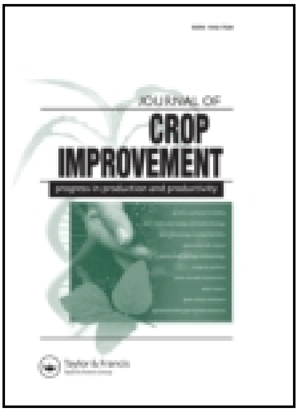

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Varietal Diffusion in Marginal Seed Systems: Participatory Trials Initiate Change in East Timor

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Participatory on-farm trials of introduced varieties of the major staple crops were implemented in East Timor to contribute to addressing chronic national food insecurity. This paper confirmed the suitability of the participatory varietal selection approach by measuring high early adoption (over 80% one year after the trials). Three years on, significant areas of the new varieties were managed by adopters, and planting material from a third of the trials had been shared with an average of five non-participating households. However, crop failures (particularly from climatic hazards and animal damage) and the loss of planting material were common, reducing subsequent diffusion with crop characteristics and the availability of planting material playing critical roles. The study showed that on-farm testing was key as a first-stage mechanism in marginal areas but insufficient alone to achieve permanent varietal insertion in these particularly isolated farmers' seed systems. To ensure long-term adoption and broad diffusion, it

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is essential to combine the approach with comprehensive, flexible and reliable planting material sources. Linking the formal and existing farmers' seed systems at the community level appears to be the most promising option. The study also demonstrated that small, well-defined surveys can be critical, cost-efficient tools to monitor technology diffusion in resource-poor areas.

KEYWORDS Farmers' selection, informal seed supply, technology monitoring, adoption survey, agricultural development

INTRODUCTION

The overall limited success of seed aid agencies and governments in marginal agricultural areas has triggered a relatively recent interest in analyzing the specificities of their seed systems (Sperling, Cooper, & Remington 2008). East Timor (Timor-Leste), a small mountainous country, one of the youngest and poorest in the world, offers a prime example of such marginal areas that have been explored very little. Over 80% of its 1.1 million people are marginal subsistence farmers, the majority of which suffer from severe poverty and food insecurity (National Statistics Directorate & ICF Macro 2010). East Timor agriculture is largely small-scale and family-based. Providing sustenance for the household is the main priority, even when cash crops are cultivated. There is negligible access to external inputs such as chemicals and, despite budgetary allocations for 'modernization' (World Bank 2009), the vast majority of farmers rely solely on manual labor. Only a fraction of rural households have good access to market, institutions, and public services (NSD & ICF Macro 2010). Agricultural extension services are just starting to develop (World Bank 2009).

Soon after the country's upheaval in 1999, a mission led by researchers from the Australian Centre for International Agriculture Research (ACIAR) and the Consultative Group on International Agricultural Research (CGIAR) identified the lack of germplasm as one of the main factors limiting agricultural production. Considering the country's post-conflict situation (Erskine & Nesbitt 2009), an intervention in this area was considered to be the most cost-effective route to impact (Borges et al. 2009). In 2001, the Seeds of Life program (SoL) started with germplasm introduction followed by varietal evaluation on-station of the major staple crops: maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz), rice (*Oryza sativa* L.), sweet potato (*Ipomoea batatas* (L.) Lam.), and peanut (*Arachis hypogaea* L.). In 2005 an expanded SoL, co-funded by ACIAR and AusAid and embedded within the Ministry of Agriculture (MAF), shifted the focus to participatory on-farm testing along with capacity building. Introduced lines, previously identified on research stations, were compared to farmers' local varieties in unreplicated trials implemented in several hundred farms every year (over 2,500 on-farm trials implemented in four years; Borges et al. 2009; SoL 2006, 2007, 2008, 2009). The primary objective was to test lines on-farm under farmers' management. A secondary objective was to disseminate the best-performing germplasm among households, farmer-to-farmer. Through several years of participatory testing, a number of lines showed high yield across East Timor's range of agro-ecological zones and agricultural diversity without additional inputs or change to the farming systems. On-farm evaluation extended to such post-harvest characteristics as taste, storability (weevil tolerance), and market potential to ensure widespread adoption. In 2007, seven introduced lines suitable for farmers and with considerable yield advantages over local varieties were released by MAF (Table 1). Their adoption by farmers augured considerable food security and economic impacts at both household and national levels (Borges et al. 2009; Erskine & Nesbitt 2009).

The first cohort of on-farm trials was implemented in the 2005/06 cropping season. The next year, a survey of all participating farmers was conducted to determine adoption rates following successful on-farm trials (Williams et al. 2008). Approximately 80%, 55%, 65%, and 80% of farmers replanted SoL varieties of maize, sweet potato, peanut, and rice, respectively. On average, 10% of participating farmers had already passed seeds on to other farmers, particularly of rice and maize. In 2008, the second year following the first on-farm trials, it was found in another exhaustive survey that 60% and 50% of farmers replanted the varieties of maize and rice, respectively, but only 5% did so for peanut and sweet potato (SoL 2009). Farmers' preferences and willingness to replant the introduced varieties were also monitored, as part of the standard data collection process. Results confirmed participants' enthusiasm for the new varieties, mostly because of their high yield and good taste (SoL 2006 to 2009).

With variety dissemination clearly progressing for some crops and not others, several questions were raised. Were adoption rates two years after trials underestimated? If not, what caused the declines in adoption? If the lack of seeds, which is a constraint to adoption elsewhere (Sperling, Cooper, &

TABLE 1 Yield advantages of SoL varieties over local checks after four years of on-farm trials (2005/2006 to 2009/2010)

Crop	No. of varieties released by MAF	Yield advantage ranges over local checks
Maize (*Zea mays* L.)	2	+46%, +50%
Sweet potato (*Ipomoea batatas* (L.) Lam.)	3	+66%, +81%, +158%
Peanut (*Arachis hypogaea* L.)	1	+47%
Irrigated rice (*Oryza sativa* L.)	1	+21%

Source: Seeds of Life (2006, 2007, 2008, 2009, 2010a).

Remington 2008; Aw-Hassan, Mazid, & Salahieh 2008) is implicated, we need to determine precisely why apparently suitable varieties are being dis-adopted in East Timor. The survey presented here, conducted three years after the initial on-farm trials, was designed to understand the mechanisms involved in the adoption and diffusion of new varieties in marginal, developing agricultural areas. The paucity of information available about East Timorese seed systems was an additional motivation for the study, particularly since the question of which characteristics these systems share with other better understood systems in other marginal seed systems needs to be answered to plan development strategies.

Most surveys to understand farmers' seed systems and varietal change concentrate on a single crop and require significant resources (sampling hundreds of households, arrays of weighted variables, and complex statistical tools; see, for instance, Sall, Norman, & Featherstone 2000; Nagarajan & Smale 2007). The lack of local resources required for such exhaustive investigations combined with the need for reliable information quickly on the four crops led to the choice of a different method. As underlined by Erenstein (2010, p. 277), "Agricultural research and development would benefit from reliable yet cheap" monitoring of uptake. This is particularly relevant in a post-conflict environment where surveying resources are limited. Despite differences in scope, our approach has similarities with Erenstein's (2010) technology monitoring methodology. A relatively small sample was chosen and a reduced but semi-structured questionnaire was used with both quantitative and qualitative data being collected. The downsize in data quantity was compensated in its quality through constant cross-checking. In order to understand seed systems and adoption mechanisms, several aspects were explored after testing in an introductory phase. Firstly, adoption rates one and two years after the initial trials were re-investigated, and information about adoption three and four years after harvest was collected for the first time. Then, replanted areas and seed dissemination were examined to evaluate, respectively, the intensity of adoption and indirect impacts. Finally, reasons for non- and dis-adoption were systematically recorded to determine why and when the new varieties receded.

This study thus tests an approach to understand and quantify key mechanisms in the adoption of varieties by subsistence farmers. The information collected also contributes to an evaluation of participatory on-farm testing programs as a vehicle for germplasm diffusion in marginal areas of developing countries.

MATERIALS AND METHODS

The survey was conducted during May–June 2009 in the four districts where SoL had implemented on-farm trials for the first time three years earlier (2005/06 season: Manufahi, Aileu, Liquiça, and Baucau). Participant sampling was stratified to represent the diversity of environmental and management conditions while maximizing district representation. At the household level, this resulted in a random selection from farmers who had possessed enough material, i.e., those who had successfully conducted a least one of the initial trials.

Consequently, as summarized by Mekbib (2007, p. 63), a "farmers' seed system is defined as a system in which seed selection, seed production, seed storage, seed management, and seed diffusion are integrated with crop production", a semi-structured (or semi-open) questionnaire covering different components of farmers' seed systems was used. Questions included planting times during the initial trial (2005/06) and subsequent cropping seasons (2006/07 2007/08 and 2008/09), size and production of the last harvested areas planted to new varieties (i.e., three years after the initial trial), and planting intentions for 2009/10 (anticipated fourth year adoption). Where relevant, date and reasons for abandoning new varieties were collected. Also solicited were the quantities of planting material given to other farming households (dissemination) and their relationship to the farmer. Opportunities for the respondents to ask questions themselves or give further explanations were encouraged.

The survey was conducted by SoL staff who had implemented the initial trials with the respondents in 2005/06. The survey was presented as part of their routine monitoring activities. Prior to the survey, training was conducted to improve the survey questionnaire and familiarize staff with handling farmers' responses. Particular attention was given to dates and quantities. Regarding field areas, few measurements were made as a prior survey determined that farmers' estimates were, most of the time, reliable (SoL 2009). Production levels, volumes, and quantities were solicited to enhance confidence in the responses. On average, each interview took one to two visits of about 20 min to complete.

Results were analyzed at the sample scale (total number of households and/or of trials), with adoption rates disaggregated per year, crop, gender and agro-ecosystem. Successful adoption for a given crop was defined as at least one introduced variety replanted and harvested satisfactorily. Statistical analyses were performed with GenStat Discovery 3.

RESULTS

Sample Characteristics

A total of 131 on-farm trials were investigated. This number approached 30% of all the trials harvested that season (approximately 25% of maize, peanut, and rice trials, and 40% of sweet potato; SoL 2006, 2007). The 131 trials corresponded to a total of 90 households, as some simultaneously conducted up to three different crop trials in 2005/06, (67% of households implemented

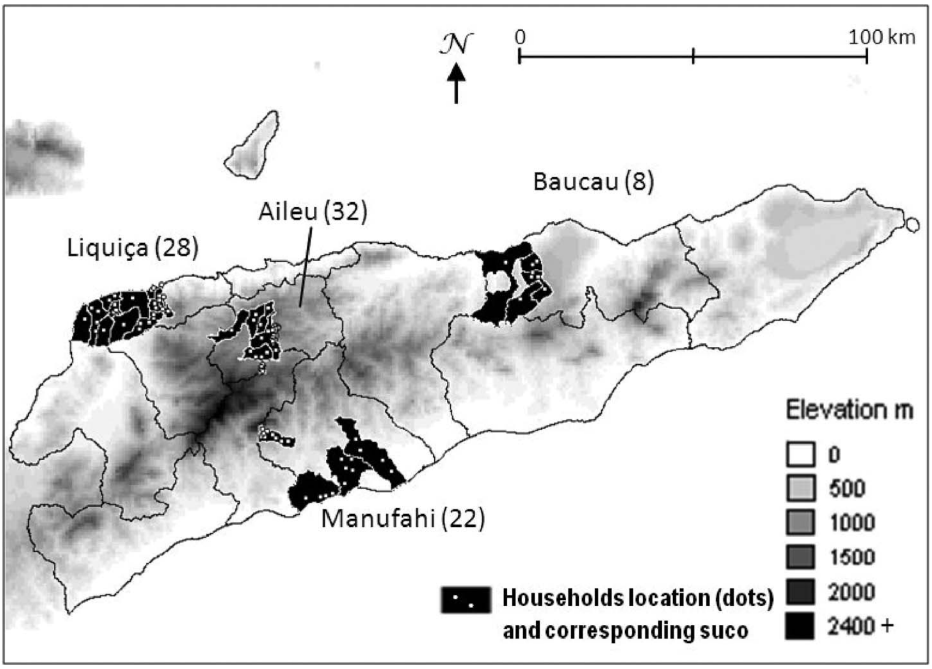

FIGURE 1 Locations of the surveyed households (number per district) in East Timor.

a single trial, 21% had two, and 12% had three). Nineteen percent of the households were female-headed, which was close to the national average of 12% (NSD & ICF Macro 2010).

Trials consisted of one (rice and peanut), two (maize), or three (sweet potato) introduced varieties compared with a local check. Seven subdistricts were represented (Alas, Same, Aileu-Villa, Liquidoe, Liquiça-Villa, Maubara, and Vemasse) corresponding to 48 hamlets (‘*aldea*’) distributed in 28 villages (‘*sucos*’, administrative division, Figure 1).

Adoption Rates

Figure 2 presents the adoption rate results for each year and crop investigated. Not replanting a variety in the subsequent season was found to be a permanent barrier (i.e., no dis-adopter later re-adopted).

Adoption rates were highest the year following the trial, particularly so for rice and maize, with nearly 95% of the farmers replanting a variety. Rates were lower for sweet potato and peanut at 75%. Adoption rates then steadily declined, with about a third of the replanting farmers dis-adopting each year. Three years after the on-farm trials, adoption rates were 45%, 32%, 13%, and 58% for maize, sweet potato, peanut, and rice, respectively, and anticipated to further fall to around 30%, 25%, 10%, and 50%, respectively, in the fourth

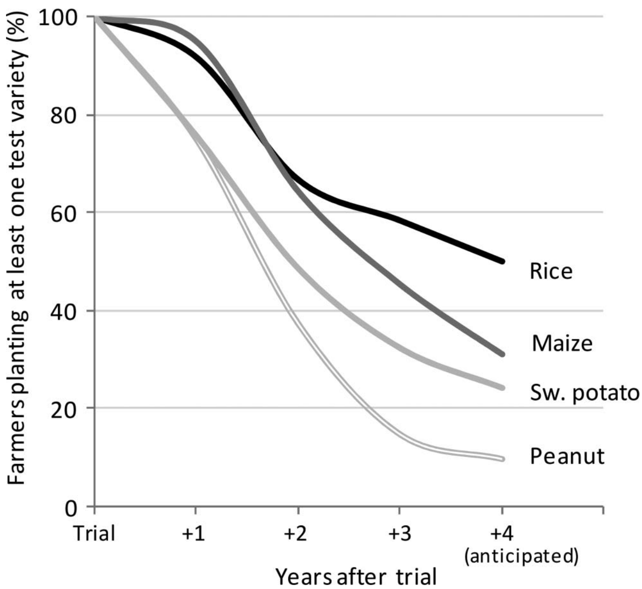

FIGURE 2 Adoption rates of one or more test varieties after the initial 2005/06 on-farm trials.

year. Male and female-headed households adopted similarly when assessed by χ^2-test. No significant agro-ecosystem effect was identified either.

Replanted Areas

The change in area three years after the initial trials (originally 25 m^2 plot per variety) was investigated. On average, maize and rice fields replanted in modern varieties were approximately 0.5 ha per household, whereas those of sweet potato and peanuts were a few hundred m^2 (Table 2). A number of farmers mentioned that they were unable to expand adoption further because of a lack of planting material. We found no evidence of a household using planting material other than from its own stock.

Fields were planted with more than one new variety for a majority of sweet potato (usually a mixture of the two or three tested lines) and for half the maize and peanut fields. New varieties were planted alongside locals that were never discarded.

TABLE 2 Areas replanted to modern varieties three years after the 2005/2006 on-farm trials

Crop	Maize	Sweet potato	Peanut	Rice
Initial average trial area (m^2)	50	50	25	25
Proportion (%) of households still replanting in 2008/09	45	32	15	58
Areas (m^2) planted per household in 2008/09	4,200	230	315	7,215

TABLE 3 Dissemination resulting from the 2005/2006 trials (2006–2009 period)

Crop	Maize	Sweet potato	Peanut	Rice
Number of trials	42	37	40	12
% of trials which led the participating household to give planting material to other families (recipient) at least once during the 2006–2009 period	43	27	25	50
Average number of recipient households per original households	5.2	4.7	2.9	5.7
Average quantity of planting material received by each recipient household	7 kg	25 cuttings	1 kg	20 kg

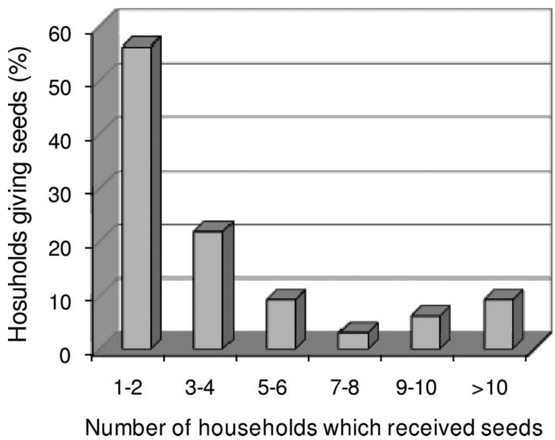

FIGURE 3 Number of households given maize, sweet potato, peanut and/or rice planting material from participating households (2006–2009 period).

Dissemination of Planting Material

A third of the trials led to the distribution of planting material to other households at some point between 2006 and 2009 (Table 3), a majority of which were to one or two other households, 20% of which were to three or four (Figure 3). Sixteen percent of all transactions accounted for 48% of the total number of recipient households. All recipients were relatives of distributing households and most were located nearby. The transactions were non-monetary.

Maize and rice were distributed more often (over 45% of the participating households) and in larger quantities than peanut and sweet potato. Regarding the latter, only cuttings were distributed, i.e., always intended as planting material. From anecdotal evidence this was also mostly the case for peanut and maize, whereas rice was distributed both as a grain for consumption and as seed for sowing.

Reasons for Dis-adopting Test Varieties

Dis-adoption is defined as the abandonment of previously adopted varieties. When asked why they had stopped planting the new varieties, farmers usually gave one main reason, less frequently a combination of two or three. Two dozen reasons for dis-adoption were recorded from a total of 126 answers with their frequencies given in Table 4.

In only 3% of the cases did farmers not replant a test variety because they disliked it (unsuitability to local conditions, otherwise taste). Mostly (97% of the time), farmers liked the varieties and wanted to replant them; they were, however, unable to do so because they had insufficient planting material (corresponding to 60% of non-replanted fields after three years, Figure 4).

The loss of planting material was very clearly attributed to the following major reasons: crop failure was most important (82%), largely caused by weather (27% too much or too little rain), followed by damage from

TABLE 4 Reasons for the dis-adoption of tested varieties (2006–2009)

Crop	Maize	Sw. potato	Peanut	Rice	All
Number of crop dis-adoption cases	31	28	37	5	101
Number of reasons invoked by farmers	42	29	48	7	126
Abandonment caused by 1 reason only (%)	68	96	76	60	78
Reasons for dis-adoption (%)					
Crop failure	**71**	**90**	**88**	**71**	**82**
- Climatic hazards	**31**	**21**	**27**	**43**	**28**
Drought / insufficient rain	19	10	13	43	16
Flooding / excessive rain	10	10	15	0	11
Wind	2	0	0	0	1
- Wandering animals	**19**	**66**	**15**	**0**	**27**
Pigs	2	31	6	0	10
Cattle	7	24	2	0	9
Dogs	7	0	6	0	5
Goats	2	10	0	0	3
- Rodents	**12**	**0**	**21**	**14**	**13**
- Poor germination	**0**	**0**	**21**	**0**	**8**
- Pests and diseases	**10**	**3**	**4**	**14**	**6**
Insects / Grubs / Worms	5	3	2	14	4
Diseases	5	0	2	0	2
Post-harvest losses	**19**	**3**	**8**	**14**	**11**
Weevil	14	0	0	0	5
All eaten by the household	5	3	8	14	6
Others	**5**	**3**	**2**	**14**	**4**
Sick / Pregnant	5	0	2	0	2
Had to move to another location	0	3	0	14	2
Dislike	**5**	**3**	**2**	**0**	**3**

Note: Weeds, stolen seeds/tubers, labor and land issues were mentioned as issues but never as a reason for loss of a crop or stored planting material. Rotten tubers were associated with excessive rainfall.

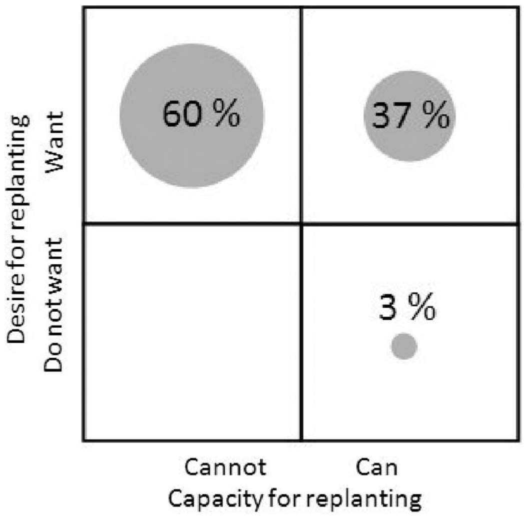

FIGURE 4 Constraints to adoption (percentages out of 131 trials) three years after the initial 2005/06 trials.

free-roaming domestic animals (27% by pigs, cattle, dogs, and goats) and rats (13% and mostly before harvest, particularly for peanut). Although diseases and insects were problems, they were seldom the reason for crop failure (6%). Post-harvest losses accounted for 11% of the reasons for losing planting material. This was mostly from maize weevil damage and insufficient production to cover both consumption and planting.

Crop-wise, sweet potato was mostly destroyed by roaming animals, but never by rats. In peanut, poor germination was recognized as a specific reason for crop failure. Of post-harvest losses, weevil damage was most important on maize (14% of seed loss reasons). The sample size for rice was small (five dis-adopting farmers), with inadequate rainfall being the main reason for the loss of the tested variety.

DISCUSSION

Adoption Rates

The adoption of modern varieties has been generally low among subsistence farmers in marginal areas of developing countries (including in East Timor, Williams et al. 2008), an issue that participatory research efforts specifically addresses (Almekinders & Niels 2002; Walker 2006). The process is still in its early stages in East Timor and varietal change is only starting. Nevertheless, with 75% to 97% (crop-wise) of participating farmers adopting modern varieties of major food crops one year after an on-farm trial, the SoL initiative is an outstanding illustration of the potential of participatory research for resource-poor farmers.

Even compared with adoption rates in similar successful initiatives (Walker 2006; Aw-Hassan, Mazid, & Salahieh 2008), the initial adoption levels of SoL varieties are exceptional. The SoL varieties are also strikingly ubiquitous across agro-ecologies. By contrast, in other participatory initiatives varieties are usually specific in adaptation and by local farmer choice (for instance, Aw-Hassan, Mazid, & Salahieh 2008). The combination of high adoption rates and broad adaptation in East Timor is an indicator of the gap existing between the introduced modern lines and the local varieties. This, in turn, reflects the lack of previous varietal research on staple crops as well as the prevailing post-conflict environment (Walker 2006; Erskine & Nesbitt 2008).

Compared with earlier surveys, we found similar maize and rice adoption rates but higher rates for sweet potato and peanut. Anecdotal evidence suggested that there were underestimates in previous data collection due to surveyors not recording specific planting dates. In this survey, particular care was taken to avoid errors linked to varying rainfall patterns, which allow one to two crop cycles (Molyneux et al. forthcoming). Additionally, regarding the vegetatively propagated sweet potato, a cutting may be planted only once, which does not signify dis-adoption since it can be maintained over time as planting material.

Another source of error came from earlier surveys heavily reliant on asking farmers about their planting intentions. However, crop failure and other seed losses usually occur unpredictably. It may be hypothesized that, after successive years of cropping new varieties, only farmers with the will, means, and conditions to replant remain adopters, while reluctant and vulnerable farmers have previously dis-adopted. Nevertheless, replanting remains difficult to predict in hazard-prone subsistence farming in a volatile, un-controllable environment. This was confirmed by a number of farmers who indicated that, "Yes, we will replant if we have the planting material to do so," thus expressing their desire to replant rather than their ability to do so. Our survey was conducted after the harvest of crops in the 2008/09 season when farmers' confidence in their ability to replant was supported by actual stocks of planting material. Risks of post-harvest losses, however, still existed and had to be accounted for. Consequently, it is best to conduct adoption surveys as late as possible after harvest or, ideally, just before planting.

The approach taken in the study was to understand key mechanisms in varietal adoption by subsistence farmers and, to this end, we tracked the initial farmers over time. We recognize that second-hand and third-hand adopters were not tracked, so the adoption levels measured for initial growers may be a low estimate of overall adoption.

Impact on Biodiversity

As previously observed (SoL 2007; Borges et al. 2009), despite their higher yields (and often better taste) SoL varieties were found to complement local varieties rather than completely replacing them, resulting in increased on-farm biodiversity. When asked why they retained their local varieties, adopters often said, "Our varieties are well adapted to our local conditions," underlining the resilience value of the landrace material. The retention of landraces is common in marginal agriculture for risk avoidance through the maintenance of heterogeneity (particularly when markets are missing) and for the conservation of desirable varietal attributes (with regard to cultivation, consumption, and social aspects) (Brush & Meng 1998; Asrat et al. 2010). Increased varietal richness was observed as a result of several other participatory varietal research initiatives (e.g., Walker 2006).

Two other side effects of SoL participatory research are the exposure of staff during the course of monitoring on-farm trials to a range of local varieties and *in situ* conservation by farmers at minimal cost (Brush & Meng 1998). This is particularly important in a poor country so far without a gene bank, as well as in the broader context of crop genetic erosion.

Replanted Areas

Typically a household in East Timor farms 0.8 to 1.5 ha, most of which is sown to maize or rice (complemented by cassava), while peanut and sweet potato are planted in small home gardens. Besides the lesser importance of these crops in the diet, several reasons explain those smaller areas. First, peanut and sweet potato planting material is heavier, more cumbersome, and fragile (Figure 5a). For sweet potato, it is difficult to maintain runners over the dry season, while for peanut sown areas are small because the crop is particularly labor intensive (fencing, weeding, harvesting).

The average areas sown with new varieties by adopters three years after the initial trials were approximately 0.5 ha per household for rice and maize and a few hundred m^2 for peanut and sweet potato (often less than 100 m^2 and up to 500 m^2). In other words, the intensity of adoption, as defined by the proportion of the area planted in new varieties (Aw-Hassan, Mazid, & Salahieh 2008), was considerable for each crop: more than half the areas in sweet potato, at least half the areas in maize and peanut, and a minimum of a quarter for rice. The frequent mentions of a lack of planting material indicated the potential for even greater scope of adoption.

Small fields are in great danger of being completely destroyed by animals (Figure 5b). In this survey, domestic animals were responsible for nearly 50% of new varietal losses for peanut and sweet potato grown in small areas compared with 30% for maize and rice. Sweet potatoes are particularly

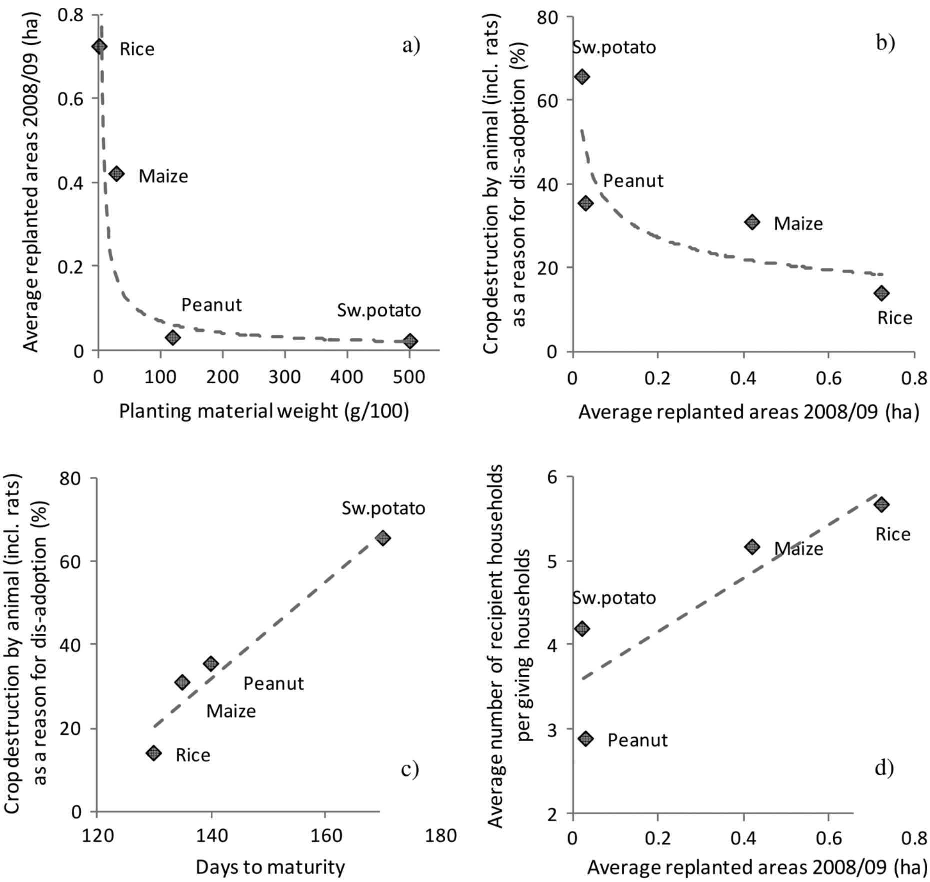

FIGURE 5 Planting material characteristics and diffusion patterns.

at risk because they are attractive to roaming domestic animals and remain in the ground for an extended period (Figure 5c).

Dissemination of Planting Material

Williams et al. (2008) found that, one year after the on-farm trials, about 10% of participating households had given planting material to family members. Three years after, at least a third of the surveyed households had shared seeds and cuttings to an average of five family-related, often neighboring, households. This may be an underestimate as farmers, probably unsure if sharing was acceptable to SoL staff, seemed reluctant to divulge the information. Notable exceptions were members of farmer groups who, in contrast, were proud of the number of people benefiting from group activities. Generally, these group farmers were also responsible for a large amount of the total seed transfer. Aw-Hassan, Mazid, and Salahieh (2008) also showed that informal farmer-to-farmer dissemination plays a key and efficient role in the diffusion of new barley varieties in Syria, with some farmers being particularly well connected to the local network(s). In our case, however, no market-based mechanism was identified: East Timorese farmers maintain their own planting material and when needed rely on social networks since the relevant public sector is very limited and the private one almost non-existent (SoL 2010b). A similar behavior was observed by Mekbib (2007) in Ethiopia because of the rigidities of the formal and private seed systems. Another recent example can be found in Chile where seed exchanges of a marginal crop rely almost solely on social networks with important 'nodal individuals' (Aleman et al. 2010). In all these cases, the common denominator was the lack of alternative seed sources. It should nevertheless be noted that even when other channels exist and cash-based exchanges develop, social networks remain critical aspects of farmers' seed systems, as underlined by the work of McGuire (2008) and Badstue et al. (2006, 2007).

Quantities of transferred planting material varied from a handful to a bag, depending on how much the households could spare. Each non-participating household receiving planting material could plant, on average, a few thousand m^2 of new varieties for rice and maize, a few hundred m^2 for peanut, and some additional m^2 for sweet potato.

Consistently with previous findings (Williams et al. 2008), maize and rice were found to be more often disseminated than sweet potato and peanut and in greater quantities. One reason for this is the existence of farmer groups for maize and rice and not for sweet potato and peanut. As also previously suggested by Williams et al. (2008), other important factors are that maize and rice produce greater quantities of planting material than peanut and sweet potato (larger planted areas [Figure 5d] and more seeds [planting units] per plant). Finally, rice was more disseminated than maize because rice farmers are generally wealthier than their maize counterparts (SoL 2008) and hence more easily able to spare seed.

Reasons for Dis-adopting Test Varieties

The study confirmed that adoption rates steadily declined, reaching 50%–10% (crop-dependent) four years after the trial. However, dis-adoption contrasted with farmers' continuing enthusiasm for the introduced varieties, indicated by the dissemination of planting material to other households and the increased areas replanted by adopters. Explanations for dis-adopting are discussed below.

A crucial factor of adoption/dis-adoption was the very small quantity of the initial planting material—sufficient for only 25 m^2. As a consequence, it was not possible for farmers to spread the risks against crop failure. Very few dis-adoptions (3%) were due to a dislike of the new varieties (Figure 4). The tested varieties were deemed suitable and/or associated with sufficient advantages compared to local checks to be selected by farmers, as proven by the high initial adoption rates. The early integration of farmers' preferences and their involvement in the selection process were critical elements of this achievement (Sall, Norman, & Featherstone 2000; Aw-Hassan, Mazid, & Salahieh 2008). Another key factor was that adoption required no change to farmer management practices.

In other participatory programmes, farmer dis-adoption is often an adaptation since formerly adopted varieties or even crops are replaced by newly available cultivars better fitted to the local agro-ecosystem or to varying circumstances such as changes in conditions (pest, climate) or in economic alternatives (new market for instance) (Walter 2006; Aw-Hassan, Mazid, & Salahieh 2008). In this case, the lack of planting material was responsible for 93% of the dis-adoption of introduced varieties. As noted by Mekbib (2007, p. 64), "In a bad cropping season, farmers were forced to use seed sources other than their own (depleted) stock." But unlike local varieties, for which seed systems are entwined with social networks that can provide planting material, East Timorese farmers are currently unable to re-access lost new varieties. Eighty-two percent of dis-adoption resulted from crop failure (primarily from climatic hazards and destruction by animals), while post-harvest issues accounted for an overall 11% shared between lean season problems (consumption of all seeds) and weevil damage on maize. The various factors invoked were often associated with a specific set of circumstances leading to the loss of planting material:

1. Climatic hazards were responsible for 28% of farmers' dis-adoption with both floods and drought being common. This reflects farmers' poor control of water, particularly critical in a country with major year-to-year rainfall fluctuations (Molyneux et al. forthcoming).
2. Free-ranging domestic animals were nearly as destructive as climatic extremes, particularly pigs and cattle, followed by dogs and goats. These animals are poorly supervised and fencing is made of natural, relatively fragile materials.
3. Rodent damage, particularly from rats, constituted 13% of the reasons for losing planting material. Most of the damage occurred during growth, as post-harvest damage is limited by various storage techniques (Guterres and Williams 2006). Social reluctance to kill rats, which are commonly associated with ancestors by animist beliefs, limits active control.
4. Downy mildew and stem borer are important maize issues in East Timor, responsible for significant losses in crop performances. Peanut is particularly affected by early and late leaf spot disease, while sweet potato suffers from leaf scab and viruses. However, insects and diseases accounted for relatively low percentages of actual crop failures (overall: 6%).
5. Another issue often related to partial crop failure was insufficient grain produced for both consumption and retention of seed from one year to the next (6% overall as well). East Timorese farmers preferentially keep

their own seeds rather than purchase from markets, which are deemed unreliable for seed quality and type. However the 'hungry season,' which affects 90% of rural households for one to six months every year (SoL 2007, 2008, 2009), puts a significant number of households under such pressure that they cannot afford to keep planting material. Additionally, farmers mentioned that the new varieties were eaten first because they tasted better. This may also result from a farmer preference to retain local seeds when facing difficult situations (risk avoidance strategy with a new technology).

6. Crop-specific reasons for losing planting material were:
   a. Maize is the chief staple food in East Timor and the crop impacted by the widest range of factors. Additional to the previously discussed factors was storage. Weevils (*Sitophilus* spp.) are a known major problem in East Timor (Guterres & Williams 2006). A common answer includes drying cobs in their sheaths and storing them above the fireplace. A very promising alternative is on-farm storage in airtight containers such as metal drums (Guterres & Williams 2006) — a solution yet to be generalized in East Timor (WFP 2006; SoL 2006) — combined with the breeding of weevil-tolerant varieties with long, tight sheaths that can be tied in a knot to create a physical barrier (SoL 2007, 2010a).
   b. Animal damage was a problem common across the crops but was by far the most important reason for varietal loss in sweet potato (66%). The combination of three factors explains this: First, sweet potato is usually grown near the house and the domestic animals (a third of losses due to pig predation only, a quarter from cattle). Second, sweet potato does not justify the heavy labor input required to build a strong fence, being considered less valuable than maize and peanut, the major staple food and cash crop respectively among non-rice farmers; nonetheless, in some regions the introduced varieties have been in the marketplace since 2007 (SoL 2008). Additionally, keeping sweet potato implies maintaining cuttings in the ground during the dry season when they are often the only green crop and hence attractive to animals. The other reasons for losing sweet potato planting material were the lack of or excess of rain (10%), the first leading to difficulties in keeping cuttings alive and the second leading to rotten tubers. No rodent nor weevil predation losses were noted. Farmers avoid sweet potato weevil infestation (*Cylas* spp.) by digging out tubers progressively as soon as soil cracks appear above them.
   c. No critical post-harvest losses due to insects were found for peanut, the shell of which, once mature, offers an effective physical barrier against most pests. Losses were mostly due to climatic hazards, rats (due to their ability to dig out pods), and the specific issue of poor germination. Anecdotal evidence suggests that this might be related to such factors as micro-nutrients (lack of Ca) or immature/damaged

seeds (particularly from fungi). Since peanuts are kept within the shell, seeds cannot be examined until planting time.

d. While climatic hazards impacted all crops, the lack of rain was the major reason for irrigated rice failure. Specifically, irrigation issues most often result from terminal drought as springs dry toward the end of the season.

The Need for Improved Planting Material Access, Information and Targeting

The survey showed that the SoL participatory trials, designed primarily to test introduced lines under farmers' management and secondly for their dissemination, were highly successful in the former objective but inadequate in the latter. For diffusion, the available quantity of planting material was found to be critical in determining adoption rates, replanted areas, and farmer-to-farmer dissemination. In 2008–2009, MAF through the Food and Agriculture Organization of the United Nations (FAO) and non-governmental organizations distributed 80 tons of SoL seeds (SoL 2009). This, however, was still insufficient to significantly impact most farmers' seed supply, or to reach a critical mass of seeds in community networks as is the case for landraces. The study showed that this is largely due to East Timorese farmers' seed systems presenting particularly acute characteristics of marginal areas in a developing country: they are resilient but extremely isolated, heavily rely on social networks, and despite important — and often uncontrollable — seed losses, they remain self-sufficient since alternative seed sources to the farmers' own stocks are negligible (Figure 6). To ensure universal availability and access to the new varieties in such environments, the need for reliable, quality, cost-effective, flexible, and sustainable planting material multiplication and distribution systems, both formal and informal, at national and community levels, was identified as critical (Sperling, Cooper, & Remington 2008; SoL 2010b).

The general lack of success of formal systems to supply modern seeds in marginal areas, as well as the undying importance of the informal sector, have been acknowledged in recent years, while the need for linking both through participatory approaches has been recognized (Bishaw & Turner 2008). Community-based seed multiplication groups offer a particularly promising avenue since farmers groups were found to contribute substantially to dissemination. The ICARDA village-based approach in Afghanistan is a recent example of this approach, which proved to be both successful and economically viable (Srinivas et al. 2010). Logistic advantages are also to be expected from locally based systems as well as added exposure of farmers to the new material. In this regard, the implementation of thousands of trials, at a national scale and closely monitored by district-based staff, not

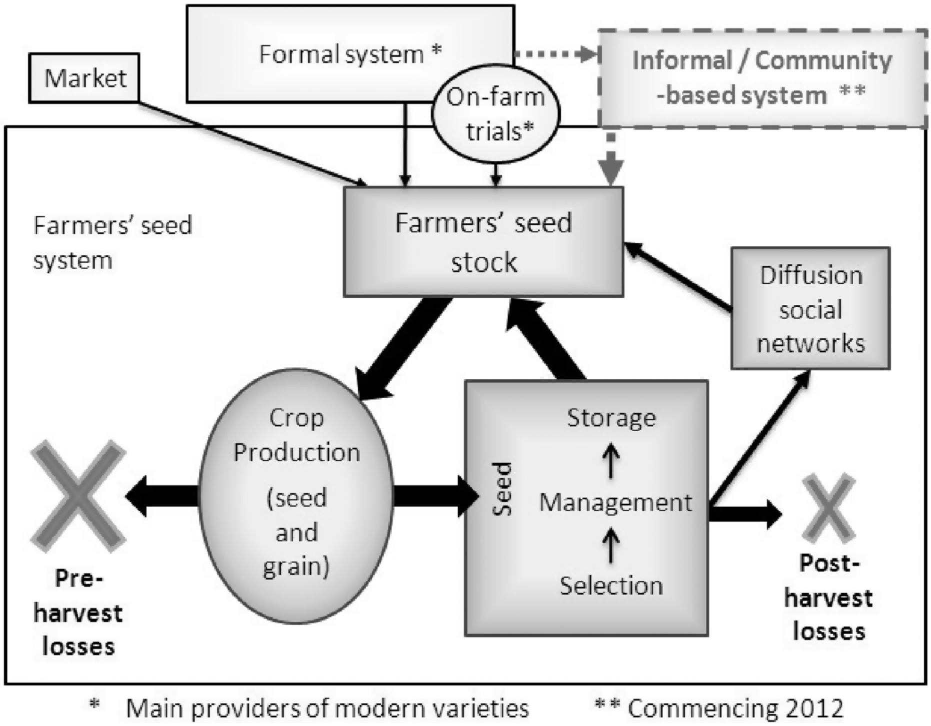

FIGURE 6 Seed systems in East Timor.

only represented an exceptional capacity-building instrument (MAF research staff), but also a significant awareness tool (information directly accessible to farmers) and extension medium (participatory development process). Those benefits need to be reinforced and completed by information campaigns using all available media forms. Sharing planting material must also be recognized as a valuable farmer attitude and encouraged.

Several other specific findings indicate the direction of future efforts. First, cost-effective on-farm storage is a prerequisite since protecting maize against weevil damage has the twin advantages of saving both food grain and seed. Particular attention should also be paid to sweet potato, peanut, and other fragile or cumbersome crops because of their specific problems on the road to diffusion. Market-based systems, still virtually non-existent for the major crops in East Timor, would require attention. Finally, further elucidation of the existing seed systems are needed to insure their adequate linkage with the newer formal system (Almekinders & Niels 2002; Sperling, Cooper, & Remington 2008). For example, since socio-economic characteristics are known to heavily influence technology uptake, a typology of farmers (including gender dis-aggregation) and farming systems could help target those households most vulnerable to hazards and varietal loss. Systematic monitoring would ensure mid-course corrections.

Lastly, it should not remain unnoticed that the extensive feedback on technology diffusion provided highlights the value of the approach taken in this study of a small, carefully designed, and meticulous survey to understand the underlying complex mechanisms in comparison to more extensive but less integrative surveys.

CONCLUSION

The SoL on-farm trials proved to be an effective tool to select new varieties of the major food crops in East Timor, confirming participatory varietal selection as a valuable research approach. The approach was also highly beneficial in capacity building and an invaluable pilot for germplasm diffusion. The adopted varieties complemented local varieties rather than replacing them, resulting in increased on-farm biodiversity.

The on-farm trials were primarily designed for selection and demonstration—varietal diffusion was a secondary function. Crop destruction by climate hazards and animals, as well as post-harvest weevil damage for maize, hinders production and thus the adoption and diffusion of the new varieties. Nevertheless, considering the small size of the initial trials, the observed replanted areas and dissemination levels three years after the trials of adopting farmers were substantial.

The identified key constraint to diffusion was the lack of seed, both in term of quantity and availability, with important crop specificities. To achieve widespread diffusion in the marginal agricultural systems of East Timor and contribute significantly to national food security, the implementation of comprehensive seed systems including seed multiplication, distribution channels, information campaigns, on-farm storage, and targeted strategies were identified as priorities.

Through the investigation of seed systems dynamics, this study provided evidence that small, well-defined surveys are critical cost-efficient tools in monitoring technology diffusion, an enterprise particularly challenging in a post-conflict, developing country environment.

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