation in SRI training increases the likelihood of SRI adoption by 64 percentage points, suggesting that the training sessions are effective in terms of promoting the spread of this technology. The intensity of adoption is not significantly affected. The training participation variable could potentially be endogenous, as farmers may self-select into training. However, if there should be a self-selection problem, this is expected to be small. Farmers were invited collectively to SRI training sessions through public announcements at the sub-village level. No selection criteria were used by the program, and the great majority of farmers who were invited to the initial meetings have continuously participated in group sessions, implying that there are hardly any drop-outs. Nonetheless, to test for systematic bias, we also estimated the model without the potentially endogenous training variable (Table A1). The coefficients of the remaining variables are hardly affected in terms of their signs and significance levels. Hence, even if the training variable was endogenous, the other estimates would still be reliable.

Overall, the analysis so far indicates that household level factors can explain SRI adoption patterns only up to a certain extent. As mentioned above, we hypothesize that there are additional, more location-specific determinants of adoption, which we analyze in the following using plot level data.

3.4.3 Adoption depth at plot level

In the previous subsection, farmers had to pass two sequential decisions to report a positive outcome of SRI area. However, SRI involves several components, and partial adoption is commonplace. In this respect, it is crucial to understand why farmers are adopting only some but not all of the four core components. A higher number of components adopted is likely to improve performance due to synergistic effects. Adoption depth can only be analyzed at the plot level, because – as was mentioned above – many farmers have more than one rice plot, and adoption depth may differ from one plot to the other. As explained in subsection 3.1, we consider a decision process, where farmers decide whether or not to use any SRI component on a given plot, before they decide how many components to use. For the estimation of this double-hurdle model, we use a household cluster correction procedure to obtain reliable standard errors, thus relaxing the assumption that all plot observations are independent. The results are shown in Table 7.

The time needed to reach the plot from the homestead has an influence on the number of SRI components applied. If the time increases, meaning that plots are located further away, fewer SRI components are adopted. Table 4 showed that the mean travel time to reach a plot is about 0.6 hours. The marginal effect in Table 7 implies that doubling this time (adding another 0.6 hours) would decrease the number of adopted components by 0.17 on average. This is not a very large effect, but it is highly significant, which also makes intuitive sense. Especially during the early adoption stages, experimentation and monitoring of the effect of every single component is useful to gain experience and improve performance. This requires frequent plot visits, so that longer travel times discourage the adoption of additional components.

The most important SRI core component in the study area is intermittent irrigation. As mentioned above, this has been adopted more widely than the other core components. Intermittent irrigation requires continuous labor input throughout the rice season, as farmers have to control water levels almost daily. The estimation results show that both decision stages are significantly influenced by the existence of a technical irrigation system on the plot. Conditional on the first stage being positive, having a technical irrigation system on the plot increases the number of adopted SRI components by 0.5.

While there may be concerns of reverse causality, this is not a problem here, because all technical irrigation systems were established by government agencies before the introduction of SRI in 2007. The results in Table 7 also demonstrate that individual control over water management fosters adoption of the first SRI component, which in most cases is intermittent irrigation. Yet the adoption of additional core components is not significantly influenced by the ability to control water individually.

Table 7. Maximum likelihood estimates and marginal effects for depth of adoption

Variable	Maximum likelihood estimates		Marginal effects	
	Decision to adopt any SRI core component	Decision on number of components	Decision to adopt any SRI core component	Decision on number of components
Time to plot from house (hours)	0.0192	-0.1160***	0.00187	-0.2863***
	(0.2842)	(0.0450)	(0.0253)	(0.1109)
Plot slope (dummy)	0.7777	0.1957***	0.0694	0.4831***
	(0.6981)	(0.0741)	(0.0615)	(0.1827)
Technical irrigation system (dummy)	1.7532***	0.2042**	0.1565***	0.5042**
	(0.4265)	(0.0917)	(0.0368)	(0.2275)
Length of irrigation period (month)	-0.0478	0.0016	-0.0042	0.0041
	(0.0501)	(0.0087)	(0.0045)	(0.0214)
Control over water management (dummy)	1.2022**	0.0673	0.1073**	0.1662
	(0.4656)	(0.0987)	(0.0405)	(0.2437)
Conductivity (mS/cm)	-0.4892***	0.0003	-0.0436***	0.0007
	(0.1520)	(0.0261)	(-0.0136)	(0.0646)
Loam (%)	0.0299**	-0.0008	0.0026**	-0.0019
	(0.0121)	(0.0017)	(0.0010)	(0.0042)
HH members of working age (number)	0.3198**	-0.0228	0.0285**	-0.0563
	(0.1255)	(0.0232)	(0.0109)	(0.0572)
HH head age (years)	-0.0031	0.0009	-0.0002	0.0024
	(0.0145)	(0.0022)	(0.0013)	(0.0056)
HH head years of schooling (years)	0.0296	-0.0007	0.0027	-0.0018
	(0.0412)	(0.0061)	(0.0036)	(0.0151)
Total land area owned (hectare)	-0.1885	0.0317*	-0.0168	0.0782*
	(0.1261)	(0.0161)	(0.0113)	(0.0395)
Share of rice in total cultivated land (%)	-0.0102	0.0013	-0.0009	0.0033
	(0.0067)	(0.0010)	(0.0006)	(0.0025)
Number of buffaloes owned (number)	-0.0150	-0.0141**	-0.0014	0.0349**
	(0.0431)	(0.0061)	(0.0038)	(0.0161)
HH having nonfarm income (dummy)	0.6702**	-0.0579	0.0598**	-0.1429
	(0.3371)	(0.0498)	(0.0300)	(0.1227)
Participation in SRI training (dummy)	2.1047***	0.8520***	0.1879***	2.1029***
	(0.3489)	(0.0855)	(0.0321)	(0.1917)
Constant	-2.2117	0.0579		
	(1.5017)	(0.2161)		
Observations	446	380	446	380
Log-Likelihood (full model)		-692.8539		

*,**,*** significantly at the 10%, 5%, and 1% level, respectively. Notes: Robust standard errors in parentheses. HH means household. Source: Own survey data.

Also related to water control is leveling of the rice fields. As mentioned above, we differentiate between completely flat plots and plots with a slight slope. Slight slopes influence the depth of adoption significantly. This is plausible, because slopes make continuous flooding difficult. Accordingly, these plots are preferred for adoption of SRI, where soils should be kept moist but not continuously flooded. In terms of the length of water availability, no significant effects are found in both decision stages, even though the descriptive analysis above indicated that SRI is applied more on plots with shorter periods of water availability. Concerning soil conditions, higher conductivity influences the probability of adopting any SRI component negatively. As salinity and electronic conductivity are positively correlated, and many of the sampled rice plots are located near the coastline, high conductivity levels are an indication of higher salt contents. Farmers seem to prefer plots with lower salinity for SRI adoption. In contrast, higher loam contents increase adoption probability. Compared to sandy soils, loam has higher nutrient potential and superior water holding capacity, which is conducive for keeping soils moist under non-flooded conditions. Other soil characteristics were not included in the model due to collinearity.

In addition to plot level characteristics, farm and household variables are included to control for socioeconomic effects on plot level outcomes. Similar to the household level results discussed above, availability of family labor plays a significant and positive role for adoption. Likewise, participation in SRI training increases adoption, with significant effects in both decision stages.

Overall, the analysis confirms that plot level characteristics are important determinants of SRI adoption. Plot characteristics also help to explain partial adoption of individual SRI components. As plot characteristics may vary even within individual farms, household level analysis is insufficient to fully understand adoption patterns. To further underline this finding, we implemented an additional specification test for the adoption depth model. We used a Wald test to compare the unrestricted model, including both household and plot level variables, with a restricted model containing household level attributes only. The results of this test are shown in the last row of Table 3; they indicate that the unrestricted model is the preferred specification. Significant differences in some of the household level parameter estimates point at potential omitted variable bias when plot level characteristics are not included.

3.4.4 Limitations

We have analyzed important aspects of SRI adoption, extending the existing literature by using plot in addition to household level data and focusing on adoption intensity and depth in addition to mere adoption status. In this chapter, we did not analyze adoption impacts in terms of productivity or household welfare, so that the results do not allow statements about whether or not a more widespread adoption of SRI is actually desirable. Of course, such impact assessment is important for policy making, and will be addressed in the following chapter. Nevertheless, this adoption research has some value on its own, because SRI is already being widely promoted by different organizations in Timor Leste and elsewhere, so that better knowledge of adoption determinants can help to improve the design of dissemination strategies. As mentioned, partial adoption and discontinuance are commonplace, but reasons are not yet fully understood.

The adoption analysis itself also has a few shortcomings. For instance, while we focused on adoption depth, we did not explain why individual components, or specific combinations of components below full SRI adoption, are adopted and others are not. Nor did we look explicitly at the factors that drive the adoption of additional recommended practices beyond the four SRI core components. Such details are beyond the scope of this study, but they may be relevant for some policy decisions and could be addressed in further research. Another interesting direction of future research on SRI adoption could be a more detailed analysis of information flows. While we identified the extension service with its special SRI group training sessions as an important driver of SRI adoption in Timor Leste, it is well known that farmers also rely a lot on information obtained from other farmers and their wider social network. Through a better understanding, technology delivery programs could build on such informal information flows and thus be made more efficient. Conley and Udry (2001) and Matuschke and Qaim (2009) have tried to capture the role of farmers' social networks in quantitative adoption research. Qualitative approaches, for instance using participant observations or focus group discussions, could also be very useful.

3.5 Conclusion

We have analyzed determinants of SRI adoption in Timor Leste, building on detailed data collected from small-scale farmers in 2009. SRI adoption patterns vary substantially, and partial adoption is commonplace. Econometric analysis showed that household level variables that influence adoption include farm size, availability of family labor, and participation in specific training programs. SRI is a knowledge-intensive technology and requires higher labor inputs. Especially in the early phase of adoption, when farmers have to get acquainted with the new system and its local adaptation, family labor cannot easily be replaced by hired labor. Yet, we also found that household level characteristics alone are insufficient to explain observed adoption patterns. Several plot level variables have a significant effect on SRI adoption and the number of different SRI components used. The relevance of plot level variables to explain adoption may also hold for other system technologies.

The availability of an irrigation system, which can be controlled individually by the farmer, is an important determinant of SRI adoption on a particular plot. Because water scarcity is a major constraint in the study area, innovative strategies to reduce water usage are attractive for local rice farmers. The practice of intermittent irrigation is used even beyond the group of SRI training participants and can be considered as a stepping stone towards more widespread SRI adoption. Thus, factors that determine the use of intermittent irrigation may indirectly affect the adoption of other SRI core components, too. Hence, the establishment of improved irrigation systems would be conducive for more widespread SRI adoption. Close proximity of a plot to the homestead also has a positive effect on adoption, as this facilitates experimentation and monitoring. Moreover, compared to conventional practices, more frequent visits to SRI plots are required for regular water control. Improved rural infrastructure would help facilitate plot access and thus SRI adoption. Other plot characteristics that influence adoption include soil conductivity, loam content, and slope. Such characteristics may vary not only across farms but also within individual farms, underlining that the commonly used farm and household level data are insufficient to understand the adoption of system technologies with location-specific features.

Our results also imply that system technologies have to be adapted to site-specific conditions. It is not yet fully known how the expected synergies between different SRI components evolve when plot level parameters change. While some experimentation by farmers is required and desirable, expecting too much from the adopters themselves can also lead to frustration and disadoption. Technological experimentation requires comprehensive knowledge, substantial input of management time, and it involves a considerable amount of risk. Hence, extension efforts should focus more on strategies towards adapting system technologies to various plot level conditions. For this, training programs have to be sufficiently flexible and location-specific, which requires new skills for training and extension agents, including experience with participatory learning. Without extension programs that are much better equipped in terms of human and financial capital, widespread and successful adoption of system technologies is unlikely to happen among smallholder farmers. Further research is needed to analyze the impacts of SRI adoption and the costs and benefits of different policy strategies.

4. Impacts of system technologies on agricultural yield and household income: the System of Rice Intensification (SRI) in Timor Leste

System technologies, such as the System of Rice Intensification, have been proposed to tackle agricultural challenges such as decreasing productivity growth and environmental degradation. Yet, the benefits for farmers are often debated and 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. In this chapter we analyze the impacts of SRI adoption on rice yield and household income. Heterogeneity is accounted for in an endogenous switching regression framework.

4.1 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 has 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 growth has 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 (NRM) technologies have been proposed to improve the efficiency of cropping systems in a systemic and sustainable way (Altieri, 2002; Rammel, 2007). Accordingly, the term system technology is also used here. System technologies build on integrated agronomic principles, responding to a wide range of challenges in different environments. Prominent approaches are conservation agriculture, agroforestry, and organic farming, which have raised considerable attention over the last few decades (Knowler and Bradshaw, 2007; Rigby, 2001). Related approaches reduce the use of external inputs such as fertilizer by enhancing the potential of locally available resources through improved management practices (Altieri, 2002). Unlike standardized input-packages, system technologies involve adaptation of practices to location-specific conditions (Lee, 2005; Rammel, 2007). As a result, best practices in one place cannot simply be generalized (Giller et al., 2009; Lee, 2005; Rigby and Cáceres, 2001).

Especially in smallholder agriculture, resource endowments and farm management options are highly diverse, which complicates the rapid dissemination of system technologies (Marenya and Barrett, 2007). For example, location-specific biophysical factors were found to influence adoption of practices in different environments (Aldy et al., 1998; Kassam et al., 2009; Ramirez and Schultz, 2000). Similarly, impacts of system technologies are likely to vary. Not considering context-specific factors may easily lead to biased estimates. A study may overestimate technological impacts if farmers with better resource endowment are more likely to adopt. In contrast, if certain practices are primarily adopted by marginal farmers, effects may be underestimated. Controlling for sample heterogeneity and selection bias is therefore important in impact analysis. This was not always done in previous research on system technologies, which may be one reason for differing results (Alary et al., 2007; Giller et al, 2009; Glover, 2011a; Kassam et al., 2009; Knowler and Bradshaw, 2007; Lee, 2005).

In this chapter, we analyze the impacts of a 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, technological impacts are still debated. Several studies found that SRI increases yields by 20-40% with water savings of up to 50% (Anthofer, 2004; Barah, 2009; Barrett et al., 2004; Ceesay et al., 2006; Gujja and Thiyagarajan, 2009; Senthilkumar et al., 2008; Thakur et al. 2010; Kassam et al, 2011; Uphoff et al. 2011). Other studies detected no significant gains or even decreasing yields (Dobermann, 2004; McDonald et al., 2006; Tsujimoto et al., 2009). Yield effects seem to depend crucially on the reference system. SRI is often adopted by smallholder farmers who cultivate rice under less-than-ideal conditions (Dobermann, 2004). Thus, yield gains may be underestimated when compared to conventional rice yields obtained under favorable conditions. On the other hand, when building on survey data, one needs to account for the fact that better or more motivated farmers may be those that adopt the technology first. A study by Barrett et al. (2004) in Madagascar found that half of the observed yield differences between SRI and conventional rice were actually due to farm and farmer characteristics rather than the technology itself.

Contradictory findings about SRI impacts may also be due to the fact that farmers adopt different SRI components and practices in different combinations. Partial adoption and discontinuance are sometimes observed (Moser and Barrett, 2006; Senthilkumar et al. 2008). Noltze et al. (2012) showed that not only farm and farmer characteristics, but also plot characteristics may influence adoption patterns and thus impacts. A few studies identified higher labor requirements of SRI as a constraint to adoption (Alagesan and Budhar, 2009; Moser and Barrett, 2002). Other studies showed that higher labor inputs occurred only in the early phase of adoption; labor requirements seem to decrease with growing SRI experience (Barrett et al., 2004; Uphoff, 2012). The last few years have seen a lively scientific debate about impacts of SRI on rice productivity (Dobermann, 2004; Glover, 2011a, b, 2012; Sheehy et al., 2004; Sinclair and Cassman, 2004; Stoop and Kassam, 2005; Uphoff et al., 2008; Uphoff, 2012).

Here, we analyze the impacts of SRI for the concrete example of Timor Leste. We extend the existing literature on SRI impacts in two particular ways. First, we analyze productivity effects by building on farm survey data. With few exceptions (Barrett et al., 2004; Sinha and Talati, 2007), most available studies on SRI impacts build on field trial data that may not be representative for real farmer conditions. We account for observed and unobserved heterogeneity by using endogenous switching regressions (e.g., Alene and Manyong, 2007; Di Falco et al., 2011; Rao and Qaim, 2011; Wollni and Brümmer, 2012). Second, we go beyond yield and also analyze SRI effects on household income. Such broader economic impacts of SRI adoption have never been analyzed.

The rest of this chapter is organized as follows. The next section introduces the principles of SRI. Section 4.3 presents the analytical framework, survey design, and descriptive statistics. Estimation results will be shown and discussed in section 4.4. The last section concludes.

4.2 The SRI technology

SRI is often described as a high-yielding and environmentally friendly technology that relies on changing farmers' agronomic practices towards more efficient use of natural resources (Uphoff and Randriamiharisosa, 2002). The principles of SRI originate from experiments conducted by farmers in Madagascar to improve rice productivity for resource-poor producers. Today, SRI is usually understood as a package of possible practices, which have to be adapted to local conditions (Glover, 2011a; Stoop, 2011; McDonald et al., 2006). 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). Weeding is more important in SRI than in traditional rice, because weeds spread more rapidly under non-flooded conditions. In Timor Leste, neither organic fertilization nor weeding have yet been widely promoted in SRI programs (Noltze et al., 2012).

Today, SRI methods have been adopted in almost 50 countries, including major rice-producing nations such as India, China, the Philippines, and Vietnam (Glover, 2011b; Senthilkumar et al, 2008; Thakur et al. 2012; Wang et al. 2003). SRI dissemination and adoption did not always happen spontaneously and unimpeded. In the beginning, development agencies and donor organizations were sometimes reluctant to promote this technology, because much of the evidence resulted from farmer and program reports rather than peer-reviewed scientific studies (Uphoff, 2012). This retarded the diffusion process, because successful adoption of SRI is training intensive and relies on effective extension services (Basu and Leeuwis, 2012). Farmers have to be convinced to break with well-known and widely applied practices of rice cultivation. Also in Timor Leste, there was some reluctance in the beginning. SRI proponents had to convince the extension agency and farmers that the innovation may be an interesting alternative to input-intensive rice cultivation systems that are too costly for Timorese smallholder producers (Deichert et al., 2009). Much of the initial skepticism has been overcome, but the ongoing debate suggests that more research is needed on SRI impacts under various conditions.

4.3 Material and methods

4.3.1 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. The true impact may be underestimated or overestimated when observed or unobserved farm and household characteristics affect the probability of technology 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 models include a treatment dummy as explanatory variable, assuming that the impact on the outcome variable can be represented as a simple intercept shift. In other words, a homogenous impact that is independent of farm and household characteristics is assumed. This is inappropriate for system 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 SRI on the basis of resource endowments and farm management options. The expected utility of SRI adoption, I_{SRI}^*, is compared to the expected utility of following conventional practices, I_{CON}^*. Farmers will adopt SRI if $I_{SRI}^* > I_{CON}^*$ and will not adopt if $I_{SRI}^* \leq I_{CON}^*$. 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:

$$I^* = S'\alpha + \varepsilon_v \quad (2)$$

$$I = 1 \; if \; I_{SRI}^* > I_{CON}^* \quad (3)$$

$$I = 0 \; if \; I_{SRI}^* \leq I_{CON}^*. \quad (4)$$

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:

$$Y_{SRI} = X'\beta_{SRI} + \varepsilon_s \; if \; I = 1, \quad (5)$$

$$Y_{CON} = X'\beta_{CON} + \varepsilon_c \; if \; I = 0. \quad (6)$$

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):

$$cov\,(\varepsilon_s, \varepsilon_c\,, \varepsilon_v) = \begin{bmatrix} \sigma_s^2 & \sigma_{sc} & \sigma_{sv} \\ \sigma_{sc} & \sigma_c^2 & \sigma_{cv} \\ \sigma_{sv} & \sigma_{cv} & \sigma_v^2 \end{bmatrix} \quad (7)$$

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:

$$E(\varepsilon_s |\, I = 1) = E(\varepsilon_s | \varepsilon > -S'\alpha) = \sigma_{sv} \frac{\phi(S'\alpha/\sigma)}{\Phi(S'\alpha/\sigma)} = \sigma_{sv}\lambda_s \quad (8)$$

$$E(\varepsilon_c |\, I = 0) = E(\varepsilon_c | \varepsilon \le -S'\alpha) = \sigma_{cv} \frac{\phi(S'\alpha/\sigma)}{1-\Phi(S'\alpha/\sigma)} = \sigma_{cv}\lambda_c \quad (9)$$

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 (e.g., Abdulai et al., 2001; Doss, 2006; Läpple and van 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):

$$E(Y_{SRI}|\, I = 1) = X'\beta_{SRI} + \sigma_{sv}\lambda_s \tag{10}$$

SRI plots/households without adoption (counterfactual):

$$E(Y_{CON}|\, I = 1) = X'\beta_{CON} + \sigma_{cv}\lambda_s \tag{11}$$

Conventional plots/households without adoption (observed):

$$E(Y_{CON}|\, I = 0) = X'\beta_{CON} + \sigma_{cv}\lambda_c \tag{12}$$

Conventional plots/households with adoption (counterfactual):

$$E(Y_{SRI}|\, I = 0) = X'\beta_{SRI} + \sigma_{sv}\lambda_c. \tag{13}$$

Equations (10) to (13) 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):

$$ATT = E(Y_{SRI}|I = 1) - E(Y_{CON}|I = 1) \tag{14}$$

$$ATU = E(Y_{SRI}|I = 0) - E(Y_{CON}|I = 0). \tag{15}$$

4.3.2 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 (WFP, 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. Conventional production systems were often not able to overcome these challenges which motivated the introduction of SRI (Deichert et al., 2009). 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 4.2. 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).

4.3.3 Sample descriptive statistics

Timor Leste is a mountainous region with a shortage of land suitable for intensive crop production (WFP, 2005). Annual rainfall levels and seasonal variability restrict most farmers to one cropping season per year. The paddy fields are located in the lowlands, either in valleys or coastal plains. On these paddy fields, only rice is grown without any crop rotation. Rice is also the main crop for most of the sample farmers. Other crops such as cassava, maize, and vegetables are often cultivated on a small scale in garden-like patches. Almost all sample 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 farms in our sample have an average size of 1.9 ha (Table 8). This includes the area cultivated and the homestead. All land cultivated is typically owned by the farms; a land rental market or sharecropping arrangements hardly exist in the study area. Paddy fields account for 68% of the total farm land on average. Yet, SRI farmers own significantly more land, and they also manage larger rice areas. In the group of technology adopters, 89% have regularly participated in SRI training. Training participation involves attending regular meetings, in which farmers are encouraged to exchange experiences and questions regarding SRI. Adopters are more likely to live in villages where overall training participation rates are higher, which may point at information spillovers in village communities. They are also more likely to be located in Bobonaro District, 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. The average household includes 6-7 household members, 3 of whom are in working age between 18-65 years. A relatively high dependency ratio implies that most farmers need to hire in labor for rice cultivation during peak seasons for standard operations such as plowing or harvesting. Data on other demographic and socioeconomic variables, such as age, education. and gender of the household head, distance to nearest input market, and access to credit were also collected and will be included in the regression analysis.

Table 8. Descriptive statistics

	Means (SD)						
	All		SRI		Conventional		
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)	**
Number of rice plots per household	1.20	(0.42)	1.28	(0.49)	1.13	(0.34)	***
Livestock units [a]	5.87	(7.20)	5.85	(6.72)	5.87	(7.51)	
Household living in Bobonaro District (%)	48.86	(50.05)	56.60	(43.92)	43.69	(49.70)	**
Household living in larger town (%)	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 conventional 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.

Most farmers in the research area own one rice plot with an average size of about 1 ha. Around 20% of the farmers cultivate more than one rice plot. Of the SRI adopters, 18% have one or more conventional rice plots in addition to SRI. This suggests that plot level characteristics may also influence farmers' adoption decision. The lower part of Table 8 shows that SRI is preferably applied on plots with a technical irrigation system, which can be controlled individually.[3] All plots without a technical irrigation system are rain-fed. Moreover, shorter water availability, measured as the time where water is available on a specific plot in months, 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.

4.3.4 Rice yield and household income

Rice yields are somewhat lower on SRI plots than on conventional plots (Table 9). 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

[3] 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.

productivity remained low in the initial phase of SRI adoption, but increased rapidly in subsequent years.

Table 9. Costs and returns on SRI and conventional rice plots

	All (SD)		SRI (SD)		Conv. (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 9 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. We do not find significant differences in labor inputs. If regular weeding and compost or other organic fertilizer were applied, as recommended in SRI programs elsewhere, labor requirements might increase. On the other hand, growing experience with SRI may reduce labor inputs over time. 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 10 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 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 1 US$ per day for both SRI-adopting and non-adopting households. The poverty rate is around 70%, using the national basic needs poverty line (Table 10).

Table 10. Annual household income in US$ by activity

	All	(%)	SRI	(%)	Conv.	(%)	
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 conventional 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.

4.4 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. We first discuss the plot level analysis, before turning to aspects of household income and poverty.

4.4.1 Yield effects

To estimate net yield effects of SRI adoption, we specified production functions for the SRI and conventional regimes on a per-ha basis (yield and all inputs are measured per ha). Different functional forms were tested, including linear, quadratic and double-log specifications, which are commonly used in empirical analyses with micro data (e.g. Battese, 1992; Griffin et al., 1987; Qaim et al., 2006; Wollni and Brümmer, 2012). Double-log specifications showed the best empirical fit. We used a Wald test to establish whether the Cobb-Douglas specification without input interaction terms, or the translog with input interactions, is more appropriate. The null hypothesis in favor of the Cobb-Douglas specification could not be rejected. In addition to inputs used in rice cultivation, a number of other explanatory variables are included to control for differences in terms of plot 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.[4] As some farmers cultivate more than one rice plot, and household characteristics may influence plot level outcomes, we use a household cluster correction procedure to obtain reliable standard errors for the estimation.

The results are shown in Table 11. Due to missing values for some of the variables, not all plot observations could be included. 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

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

saturated but not flooded conditions require careful individual water management. Noltze et al. (2012) highlighted the importance of technical irrigation systems and identified the use of intermittent irrigation as a stepping stone towards the adoption of SRI in Timor Leste. Inability of water control was also identified as a major constraint for SRI farmers in Vietnam (Uphoff, 2012).

The two regime equations are shown in the second and third column of Table 11. Labor has the biggest production elasticity in both regimes. Increasing labor input by 1% would increases rice yield by about 0.3% on average. It was mentioned that certain labor-intensive practices such as weeding and compost preparation, which are recommended for SRI, are not yet widely applied in Timor Leste. Depending on rice prices and the individual opportunity cost of labor, these results suggest that it may be worthwhile to allocate more labor to rice cultivation. Given the early adoption stage of SRI, labor productivity may further increase in the future with growing experience.

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.

Table 11. 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 σ_s, ln σ_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.[5] 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 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. The relevance of plot accessibility for SRI yields has rarely been addressed in previous studies.

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, which also introduced SRI, 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. In addition, hybrid seeds were imported from Indonesia and could not be distributed in time, so that some farmers were forced to extend their cropping cycle beyond the end of the rainy season. In our estimates, 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 negative performance of hybrids in this particular context should not be misinterpreted as if hybrids were generally not suitable for SRI. There are still some knowledge gaps about the most suitable types of seeds for particular situations (Villa et al., 2012). Bueno et al. (2010) found that some rice hybrids did not show improved performance when compared to other inbred lines under non-permanent flooded

[5] 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).

conditions. On the other hand, the highest SRI yields have been achieved with hybrids seeds (Uphoff and Sinclair, 2004). The fact that SRI reduces the amount of seeds used per unit of land facilitates the adoption of improved and more expensive rice varieties or hybrids by resource-poor farmers. This bodes well for harnessing complementarities between agronomic and breeding innovations.

The lower part of Table 11 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 (14) and (15) to calculate the average treatment effects of SRI adoption on rice yields. These calculations establish net impacts, that is, they control for negative hybrid effects and other confounding factors. Results are shown in Table 12. Strikingly, SRI farmers would have significantly lower yields had they not adopted SRI, implying an ATT of 46%. This result is specific to SRI farmers in Timor Leste and should not be generalized. Yet, high SRI yield gains were also reported in several other countries, including Cambodia, India, and Madagascar (Anthofer, 2004; Barah, 2009; Barrett et al., 2004; Ceesay et al., 2006; Gujja and Thiyagarajan, 2009; Senthilkumar et al., 2008; Thakur et al. 2010; Kassam et al, 2011; Uphoff et al. 2011). The big positive ATT of SRI adoption in Timor Leste, combined with the insignificant yield difference found above in the simple comparison, clearly points at negative selection bias that 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. The ATU, which is also shown in Table 12, is positive and significant too, but much smaller than the ATT. Mean yields on conventional rice plots could be 11% higher when SRI were used on these plots. The large difference between ATT and ATU underlines heterogeneity in impacts due to various agroecological and socioeconomic factors.

Table 12. 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
Conv. 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.

4.4.2 Household income effects

We now estimate the endogenous switching regression model of total income at the household level, differentiating between SRI and conventional households. For the regime equations, we considered different possible functional forms. The log-linear specification, with the logarithm of annual household income as dependent and linear explanatory variables, showed the best empirical fit, based on the Akaike information criterion (AIC) (Greene, 2008). The log-linear AIC of 3.97 was significantly lower than the linear AIC of 19.23. Again, the share of training participants in the village serves as instrument for SRI adoption in the criterion function.

The estimation results are shown in Table 13. 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 13). One additional ha increases their household incomes by 24%. Farm size is less relevant for SRI households, who manage somewhat larger farms and also generate more income from off-farm employment. It is possible that labor constraints may hinder SRI farmers to benefit more from additional farm land. Livestock ownership contributes more to the incomes of SRI adopters, even though the effect is also positive and significant for the non-adopters.

Table 13. 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 larger town (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.

This is underlined by the large and significant positive effect 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. For conventional farmers, a large and positive effect is found for households living in larger rural towns (as compared to smaller villages). Due to the lack of input and output markets in many villages, farmers depend on markets in the towns of Suai (capital of Covalima District) and Maliana (capital of Bobonaro District). Both towns supply relevant products and services for all kinds of farm operations and off-farm economic activities. Both towns also provide a wide range of wage employment activities.

Table 14 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 it is not surprising that the total household income gains are smaller than the yield gains discussed 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 14 suggests that non-adopting households would not benefit if they switched to SRI. Hence, their decision of non-adoption seems to be rational.

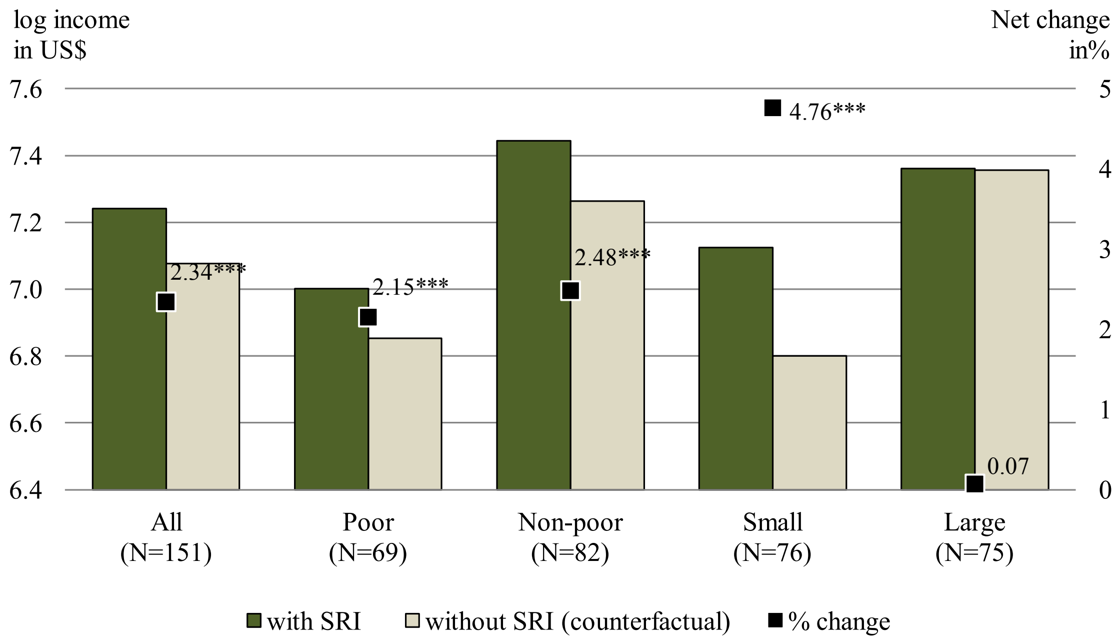
Table 14. Average treatment effects of SRI on household income

		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
Conv. 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 5 shows 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 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 5. The effect of SRI adoption on the income of adopters



*** Significant at the 1% level. Notes: Poor and non-poor are defined as explained in Table 10. Small farms are those with less than 2 ha of land owned (large farms have≥ 2ha) . Source: Own survey data.

4.5 Conclusion

This chapter has analyzed the impact of SRI in Timor Leste. Using an endogenous switching regression framework, we accounted for heterogeneous impacts and controlled for selection bias. This is important in smallholder settings where farm and plot level conditions are very diverse. Heterogeneity was not always considered in previous SRI research, which may also explain why findings are sometimes contradictory. Another novel contribution is that we went beyond yield and also analyzed household income effects of SRI adoption. This was never done in previous studies.

Simple comparison of yields and incomes between SRI adopters and non-adopters in Timor Leste did not reveal significant differences. However, we found negative selection bias. Controlling for this bias 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 this particular situation. SRI-adopting small farms benefit over-proportionally.

Projections show that current non-adopters of SRI would realize smaller yield gains and slightly negative income effects when they switched to SRI. This confirms that impacts depend on micro-level agroecological and socioeconomic factors. In Timor Leste, SRI does not seem to be beneficial when compared to conventional rice grown under favorable conditions and with best management practices. While similar findings were reported previously (Dobermann, 2004; McDonald et al., 2006), there is also evidence that SRI can outperform conventional best management practices in many situations (Anthofer, 2004; Barrett et al., 2004; Ceesay et al., 2006; Senthilkumar et al., 2008). This discussion shows that broad generalizations without reference to the specific context should be avoided.

The analytical approach developed and used here has clear advantages, as it accounts explicitly for farm and plot level heterogeneity. But it also has a few limitations, which we discuss in the following with a view to implications for future research. Some of this discussion also applies to system technologies more generally. First, SRI involves different recommended components, not all of which are adopted by farmers. We defined SRI plots as those where four core components were adopted. But there are additional components, and different combinations may result in different impacts, as field experiments suggest (Chapagain and Yamaji, 2010; Mishra and Salokhe, 2008). This was not analyzed here but should be looked at in future research under practical farmer conditions.

Second, impacts of NRM technologies depend on the farmers' capacity to adapt general principles to local circumstances (Lee, 2005; Knowler and Bradshaw, 2007). For SRI, decisions on optimal water levels, transplanting time, and plant spacing are knowledge intensive and rely on farmers' ability and motivation to experiment. Impacts may change over time with growing experience, which we were not able to examine with the cross-section data available. Proper analysis of impact dynamics requires panel data (Kouser and Qaim, 2011).

Third, and related to the previous point, impacts depend on access to good information and advice (Basu and Leeuwis, 2012). In Timor Leste, SRI was introduced by the national extension service through special training programs. But from historical experience it is well known that public extension programs have not always been very effective in developing countries (Anderson and Feder, 2007). Future research should analyze the linkages between different extension approaches, farmers' adoption, and technological impacts on productivity and household welfare. Identifying new cost-effective extension approaches is important to promote the successful spread of knowledge-intensive system technologies (Noltze et al., 2012).

Finally, while we went beyond yield and also analyzed household income effects, there are broader benefits that system technologies could entail, including positive environmental externalities (Lee, 2005; McIntyre et al., 2009). Such effects were not analyzed here. In terms of adoption incentives, it 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. Broader implications – looking beyond the farm and household level – should be addressed in future research.

5. Conclusions

The agricultural sector is subject to ongoing economic and environmental challenges, calling for innovative strategies to improve human well-being and future food security. One group of particular interest is smallholder farmers, who contribute substantially to global agricultural output but are strongly affected by persistent poverty and growing agro-environmental challenges. Moreover, smallholder agriculture is confronted with a range of market failures, strengthening the need for improved policies (Binswanger and Deininger, 1997; Birner and Resnick, 2010). One major constraint is the limited access of smallholders to modern technologies, which are often input-intensive and costly. Natural resource management practices, have been proposed to improve the efficiency of cropping systems in a sustainable and affordable way for small-scale producers. While there is hope that adequate technologies are able to pave the road out of poverty, it is essential to understand the opportunities and constraints related to adoption and impact of innovations.

This study aimed to contribute to new development perspectives by analyzing the case of the System of Rice Intensification (SRI) in Timor Leste with regard to future opportunities and challenges of agriculture and the rice sector in particular. A study of this nature is vital, because the role of resource conserving system technologies has been widely recognized by practitioners, researchers and policy makers. With regard to the literature, it was found that although SRI has been widely promoted, worldwide adoption rates are modest and the impacts remain highly debated. We pointed out that system technologies such as SRI offer opportunities to adapt agronomic and ecological principles to farmers' needs and local conditions. As a consequence, practical implementation varies and is often found to be context-specific. However, a considerable diversity of farmers' adoption patterns complicates farm-level assessment of technology impacts. The challenge is to assess where particular practices may best fit, and which types of farms are likely to benefit most. We started out by hypothesizing that both adoption and impact of SRI depend on very detailed location, household and plot specific factors, which have to be analyzed in order to assess the full potential of the technology.

In order to assess the opportunities and constraints related to adoption and impacts of SRI, the following objectives have been addressed: first, we identified farmers' adoption patterns and differences between SRI and non-SRI farmers. Second, we analyzed the factors that drive farmers' adoption decisions. Finally, the impacts of SRI in terms of yield, household income and poverty have been assessed. We controlled for different adoption patterns, plot and household heterogeneity, differential technology effects and selection bias using different econometric estimation procedures. For the adoption analysis, double-hurdle models were developed to explain farmers' decision making process. The impacts of adoption were estimated by an endogenous switching regression framework. The analytical approaches applied here have specific advantages for the analysis of cross-sectional data in ex-post evaluation designs and may also be useful for the assessment of other system technologies.

We began our analysis identifying SRI adoption patterns and differences between SRI and non-SRI farmers. We have shown that adoption patterns vary substantially, and partial adoption is commonplace. Whereas some components are widely applied by households in the research area, others lack widespread acceptance. The highest adoption rates were recorded for the group of training participants. However, the descriptive analysis also revealed that land and household characteristics seem to play a role in the adoption decision. For example, owners of larger farms are more likely to adopt SRI. The outcomes point at potential heterogeneity among adopters and non-adopters.

After identifying farmers' adoption patterns, we were interested in the factors that influence the adoption decision. However, the adoption of multi-component SRI is a complex process. Different decisions points were identified. Econometric analysis showed that household level variables such as farm size, availability of family labor and participation in extension training determine the initial adoption decision and the share of rice acreage under SRI. However, household level characteristics alone are insufficient to explain adoption. Several plot level determinants have a significant effect on SRI adoption and the number of components used. For example, the availability of an irrigation system, which can be individually controlled by the farmer, is an important determinant for SRI adoption on a particular plot.

These findings provided important insights into farmers' adoption decisions and constraints. To assess whether adoption is actually desirable, we analyzed the impacts of SRI in terms of rice yields, household income and poverty. Thereby, our study accounted for variability among household and plot level parameters, as well as for differential technology impacts between adopters and non-adopters of SRI. The comparison of yields revealed negative selection bias, meaning that SRI is adopted on plots and by farmers that would have below average yields without adoption. Controlling for external factors and selection bias, it was estimated that SRI has a positive yield advantage against the counterfactual outcome of non-adoption. The yield effect is accompanied by reduced production costs due to lower use of inputs such as water, seeds and pesticides. We also found a small but significant positive effect on adopters' income. Both poor and non-poor households benefit from adoption. Especially smaller and more specialized farms realize high returns from adoption.

The empirical findings demonstrate that SRI adoption can result in positive effects for resource-poor producers in Timor Leste. However, it was also found that successful adoption depends on location-specific characteristics including various plot and household level attributes, thus at least some of the productivity gains reflect farm- and plot-specific effects. However, we found that SRI yields do not exceed the yield levels of other best management practices in the research area. The estimates also revealed that non-adopters would realize much smaller yield gains and slightly negative income effects when they would switch to SRI. Hence, their decision of non-adoption seems to be rational. Such heterogeneity in impacts can also be expected for other complex system technologies, but was often not accounted for in previous economic studies.

The results imply that SRI is not inevitably the best management option for all farmers and plots, which has often been supposed by SRI advocates. As a consequence, SRI should not hastily be introduced as a panacea to increase rice productivity, but rather as one promising strategy besides other best management practices. To date, SRI is flexible and still evolving, thus future research should also focus on how SRI components work well with other best practices. Some alternative approaches, such as alternate wetting and drying (AWD), organic farming or aerobic rice cultivation already share one or more principles related to SRI. Moreover, there is only very limited knowledge about the interactions among SRI and specific rice cultivars. To date the best

SRI yields have been achieved with high-yielding varieties or hybrids (Uphoff and Sinclair, 2004). Since SRI reduces the amount of seeds per unit of land, it slashes higher costs for farmers using improved and more expensive cultivars. This could also be an important attribute for Timorese producers, in case improved varieties become more broadly available on local markets. However, we should mention that the introduction of SRI in Timor Leste is still in its early stage, and SRI-adopting farmers have only very few years of experience. It can be expected that productivity effects of SRI increase when farmers gain more experience with the new system. The role of experience may also be relevant for other knowledge-intensive system technologies. Furthermore, the nature of these outcomes applies for the introduction of system technologies to different agroecological and socioeconomic environments and is therefore not limited to the Timorese context.

Understanding farmers' incentives and constraints of technology adoption is crucial for the formulation of adequate development strategies. In the case of complex system technologies, adaptation requires comprehensive knowledge and management time, and involves a considerable amount of risk. In SRI, practices require a profound understanding of its agroecological principles in order to manage its various components towards an optimized resource use. However, expecting too much from the farmers themselves can easily lead to frustration and disadoption. We found that participation in specific training programs increases the probability of adoption. Regular training is likely to improve farmers' adaptation capacity and the benefits derived from knowledge- and labor-intensive system technologies. Thereby, extension services should support farmers by translating general principles into practical advice, perhaps with a focus on households that have relatively high opportunity costs of labor. This is especially relevant in the early phase of adoption, when family labor cannot easily be replaced by hired labor. Overall, our results imply that without well-equipped extension programs, widespread and successful adoption of complex system technologies is unlikely to take place in smallholder agriculture. For this, public and private investment programs should extent the coverage of extension services and agricultural research.

In the case of system technologies, local farmer knowledge can substantially contribute to more appropriate technology designs. Empowering user participation is essential for strengthening human capital in smallholder farming systems. The integration of local farmer knowledge may further enhance the knowledge-base of SRI and rice cropping systems in general. For this, innovative extension strategies such as community-based learning and farmer-to-farmer extension are required. In such models, selected and well-trained farmers usually act as an intermediary for transferring the technology among farmers in the community, making extension services self-supporting and thus more sustainable.

In addition, the lack of well-established farmer organizations restricts producers' access to agricultural technology, credit and information. Strengthening the development of farmer organizations should be better accentuated in the policy agenda of development programs, especially in marginal areas with limited access to government services. In Timor Leste, training groups that have been developed by extension services, could be a first step towards the establishment of self-reliant farmer organizations. Some farmer groups have already started to add additional topics such as post-harvest and marketing strategies to their agenda. This observation accentuates a demand for enhanced services.

Moreover, we identified several technical factors that support adoption and found that improved rural infrastructure of roads and irrigation systems would help to facilitate the uptake of SRI. This seems to be a quite costly investment for the improvement of rice production. However, infrastructure has much wider implications for rural communities improving the production of various agricultural products, market access and transport systems. Thus complementary growth effects can be expected. The proportionate costs could be lowered by incorporating such strategies into existing cross-sector development programs which often focus on infrastructure, however, not necessarily on rural roads and irrigation. For example, road construction does usually include the installation of drainage channels which could potentially be integrated into agricultural irrigation systems. The practical implementation depends on the harmonization of interests among various stakeholders and government institutions.

Our findings imply that SRI can not only be economically profitable, but is also an environmental friendly and resource conserving approach of rice cultivation. Natural resources are economic goods which require proper management to provide sustainable growth. The SRI practice of intermittent irrigation increases the productivity of rice per unit of water and reduces the total input of irrigation water in contrast to other best management practices. This is an important attribute in a water-scarce environment such as Timor Leste. In this regard, our analysis identified intermittent irrigation as a stepping stone towards the full adoption of SRI. In addition, lower water input decreases the probability that paddy fields suffer from salinization, which is a common problem in the proximity of coastal plain lands where most of the world's high-potential rice areas are located. This could become even more relevant if sea levels continue to rise. However, the implementation of water saving practices depends on the awareness of the local community and researchers have to understand that immediate problems of poverty may downgrade soil degradation in farmers' priority lists.

A more general constraint to adoption of knowledge-based system technologies is the lack of education among farmers. In our sample, only very few farmers have formal education beyond primary level. The analysis did not detect an unambiguous effect of schooling, however, better education may increase the awareness of environmental challenges, which is relevant for sustainable adoption of resource conserving practices. Today environmental and agricultural knowledge is also gained through extension services which often substitute formal school education. Improving educational levels will be of critical importance for the future of farmers in Timor Leste.

The results contribute to agricultural planning and the formulation of rural development strategies. Nevertheless, areas for future research remain. First, each analysis is constrained by the available data. Using a cross-sectional data set restricts our analysis to one point in time. The availability of panel data could provide further insights into adoption dynamics and the impacts of the technology over a longer period. Second, some limitations are related to the adoption analysis. While we have focused on the depth of adoption, meaning the number of components adopted, we did not explain why individual components or specific combinations are adopted and others are not. The main difficulty was to identify adequate clusters representing the high variability of recorded adoption patterns. Moreover, we did not look explicitly at the factors that drive the adoption of the additional SRI practices beyond the core components. This does also apply for the impacts of the additional components, which have not been included in the analysis but may have significant complementary yield effects. Such details can be relevant for policy decisions and should be addressed in further research.

Since we have proposed to use innovative extension concepts for the further dissemination of SRI, future research should also focus more intensively on information flows among farmers, the role of social networks and communication channels. A better understanding of the dissemination of agricultural knowledge could lead to further improvement of technology delivery programs. Finally, while many incremental costs of adoption emerge at the farm level, the wider benefits of resource conserving practices accrue at the regional or even global level. Such externalities are difficult to be captured by private farms, which may in turn lead to an underinvestment in associated technologies. Assessing these broader implications requires an analysis beyond the farm gate and should be subject to further research.

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Appendices

Appendix A. Additional tables and figures

Table A1. Maximum likelihood estimates for status and intensity of adoption, excluding the SRI training dummy

Variable	Maximum likelihood estimates	
	Decision to adopt SRI	Decision on SRI acreage
Household members in working age (number)	-0.0405	0.0698***
	(0.0468)	(0.0218)
Household head age (years)	0.0062	-0.0034
	(0.0063)	(0.0032)
Household head years of schooling (years)	0.0067	-0.0005
	(0.0171)	(0.0083)
Total land area owned (ha)	0.1244**	0.6368***
	(0.0611)	(0.0267)
Share of rice in total arable land (%)	0.0032	0.0233***
	(0.0028)	(0.0014)
Number of buffaloes owned (number)	-0.0115	0.0093
	(0.0167)	(0.0083)
Household having nonfarm income (dummy)	0.0227	-0.0341
	(0.1362)	(0.0678)
Access to formal credit (dummy)	-0.0319	0.0304
	(0.1325)	(0.0642)
Distance to nearest input market (km)	-0.0033	-0.0050
	(0.0156)	(0.0070)
Natural disaster (dummy)	-0.0737	-0.0924
	(0.1462)	(0.0728)
Accident/illness (dummy)	-0.3930**	0.0787
	(0.1979)	(0.1041)
Household living in Bobonaro (dummy)	0.3413**	0.0705
	(0.1350)	(0.0648)
Constant	-1.0452**	-1.6766***
	(0.4185)	(0.2268)
Sigma		0.3566***
		(0.0214)
Observations	397	397
Log-Likelihood		-305.4399

*,**,*** significant at the 10%, 5, and 1% level, respectively.

Notes: Robust standard errors are shown in parentheses.

Appendix B. Household questionnaire

Introduction

We are researchers from the University of Goettingen (Germany), which is collaborating with the Rural Development Project (RDP II).

We want to know more about your livelihood and particularly about how you cultivate wet rice. Your responses are very helpful to improve future development projects and programs. You will, however, not obtain any direct benefits, for example money, from participating in this survey. Your responses will be strictly used for research purposes and will be treated as confidential.

We respect all answers you give and want to remind you that there are no right or wrong answers. If you have any questions, please address them to the interviewer.

Date of interview (dd/mm/yy):______/_______/________

Name of respondent: Telephone/Mobile:

Respondent is head of household ☐ yes ☐ no

Did your HH grow wet rice in the last 12 month?
☐ yes ☐ no *(If no, please stop the interview here!)*

Enumerator: Supervisor: Data Encoder:

1. Location details

Location description:

District: ______________________ Subdistrict: ______________________

Suco: ______________________ Aldeia: ______________________

2. Household data

2.1. Household composition (respondent: HH-head or most informed household member)

Note: Members of a household are all people, who usually eat from the same pot and sleep under the same roof. Include also members who are absent for less than two months!

Id. code	2.1.1. Name of HH-member	2.1.2. Relation with head of household (code 1)	2.1.3. Sex (m/f)	2.1.4. Age (in years)	2.1.5. Education (code 2) *Only for members of HH who are older than 5 years*	2.1.6. Main occupation (code 3)	2.1.7. Can you read a letter? (code 4)	2.1.8. Can you write a letter? (code 4)	2.1.9. Place of birth (code 5)	2.1.10. Marital status (Code 6)	2.1.11. Religion (code 7)	2.1.12. Do you speak .... fluently?			
												Tetun	Indonesia	Portugese	English
(Head) 1															
(Spouse)2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															

Code 1: Relation with head of family
1. family head
2. husband/wife
3. father/mother
4. grandfather/-mother
5. child
6. grand-child
7. brother/sister
8. father/mother-in-law
9. cousin/cousine
10. uncle/aunt
11. brother/sister-in-law
12. nephew/nice
13. other relation with fam. head
14. no relation with fam. head

Code 2: Education
1. No school
2. SD1
3. SD2
4. SD3
5. SD4
6. SD5
7. SD6
8. SMP1
9. SMP2
10. SMP3
11. SMA1/SMU1
12. SMA2/SMU2
13. SMA3/SMA3
14. University

Code 3: Main occupation
1. too young to work
2. has no profession
3. farmer
4. hunter
5. woodcutter
6. rattan collector
7. trader
8. self-employed/own business (e.g. shop, garage)
9. civil servant (e.g. teacher)
10. Employee (company)
11. fisherman
12. housewife
13. student
14. Retired
15. other (specify)

Code 4: Read/write
1. Yes, without difficulties
2. Yes, but with difficulties
3. No

Code 5: Place of birth
1. This posto
2. Other posto
3. West Timor
4. Other in Indonesia
5. Other

Code 7: Religion
1. Islam
2. Hindu
3. Protestant
4. Katolik
5. Buddha
6. other (specify)

Code 6: Martial status
1. Married
2. Divorced
3. Seperated
4. Widow or widower
5. Never married

2.2. Housing

2.2.1. What is the main source of water for drinking in your HH?							
Bottled water	Tab water	Pump	Well	Spring	River, Lake, Pond	Rainwater	Other (specify) …………………..

2.2.2. What is the main source of light in your dwelling?					
Electricity	Private generated electricity	Petromax	Lamp	Candels or battery flash lights	Other (specify)
2.2.3. Is the dwelling owned by a person of your HH?				(1) yes, (2) no	

2.2.4. Distance to market from house? (km)	2.2.5. How long does it take you to walk to market from house? (min)

2.3. Access to facilities

Facility	2.3.1. Do you or any of HH-member use facility? (1)yes;(2)no	If no, why don't you use facility? (Code 1)	2.3.2. How far is facility from your house? (km)	2.3.3. How do you normally travel to facility? (code 2)	2.3.4. How long does it take to get to facility? (min.)
Primary school					
Clinic					
Bank					
Bus terminus					
Veterinary facility					
Police station					

Code 1: reason
1. don't need to use
2. too far away
3. too expensive
4. don't know
5. other (specify)

Code 2: travel
1. walk
2. bicycle
3. car
4. bus
5. riding horse
6. motorbike
7. other

3. Wage employment

3.1. Has anyone of your HH worked as a wage laborer or contract laborer (daily/weekly/monthly payment of money or fixed payments for specific jobs) in the last 12 months? (   ) yes   (   ) no

If for ID.code (HH-members) the answers for 3.1. was' no', do not include ID.code member in the following table!

Id. Code	3.2.1. Wage / contract job (code 1)	3.2.2. How many hours per days are you used to work in occupation?	3.2.3. How many days per week are you used to work in occupation?	3.2.4. During which months did you work in job during the past 12 month?												3.2.5. How much is your payment for wage employment?	
				3.2.4.1. January	3.2.4.2. February	3.2.4.3. March	3.2.4.4. April	3.2.4.5. May	3.2.4.6. June	3.2.4.7. July	3.2.4.8. August	3.2.4.9. September	3.2.4.10. October	3.2.4.11. November	3.2.4.12. December	3.2.5.1. ($)	3.2.5.2. What period of time did the payment cover? (1.Hour 2.Day 3.Week 4.Month)

Code 1: Occupation (wage employment)
1. Professional/technical expert
2. Managerial, administrative and decision making staff
3. Clerical
4. Sales worker
5. Service worker
6. Workers in agriculture and husbandry
7. Worker in forestry
8. Worker in fishing
9. Working in hunting
10. Production worker
11. Transportation operation worker
12. Unskilled workers
13. Construction worker
14. Others (specify)

3.4. In the last 12 months has your family earned income from non-agricultural self-employment, such as (read code 1)?
(   )yes, (   )no

3.4.1. Self employment (code 1)	3.4.2. Which member of the household bears the main responsibility of the business? Member I.D.:………	3.4.3. When started? (year)	3.4.4. Sales value in the last 12 months? ($)	3.4.5. Expenses for the labor in the last 12 months? ($)	3.4.6. Expenses for other inputs in the last 12 months?	3.4.7. For how many months during a year do you earn money with this business?	3.4.8. How many hours did you normally work in self-employment in 1 month (when active in self employment)?

Code 1: Self employment
1. Kiosk
2. Home production (cloth, craft, food (fried banana))
3. Carpenter
4. Stone collection
5. Small trader
6. Daily laborer
7. Selling dry wood (for cooking)

8. other (specifiy): ____________________

9. other (specifiy): ____________________

10. other (specifiy): ____________________

4. Farming, Livestock, Forestry and Fisheries

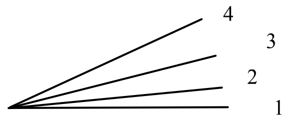
4.1. Plot section *(all plots cultivated and/or owned should be listed here; please, make sure that plots are treated as single plots, if the same cultivation technique is applied (e.g. SRI, Hybrid, Traditional)! Please sum up single plots)*

Plot No.	4.1.1 'Name' of plot	4.1.2 Kind of land (code 1)	4.1.3. Time to get to the plot from house (min)	4.1.4. Estimated area		4.1.5. Crop 1		4.1.6. Crop 2		4.1.7. Crop 3		4.1.8. Slope (code 3)	4.1.9. Tenure status (code 4)	4.1.10 Mode of irrigation on plot (code 5)	4.1.11 How many month do you have irrigation per year? (month)
						IN THE LAST 12 MONTH									
				4.1.4.1. Area cultivated	*4.1.4.2. Units 1. ha 2. m*m 3. Ares 4. other*	4.1.5.1. Main crop (code 2)	4.1.5.2. 'Intercropping' with 2nd crop (code 2)	4.1.6.1. Main crop (code 2)	4.1.6.2. 'Intercropping' with 2nd crop (code 2)	4.1.7.1.Main crop (code 2)	4.1.7.2. 'Intercropping with 2^{nd} crop				
1															
2															
3															
4															
5															
6															

Code 1: Kind of land
1. Annual crops or fallow
2. Tree crop land
3. Forest
4. Pasture
5. Plantation
6. Rice field
7. Bush/Underbush
8. Grassland
9. Swamp
10. Garden/Garden plot
11. Water surface/Fish pont
12. House/building
13. other (specify)

Code 2: crop
1. Rice
2. Corn/maize
3. Cassava
4. Coffee
5. Kidney beans
6. Sweet potatoe
7. Potatoe
8. Taro (Talas/Kontas)
9. Squash
10. Mung bean
11. Soy bean
12. Coconut
13. Peanuts
14. Vegetables
15. Bananas
16. Papaya
17. Jackfruit
18. Pineapple
19. other (specify)

Code 3: land types
1. flat land
2. slight slope
3. moderate slope
4. steep slope



Code 4: Tenure status
1. fully owned
2. rented-in
3. rented-out
4. share cropped
5. communal
6. government land
7. other (specify)

Code 5: Mode of irrigation
1. Not irrigated
2. Tubewell
3. Ditch/canal
4. Pond/tank
5. River
6. Spring
7. Mixed
8. other (specify)

4.2. Rice

Please transfer the **plot no. for rice plots** of section 4.1. into the following tables!

Remember: A rice plot is defined as the sum of all (small) rice plots with equal cultivation technique (Traditional, SRI, Hybrid)! Please ask again, if the rice plots of 4.1.include all rice production of HH.

If more than one rice plot, please draw a sketch and add plot number and name! Show sketch to farmer between the following rice questions as often as possible!

4.2.0.1. Plot No. *(section 4.1.)*				
4.2.0.2. Plot Name *(e.g. Traditional, Hybrid, SRI)*				
4.2.0.3. How often do you (expect to) harvest on plot in 2009?				
4.2.0.4. In (the 1st harvest of) 2008, what was the plot size (*please discuss with farmer in comparison with current plot size*)				
4.2.0.5. In (the 1st harvest of) 2007, what was the plot size (*please discuss with farmer in comparison with current plot size*)				
4.2.0.6. On plot, do you have influence on water management? (code 0)				
4.2.0.7. Soil quality (PH-value) – *will be measured with farmer on the field during village field day*				
All following questions are related to the 1st rice harvest on plot in 2009! 4.2.1. Variety of rice seeds used on plots				
4.2.1.1. Which rice variety did you use? (code 1)				
4.2.1.2. How much input of rice variety did you apply? (kg)				
4.2.1.3. From which source do you know about how many kg of rice variety per plot? (code 2)				
4.2.1.4. How much did you pay for kg of seeds of rice variety? ($)				
4.2.1.5. Did you use a method to select good quality seeds? (code 3)				

Code 0: water management
1. self managment
2. water user group/ community
3. no influence

Code 1: rice varieties
1. Seere weite
2. Silaung
3. IR 64
4. Lokal Maliana
5. Bimas
6. Bubur musan
7. IR 16
8. Membrano
9. IR 8
10. Lokal mean
11. Lokal mutin
12. Lokal rita
13. Hybrid
14. Other (specify)

Code 2: source
1. instruction delivered with product
2. family
3. neighbours
4. extensionist
5. farmer group
6. radio/television
7. self experience
8. other (specify)

Code 3: method of seed selection
1. 'water method'
2. traditional
3. other (specify)

4.2.1.6. From which source do you know about method? (code 2)					
4.2.1.7. Since when have you used method? (year)					
4.2.2. Nursery					
4.2.2.1. Kind of nursery (Code 4) *If farmer did 'broadcasting', go to 4.2.3.*					
4.2.2.2. How many days of nursery?					
4.2.2.3. Did you use compost for nursery? (1) yes, (2) no					
4.2.2.4. From which source do you know about this kind of nursery? (code 2)					
4.2.2.5. Since when have you used this kind of nursery? (year)					
4.2.2.6. Workload nursery (days)					
4.2.2.7. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.2.8. Have you ever applied another kind of nursery on plot? (code 3) *If no, go to 4.2.3.*					
4.2.2.9. Since when have you stopped using it? (year)					
4.2.2.10. How long had you been using it? (years)					

Code 4: nursery
1. Conventional seedbed on plot
2. Mat nursery with banana leafs
3. Tray nursery
4. Broadcasting

4.2.2.11. Why have you stopped using it? (Code 5)					
4.2.2.12. Workload nursery (days)					
4.2.2.13. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.3. Composting/Ploughing/Leveling					
4.2.3.1. Did you do composting (organic fertilisation) on plot? *If no, go to 4.2.3.3.*					
4.2.3.2. Since when have you done composting? (year)					
4.2.3.3. Have you ever applied composting on plot? *If no, go to 4.2.3.9.*					
4.2.3.4. Since when have you stopped using it?					
4.2.3.5. How long had you been using it? (years)					
4.2.3.6. Why have you stopped using it? (Code 5)					
4.2.3.7. Workload composting (days) Only for bringing compost to the plot!					
4.2.3.8. Workload	Total				

Code 5: Reason for disadoption
1. needs too much labor
2. don't know much about it
3. no good results
4. too difficult

(people needed)	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.3.9. Did you do ploughing of plot before planting? (1) yes, (2) no					
4.2.3.10. How did you do ploughing before planting? (code 6)					
4.2.3.11. Workload (days) ploughing? *If ploughing and leveling together, skip 4.2.3.12.!!!*					
4.2.3.12. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.3.13. Did you do leveling of plot before planting? (1) yes, (2) no					
4.2.3.14. How did you do leveling of plot before planting? (code 6)					
4.2.3.15. From which source do you know about leveling (code 2)					
4.2.3.16. Workload (days) leveling?					
4.2.3.17. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				

Code 6: ploughing
1. buffalo trampling
2. buffalo or cow with plow
3. tractor

4.2.4. Transplanting of seedling *Note: If respondent did broadcasting on plot (4.2.2.1.), please go to 4.2.5. 'Planting details'*					
4.2.4.1. In which month did you do transplanting?					
4.2.4.2. How old were seedlings when you did transplanting (days)					
4.2.4.3. From which source do you know how old seedlings have to be when time of transplanting? (code 2)					
4.2.4.4. Since when do you apply time of transplanting? (year)					
4.2.4.5. How much time did it take to bring seedling from nursery to the soil? (min)					
4.2.4.6. Did you use L-shaped technique to transplant the seedling? (1) yes, (2) no					
4.2.4.7. Have you ever applied another time of transplanting (age of seedlings)? (days) *If no, go to 4.2.4.11.*					
4.2.4.8. Since when have you stopped using it?					
4.2.4.9. How long had you been using it? (years)					
4.2.4.10. Why have you stopped using it? (Code 5)					
4.2.4.11. Workload (days) transplanting					
4.2.4.12. Workload (people needed)	Total				
	HH				
	Paid labor				

	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.5. Planting details					
4.2.5.1. Did you do row planting? (1) yes, (2) no *If no, go to 4.2.5.5.*					
4.2.5.2. Did you use rake for row planting? (1) yes, (2) no					
4.2.5.3 Since when did you do row planting?					
4.2.5.4. From which source do you know about row planting? (code 2)					
4.2.5.5. Have you ever applied row planting? (1) yes, (2) no *If no, go to 4.2.5.9.*					
4.2.5.6. Since when have you stopped using it?					
4.2.5.7. How long had you been using it? (years)					
4.2.5.8. Why have you stopped using it? (code 5)					
4.2.5.9. Did you plant single seedlings per hill? (1) yes, (2) no *If no, go to 4.2.5.11.*					
4.2.5.10. Since when do you plant single seedlings per hill?					
4.2.5.11. Have you ever applied planting single seedlings per hill? (1) yes, (2) no *If no, go to 4.2.5.15.*					
4.2.5.12. Since when have you stopped doing it?					

4.2.5.13. How long had you been doing it? (years)				
4.2.5.14. Why have you stopped using it? (code 5)				
4.2.5.15. Distance of plants/spacing (cm)				
4.2.5.16. From which source do you know about distance of plants/spacing? (code 2)				
4.2.5.17. Since when do you apply the distance of plants/spacing? (year)				
4.2.5.18. Have you ever applied another distance of plants/spacing? (cm) (1) yes, (2) no *If no, go to 4.2.6.*				
4.2.5.19. Since when have you stopped doing it?				
4.2.5.20. How long had you been doing it? (years)				
4.2.5.21. Why have you stopped using it? (code 5)				
4.2.6. Irrigation and water control				
4.2.6.1. Did you do circular re-irrigation on your plot? (alternating flooding and drying) (1) yes, (2) no *If no , go to 4.2.6.6.*				
4.2.6.2. Times of re-irrigation during last season				
4.2.6.3. From which source do you know about re-irrigation (code 2)				

4.2.6.4. For re-irrigation did you have to modify your irrigation system? (y/n)					
4.2.6.5. Since when do you do re-irrigation?					
4.2.6.6. Have you ever applied re-irrigation on plot? (1) yes, (2) no *If no, go to* *4.2.6.10.*					
4.2.6.7. When have you stopped doing it?					
4.2.6.8. How long had you been doing it? (years)					
4.2.6.9. Why have you stopped using it? (code 5)					
4.2.6.10. Workload (days) for water management					
4.2.6.11. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.7. Weeding					
4.2.7.1. Did you do weeding? (1) yes, (2) no *If no, go to* 4.2.7.7.					
4.2.7.2. How did you do weeding (code 7)					
4.2.7.3. When did you do 1st weeding after planting/transplanting (days)					

Code 7: weeding
1. by hand
2. weeder/landak
3. other (specify)

4.2.7.4. Total number of weeding during last season					
4.2.7.5. From which source did you know about weeding (code 2)					
4.2.7.6. Since when do you do weeding? (year)					
4.2.7.7. Have you ever applied weeding on plot? (1) yes, (2) no *If no, go to 4.2.8.*					
4.2.7.8. Since when have you stopped doing it?					
4.2.7.9. How long had you been doing it? (years)					
4.2.7.10. Why have you stopped using it? (code 5)					
4.2.7.11. Workload (days) for one weeding					
4.2.7.12. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.8. Herbicides					
4.2.8.1. Did you use any herbicide on plot? (1) yes, (2) no					
4.2.8.2. How much did you spent for herbicide? ($)					
4.2.8.3. Workload (days)					

4.2.8.4. Workload (people needed)		Total				
		HH				
		Paid labor				
		How much did you pay for paid labor (in total ($))				
		Friends, neighbours				
4.2.9. Pesticides/Fungicides						
4.2.9.1. Did you use any pesticide on plot? (1) yes, (2) no						
4.2.9.2. How much did you spend for pesticide on plot? ($)						
4.2.9.3. Workload (days)						
4.2.9.4. Workload (people needed)		Total				
		HH				
		Paid labor				
		How much did you pay for paid labor (in total ($))				
		Friends, neighbours				
4.2.10. Fertilizer						
4.2.10.1. Did you use any fertilizer on plot? (code 8)	1					
	2					
	3					
4.2.10.2. How much did you spend for fertilizer on plot? ($)						
4.2.10.3. Workload (days)						
4.2.10.4. Workload		Total				

Code 8: Fertilizer
1. UREA
2. SP 36
3. TSP
4. Pupuk daun (Fertilizer for leafs)
5. Other (specify)

(people needed)	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.11. Yields, Harvest & Treshing					
4.2.11.1. Date/month of harvest on plot? *(e.g. 1=January, 2=February, 3=March,....)*					
4.2.11.2. Workload for harvest (days)					
4.2.11.3. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.11.4. How did you do threshing? (Code 9)					
4.2.11.5. Workload for treshing (days)					
4.2.11.6. Workload (people needed)	Total				
	HH				
	Paid labor				
	How much did you pay for paid labor (in total ($))				
	Friends, neighbours				
4.2.11.7. In last harvest, how many of units did you harvest on plot?	Number				
	1. kg 2. tons 3. bins 4. bags/saks (50 kg) 5. bags/saks (75 kg)				

Code 9: Treshing
1. manual
2. treshing machine
3. other (specify)

	6. bags/saks (100kg)				
4.2.11.8. How much of paddy yields did you sell to private trader (government)? (kg)	Number				
	1. kg 2. tons 3. bins 4. bags/saks (50 kg) 5. bags/saks (75 kg) 6. bags/saks (100kg)				
4.2.11.9. How much of milled rice yield did you sell directly on the market? (kg)					
4.2.11.10. What price did you get selling milled rice directly on the market? ($/kg)					
4.2.12. Milling					
4.2.12.1. How far is the mill from your house? (km)					
4.2.12.2. How much did you have to pay to process rice in mill? ($ or kg of rice)					
4.2.12.3. How much is the transport from plot to mill? ($ or kg of rice)					
4.2.12.4. How much of yield do you keep for new seeds in the next rice season? (kg)					

4.3. Crops harvested *(except paddy rice)*

4.3.1. Did you harvest any crop during the last 12 month?	4.3.2. How much crop did you harvest during the last 12 months?	4.3.3. 1. Kg 2. Kaleng (11 Litres) 3. Kaleng susu (390g) 4. Buah (piece) 5. Karung (38) 6. Karung (50) 7. Karung (100 kg) 8. Bundle	4.3.4. How much of the crop you harvested during the last 12 month was sold?	4.3.5. What price did you get for the crop you sold?	4.3.6. Did you use any input for crop in the last 12 months?	4.3.7. How much input did you purchase during the last 12 months? **Code 1: Input** 1. manure 2. fertilizer 3. pesticide 4. herbicide 5. seeds		4.3.8. Workload to cultivate crop in the last 12 month?	4.3.9. Workload (people needed)				
Crop Name	Quantity	Unit	Quantity	$/unit	(code 1)	Quantity	Unit (1=litre, 2=kg)	Days	Total	HH	Paid labor	How much did you pay for paid labor (in total ($))	Friends, neighbour
Maize													
Cassava													
Coffee (drybeans)													
Kidney beans													
Sweet potatoe													
Potatoe													
Taro													
Squash													
Mung bean													
Soy bean													
Coconut													
Peanuts													
Vegetables													
Bananas													
Papaya													
Pineapple													
Other (specify)													

4.4. Livestock section

4.4.1. During the last 12 month, has any member of HH raised any animal?	4.4.2. How many animals are owned by your HH today?	4.4.3. If you sell one of these animals today, how much money could you get for it?		4.4.4. How many of your animals did you sell in the last 12 month?	4.4.5. How much money did you get for animal?	4.4.6. How many of your animals did you eat in the last 12 month?	4.4.7. How many of animal died, got lost, were stolen during the last 12 month?	4.4.8. How many of your animals did your HH gave away (gifts or dowry) during the last 12 month?	4.4.9. How many animals did your HH purchase during the last 12 month?		4.4.10. How many animals did you received as a gift during the last 12 month?	4.4.11. How much did you spend for vaccination of animal during the last 12 month?	4.4.12 Workload to raise animal in total during 1 week?	4.4.13. Workload (people needed)?				
	Number	$		No.	$	Number	Number	Number	N.	$/ea	Number	$/animal	Hours					
Animal		Small	big											Total	HH	Paid labor	Costs ($)	Family/ friends
Buffalo																		
Bali cow																		
Horse																		
Pig																		
Goat																		
Sheep																		
Chicken																		
Duck																		
Other (specify)																		

4.5. Products from livestock

4.5.1. During the last month did you produce any of product?	4.5.2. Quantity of product produced during last month?	4.5.3. Unit of quantity of product? (1. Litre, 2. Kg, 3.Number)	4.5.4. Quantity of product sold in the last month?	4.5.5. Price of unit in the last 12 month? ($)	4.5.6. Workload of processing/ selling of product (days)?	4.5.7. Workload (people needed)?				
						Total	HH	Paid labor	Costs ($)	Friends, family
Eggs										
Milk										
Coat, skin										
Other										

4.6. Forestry

4.6.1. Did your HH collect/produce any of product during the last 12 month?			4.6.2. How much did you receive from the sale of product in the last 12 month?	4.6.3 Workload	4.6.4. Workload (people needed)				
Product	Amount	Unit	$ (total)	Days	Total	HH	Paid labor	Costs ($)	Friends, family
Timber wood		Cubic metres							
Fuel wood		Bunch (.04 cu.m)							
Sandal wood		Kg							
Honey		Litres							
Rattan		Pieces							
Bamboo		Pieces (1.85 m)							
Candle Nut		Kg							
Other		(specify)							

4.7. Fishing/ Aquaculture

4.7.1. What is the value of the fish you catched consumed by members of your HH during the past 3 month? (in $)	4.7.2. What is the value of the fish you catched and purchased/or gave away to others for free during the past 3 month? (in $)	4.7.3. Workload (days)	4.7.4. Workload (people needed)				
			Total	HH	Paid labor	Costs ($)	Friends, family

4.8. Farming Equipment

4.8.1. How many implements does your HH own today?		4.8.2. How many equipments does your HH own today?	4.8.3. During the last 12 month has any member of HH owned equipment? (y/n)	4.8.4. During the last 12 month has any member of HH rented equipment? (y/n)	4.8.5. How many days in total did you rent equipment during the last 12 month?	4.8.6. How much did you spend per day to rent equipment?
Implements	Number	Equipment			Days	$
Hoes		Tractor				
Axes		Machine pulled plow or harrower				
Shovels		Animal pulled plow				
Picks		Mechanical water pump				
Big knife		Motorized thresher				
Sickle/Reaping hook		Rice winnower				
Hand thresher		Rice/Corn mill				
Rice miller		Motorized insecticide pump				
Crop drying area		Weeder				
Basket		Manual coffee grinder				
Other…		Ox cart				

5. Assistance received from other than HH’s members

5.1. Assistance	5.2. Have you or any member of HH received assistance from source during the past 12 month? 1. yes 2. no	5.3. What was the (estimated) value of assistance that you received in total during the past 12 month?		
		5.3.1. Government	5.3.2. Non-government Agency	5.3.3. Individuals
		$	$	$
Pensions				
Cash assistance from inside Timor Leste (not pensions!)				
Cash assistance from abroad (not pension!)/remittances				
Vaccination for cattle/buffalo				
Seeds				
Fertilizer				
Fruit tree				
Agricultural tools				
Non-agricultural tools				
Fishing nets				
Shelter/house repair assistance				
Building materials				
Rice (for eating)				
Corn (for eating)				
Other food (specify)				
Other (specify)				

6. Social/human capital

6.1. Membership in groups/organizations

6.1.1. User/ community group	6.1.2. Did you or someone from your HH participate in group during the last 12 months? (1)yes, (2) no	6.1.3. Are there any fees according to participation in group?	6.1.4. How many group meetings took place in the last 3 months?	6.1.5. How many times did you attend these meetings in the last 3 months?	6.1.6. What were the main activities of group in the last 3 months?	6.1.7. What benefits did you gain from the activities of the group in the last 3 months?
		$/month			1. credit 2. input purchase 3. production 4. physical infrastructure 5. marketing 6. information 7. social gathering 8. other (specify)	1. credit 2. input purchase 3. production 4. physical infrastructure 5. marketing 6. information 7. social gathering 8. other (specify)
Farming						
Women						
Youth						
Sport						
Church						
Other (specify)						

6.2. Agriculture extension

6.2.1.Have you heard about extension workers (MAF) in your village?	Yes		No		
6.2.2. Have you ever met an extension worker (MAF)?	Yes		No		
6.2.3. Has you or any member of HH ever participated in a group meeting from extension workers?	Yes		No		
	6.2.3.1. If yes, who? 1. respondent 2. spouse 3. both 4. other (specify)		6.2.3.2. If no, why not? 1. not interested 2. too far 3. don’t know place or time 4. not enough time 5. other (specify)		
	If yes, go to section ‘contact farmers’		*If no, go to section ‘noncontact farmers’*		
Contact farmers					
6.2.4. How many times did the extension worker visit you in the last four weeks?					
6.2.5. During the last visit, how many other farmers participated?					
6.2.6. What is the main activity of your farmer group?	Demonstration	Information	Social/ community	Extension	Other (please specify)
6.2.7. Are you participating in regular meetings?	Yes		No		
6.2.8. Would you like to be visited...	More frequently	Less frequently	Same		
6.2.9. Do you use (at least) one of recommended practices?	Yes fully	Partly	No, not at all		

6.2.10. Do you tell other farmers about recommended practices?	Yes		No	
6.2.11. Have you ever heard about the System of Rice Intensification (SRI)?	Yes		No	
6.2.12. If yes, from which source did you hear about SRI? (code 1) *Please list up to 4 answers only!*				
Noncontact farmers				
6.2.13. Are you aware that an extension agent comes regularly to your village?	Yes		No	
6.2.14. Do you know where the extension agent conducts meetings?	Yes		No	
6.2.15. Do farmers from a farmer group discuss extension recommendations with you?	Yes		No	
6.2. 16. Have you ever heard about the System of Rice Intensification (SRI)?	Yes		No	
6.2.17. If yes, from which source did you hear about SRI? (code 1) *Please list up to 4 answers only!*				

Code 1: source
1. family
2. neighbours
3. extensionist
4. farmer group
5.radio/television
6. NGO
7. Sign/demonstration plot
8. Other (specify)

6.3. Membership in program

Program	6.3.1. Did you or someone from your HH participate in program during the last 12 month? (1)yes, (2) no	6.3.2. Since when do you participate in program (mm/yyyy)?	6.3.3. How many group meetings took place in program in the last 3 month?	6.3.4. How many times did you attend meetings of program in the last 3 month?	6.3.5. What were the main activities of program group in the last 3 month? 1. irrigation 2. Planting techniques 3. Technical recommendations 4. Input use (fertilizer, persticides, herbicides) 6. other (specify)	6.3.6. What benefits did you gain from the activities of the program in the last 3 month? 1. irrigation 2. Planting techniques 3. Technical recommendations 4. Input use (fertilizer, pesticides, herbicides) 5. other (specify)	6.3.7. What problems did the group of program encounter in its activities during the last 3 month? 1. no problem 2. too few members 3. members not motivated 4. no leadership 5. lack of funds 6. lack of rules 7. lack of influence 8. other (specify)
Agricultural programme from other agency (e.g. NGO)	 Name agency:						
Tractor program from government							
Hybrid program from government							
Other (specify)							
Other (specify)							

7. Negative events

7.1. In the last 5 years, did any major crop fail due to natural disasters (drought, flood, heavy rain,...)? (y/n)

7.2. If a crop failed for several years, please list this crop separately for every year it failed

7.2.1. Crop (code 1)	7.2.2. Year the crop failed	7.2.3. Reason for failure (code 2)	7.2.4. Percent of yield lost to 'normal yield' (%)

Code 1: crop
1. Rice
2. Corn/maize
3. Cassava
4. Coffee
5. Kidney beans
6. Sweet potatoe
7. Potatoe
8. Taro
9. Squash
10. Mung bean
11. Soy bean
12. Coconut
13. Peanuts
14. Vegetables
15. Bananas
16. Papaya
17. Jackfruit
18. Pineapple
19. other (specify)

Code 2: Reasons for failure
1. lack of water/draught
2. other weather phenomena
3. desease/ pest
4. other

Code 3: member was
1. head
2. spouse
3. other male member
4. other female member

Code 4: cause
1. illness
2. accident
3. other

7.3. Was there any major accident/illness in the last 5 years, that made an adult member (age 15-55) of your HH was unable to work for at least 2 month or totally stopped working? (   ) yes   (   ) no

7.4. .If yes, please answer the following table

7.4.1. Year, it occurred	7.4.2. Sex (m/f)	7.4.3. Age (years)	7.4.4. Member was? (code 3)	7.4.5. Cause of inability to work? (code 4)	7.4.6. For how many month HH-member could not work?

8. Credit

Credit source	8.1.1. Did you take any credit during the last 12 month? (1)yes, (2) no	8.1.2. If you would need a loan today, could you get one? (1)yes, (2) no	8.1.3. Did you apply for a loan before, and did not get the whole sum of your request? (1)yes, (2) no
Bank			
Governmental credit programme			
Credit group			
Shopkeeper/trader in village			
Shopkeeper/trader outside village			
Relatives in village			
Friends in village			
Other persons in village			

8.2.1. Are you a member of an informal credit or saving group? (   ) yes   (   ) no

8.2.2. If no, have you ever been a member of an informal credit or saving group? (   ) yes   (   ) no

☺ THANK YOU VERY MUCH FOR YOUR ATTENTION ☺