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*Research article*

# Improving rice-based rainfed production systems in Southeast Asia for contributing towards food security and rural development through sustainable crop production intensification

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**Abstract:** Continuing degradation of the environment and the cumulating food, energy, water and financial crises have led to a situation where many people's access to sufficient, nutritious food is affected as well as their livelihoods, income, and ultimate food and nutrition security. In the wake of these stresses and crises, there is an emerging interest to find efficient, easily accessible and sustainable approaches that can address these crises. One candidate for this is the System of Rice Intensification (SRI) with its "less can produce more" prescription. A regional collaborative project currently underway is being implemented in rainfed areas of the Lower Mekong River Basin (LMB) countries. This involves smallholder rice farmers, researchers, extension personnel, and development professionals, together with staff of relevant government ministries (http://www.sri-lmb.ait.asia/). The project objective is to produce healthier and profitable rice crops under rainfed conditions using SRI methods, evaluated and refined through farmers' participatory action research (FPAR). As part of the action-research, more than 120 sets of field experiments have been carried out at 60 FPAR sites in Cambodia and Thailand, directly involving 3600 farmers. The experiments have ranged from the integration of many SRI principles with farmers' current local practices or improved practices which was termed as "SRI-transition" to full demonstrations and assessments of SRI methodology, i.e., SRI demonstration. The initial calculation of yields has showed an average paddy yield of 5.03 t/ha with SRI-transition, whereas with SRI-demonstration the average yield was 6.41 t/ha. These yields were 60 and 100% higher than the average baseline yield in the region, 3.14 t/ha, for the same farmers and same locales. Productivity gains (dollars gained/dollars spent per ha) were calculated for both rainfed and irrigated production areas. In comparative terms, the economic gains for farmers were found to be higher in rainfed areas when using the new methods. This paper addresses the potential of new strategies to promote food security in rainfed areas in the LMB region by managing household and natural resources more productively.

**Keywords:** Lower Mekong River Basin; System of Rice Intensification; rainfed rice production; food and nutrition security; smallholder farmers

## 1. Introduction

Continued degradation of the environment and the various food, energy, water and financial crises which have been caused by multiple drivers, including prevailing economic models for production, consumption and development, have led to a broader realization that these crises, if not addressed successfully, impede people's access to sufficient, nutritious food, affect their livelihoods, income and food prices, and ultimately worsen food and nutrition security. Although the repercussions of these multiple crises are global in nature, the vulnerability of rural communities whose livelihood is directly linked to agriculture and who are mostly food-insecure is a major concern for predominantly local agrarian economies. In particular, this is relevant in the Lower Mekong River Basin (LMB) region where a majority of the countries' poor households live in rural areas and depend on agriculture for their livelihoods.

The LMB region encompasses the Lao PDR, Vietnam, Thailand and Cambodia. Out of 65 million inhabitants of this large basin (604,300 km$^2$), 60 million people in the LMB reside mostly in rainfed areas. Agriculture along with fishing and forestry employs 90% of the people living in the Lower Basin, mostly on a subsistence level. Over 10 million hectares of land are devoted to rice cultivation in the LMB, out of which 6 million hectares are rainfed, characterized by seasonal flooding and drought, low cation exchange capacity and low organic matter in the soil, and low availability of phosphorus, all resulting in lower productivity. Farmers operate with limited cash flows so they must carefully weigh the risks of adopting any costlier farming techniques, given the level of uncertainty.

There is widespread poverty in the basin, and almost one-third of its population are living on less than one dollar per day. For example, in Northeast Thailand, the largest rice-producing area in the country with the greatest number of farms (2.7 million); income per capita is less than 40% of the national average, and the incidence of poverty is high, affecting more than 37% of the population [1]. Though the situation has relatively improved in recent years, still almost three out of five poor people in the country reside in this region.

The situation is even more depressing and chronic in Cambodia, where rainfed lowland rice is the single most important crop, occupying 69% of the total cultivated area [2] and contributing 75% toward people's per capita calorie supply; almost 36% of this population is food-insecure [3]. Likewise, in Laos the average GNP per capita is just US$280—lowest among all LMB countries. Rice constitutes almost 70% of the calorie and protein intake of Lao households, and chronic malnutrition affects up to 47% of the population. A similar situation prevails in upland areas of Vietnam, where the rainfed rice-based production system predominates and is associated with widespread food insecurity.

These figures show that the rice-based production system is the mainstay for most households' survival, although presently an inadequate one, constraining both livelihoods and food security in the region. Major and common constraints to rice production in the region are poor fertility of the soil, highly seasonal and unreliable patterns of rainfall, frequent droughts, and limited access to inputs and credit [4], plus limited farm management skills. The population of the LMB is expected to increase from 60 million to 90 million by 2050 [5] without any real increase in availability of production resources.

This will further increase the demand for food and put greater adverse pressure on land and other natural resources [6]. This means that large increases in the amount of water and other physical inputs would be required to achieve the goal under a "business as usual" scenario. No economic sector consumes as much fresh water as agriculture. Current irrigation water withdrawals already cause stress in many of the world's major river basins [7]. There is stiff competition between industries and agriculture for water, so very little room for expansion of large-scale irrigation is available.

An additional, exacerbated threat to food supply is expected from climate change. The rainy season from May to October is expected to intensify with an increase in rainfall in the wettest months, whereas in the dry season from November to April the basin is expected to receive slightly less rain than now. Thus, both seasonal water shortages and floods are expected in the region. Farmers of the basin have already been experiencing early drought spells for the last 2–3 years, although the currently ongoing El Niño phenomenon complicates attribution.

While food security at a national level is not an issue in the Lower Mekong region if there is sufficient rain during the growing season and if there is a stable national and international market, at the household and individual levels food and nutrition security is still a major concern in Cambodia and Laos and in some parts of Vietnam and Thailand. For example, in Thailand, national per capita availability of rice is the highest in the world; however, farmers of the Northeast region still struggle to escape from temporary and seasonal food insecurity. Thus, agriculture faces increased demands for food, on one hand, and threats to production due to resource constraints and climate change variability, on the other. A step towards addressing the challenges of increasing food demand and reducing poverty is to increase sustainably the agricultural productivity especially of smallholder farms.

Several interdisciplinary and integrated modes of enquiry have been established at the plot level with a "less can be more" prescription. Recently the System of Rice Intensification (SRI) has been gaining momentum at farmers' field level, capturing their attention by enabling them to get higher yields with reduced external inputs, and fuelling their capacity for innovation (e.g., SRI concepts and methods are being extrapolated to other crops, such as wheat, finger millet and sugar cane [8].

It is believed that SRI could be instrumental in developing sustainable solutions to local agricultural problems, especially for smallholders who have fewer economic inputs but who have better control over their resources [9,10]. The SRI management principles—transplanting young seedlings, giving plants more space, avoiding continuous flooding—when implemented together have in many instances resulted in substantial increases in yield while reducing input use [10–13]. Most of the good results, more specifically *evaluation results*, have been reported from irrigated areas, however; whether SRI idea can be useful in achieving higher yields with greater resource use efficiency in rainfed areas is still to be understood.

To understand this and to learn more about SRI's usefulness for contributing towards achieving food security at household level, a regional collaborative project, funded by the European Union, is being implemented in rainfed areas of the Lower Mekong River Basin (LMB) countries involving smallholder farmers (including women and landless), researchers, extension personnel, and development professionals, together with staff of relevant government ministries (http://www.sri-lmb.ait.asia/). The project objective is to produce healthier and profitable rice crops under rainfed conditions using SRI methods, evaluated and refined through farmers' participatory action research (FPAR).

This paper shares the results of more than 120 sets of field experiments, which were carried out at 60 FPAR sites located in five provinces in Cambodia and Thailand directly involving 3,600 farmers during wet season of 2014 from June to December. It addresses the potential for introducing new strategies for managing household resources more productively for rainfed agriculture so as to contribute towards enhanced food security in the LMB region using farmer-participatory learning methods.

## 2. Materials and Methods

### *2.1. General approach*

Five food-insecure provinces, three in Cambodia and two in Thailand, were selected in consultation with relevant government ministries, respectively, the Ministry of Agriculture, Forestry and Fisheries (MAFF) in Cambodia and the Ministry of Education (MoE) in Thailand. In the latter selection, provinces were identified by the National Food Insecurity and Vulnerability Mapping System (FIVIMS). Then in each province, three districts were selected, making a total of 15 districts in the region (Figure 1). Out of these 15 districts, 13 districts were entirely rainfed, whereas two districts, both located in Northern Thailand, have partial access to irrigation facilities.

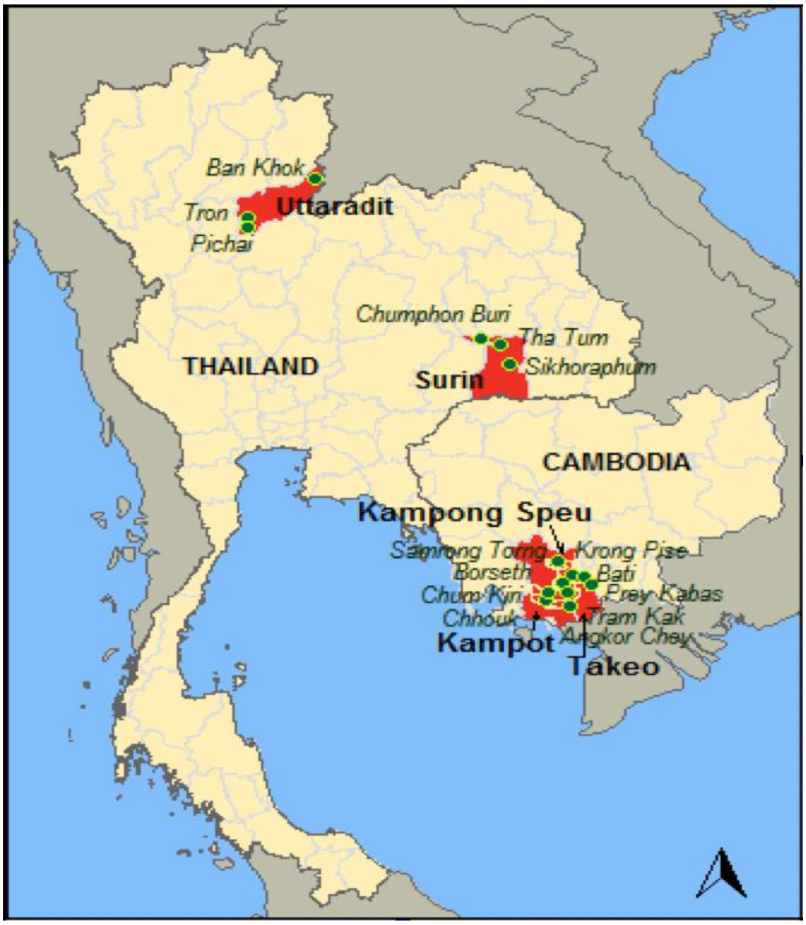



**Figure 1. Geographical map showing the action research site, 9 districts and 3 provinces in Cambodia and 6 districts and 2 provinces in Thailand.**

*2.2. Baseline survey*

Prior to commencement of farmer's participatory field experimentation, a baseline survey was done in each identified FPAR district with the objective of visualizing the pre-project scenario and for establishing criteria for selecting village and farmer, landless and women participants. With this information, a representative sample of farms was selected from each identified FPAR district in terms of farm resources, area, and crop type.

The respective farmers were surveyed using a semi-structured questionnaire designed for the purpose. The questionnaire was developed and adapted as per country-specific needs prior to pre-testing at village level. Questions were asked about general household information, farm characteristics, and socio-economic conditions, access to productive capital, agricultural practices, production and income, migration patterns, and familiarity with SRI. Pre-testing was done, and accordingly questions were modified and finalized. The final questions were translated into the respective local languages prior to the survey.

The baseline findings were used to assess and benchmark the existing parameters for comparison, and also for design of training interventions, including FPAR curricula and training module design, and the design of field experimentation.

General biophysical and socio-economic characteristics for sampled villages and households in all five provinces are given in Table 1, which were gathered through participatory rural appraisal and baseline survey.

**Table 1. Biophysical and socio-economic characteristics of five provinces of Cambodia and Thailand (Values shows mean ± standard error).**

| | Cambodia | | | Thailand | |
|---|---|---|---|---|---|
| | Kampot | Kampong Speu | Takeo | Surin | Uttaradit |
| Soil characteristics | Sandy loam *(Chumkiri district.);* Loam *(Angkor Chey and Chhouk districts.)* | Sandy loam (Krong Pisey district); Loam *(Samrong Trong and Borset districts.)* | Sandy loam (Tram Kak district); Loam (Prey *Kabas and Bati districts.)* | Sandy loam (Tha Tum and Srikoraphum districts); Clay loam (Chumponburi dictrict) | Clay (Ban khok, Pichai and Tron districts) |
| Average annual rainfall (mm) | 1409 ±110.21 | 1297 ±105.63 | 1318 ±102.35 | 1294 ±111.51 | 1243 ±103.54 |
| Topography | Lowland | Lowland | Lowland | Lowland | Lowland (Tron and Pichai) and Upland (Ban Khok) |
| Average landholding (ha/household) | 0.9 ±0.008 | 0.64 ±0.003 | 0.84 ±0.004 | 3.04 ±0.002 | 3.4 ±0.003 |
| Average age of farmers (years) | 54 ±2.16 | 55.25 ±2.78 | 57.5 ±2.58 | 55.25 ±2.21 | 57.5 ±2.57 |

| | | | | | |
|---|---|---|---|---|---|
| Average household members | 5.6 ±0.22 | 6 ±0.31 | 5.9 ±0.21 | 4.63 ±0.19 | 4.53 ±0.11 |
| Average household labour | 4.76 ±0.17 | 5.1 ±0.19 | 4.42 ±0.18 | 2.3 ±0.09 | 2.2 ±0.07 |
| Total household income (US$) | 1906.13 ±115.5 | 2473.3 ±112.8 | 1939.34 ±145.12 | 5976.57 ±239.04<br>2162.67 ±64.86* | 6178.98 ±216.16<br>2627.01 ±112.96* |
| % income from rice farming with respect to total household income | 19 ±0.66 | 21 ±0.84 | 22 ±0.92 | 48.66 ±1.70<br>22.33 ±0.77* | 76.84 ±3.15<br>32.66 ±*1.07 |
| % income from **non-rice** farming | 15 ±0.66** | 8 ±0.18** | 6 ±0.24** | 10 ±0.25 | 9 ±0.29 |
| From livestock *(only 30-40% household in Cambodia)* | 67 ±%2.68 | 51 ±%1.9 | 62 ±2.48% | -- | -- |
| % Off farm income with respect to the total annual income | 40.1 ±1.8 | 38.21 ±1.68 | 42.3 ±1.22 | 51.34 ±2.00<br>56.97 ±2.16* | 15.82 ±0.52<br>41.92 ±1.55* |
| Average rice yield (t/ha) | 2.01 ±0.07 | 3.04 ±0.10 | 3.00 ±0.12 | 2.48 ±0.09 | 4.98 ±0.12 |
| % rice insufficiency*** | 19 ±0.79 | 14 ±0.30 | 17 ±0.45 | Sufficient production (but not stored for self-consumption) | Sufficient production (but not stored for self-consumption) |
| Household loans (US$) | 1042 ±45.84 (34% household) | 937 ±43.16 (45% household) | 844 ±38.82 (60% household) | 2294 ±100.93 (91.67% household) | 3442 ±134.23 (95% household) |

*Figures are for smallholders in project area

**only 10% household

***rice shortage with reference to rice food demand: 143 kg of milled rice/person in Cambodia and 110 kg rice/person in Thailand

### *2.3. Action research group and farm selection*

Using standard selection criteria [10], in each province three districts were selected, and in each district, four FPAR sites were identified for farmer-led field experimentation. At province level, a representative catchment area—centrally-located for a farmers' participatory action research site, also known as the CFPAR site—was selected for common meetings and for conducting season-long training and field experiments.

The training involved farmers selected from all three districts, district trainers, provincial coordinators, and resource persons from the project's regional coordination unit. From each district, eight farmers, two landless, and one district trainer from the local agriculture ministry were selected. The selection process ensured participation of at least 50% women farmers from each district.

The selection process itself commenced with an inception meeting for the whole community with the objective of discussing the purpose of the action research, creating ownership of the project, and discussing criteria for participation, i.e., representativeness for the catchment, definition of SRI, development of low-cost and profitable location-specific technology, farmers evaluating different options, etc.

Following that, a season-long training around field experiments, i.e., Central Farmers Participatory Action Research (CFPAR), was conducted with the objective to build and strengthen their capacity in experimentation and to develop training curricula on scientific, technical, social and managerial aspects. As a part of training on designing, conducting and evaluating field experiments, SRI and conventional practices were applied at each CFPAR site for comparison and evaluation purposes. The experiments were designed using randomized block design where each experiment had at least three treatments and four replications.

In successive seasons, two CFPAR-trained farmers, functioning as farmers' trainers, initiated FPAR experimentation at each FPAR site. On an average, two or more experiments were set up at each FPAR site using the same field layout practiced at CFPAR site, i.e., randomized block design with four replications. Each experiment involved 25–30 farmers. The size of the field experiments varied from 700 to 1000 $m^2$.

Prior to the CFPAR at provincial level, a regional training workshop was organized for all provincial coordinators and country coordinators with an objective to familiarize and strengthen the scientific capacity for experimental design, setting, data observation, analysis and recording; and to agree upon the country-specific criteria for selection of districts, villages, the CFPAR site, and farmer and landless participation.

### *2.4. Identification, testing and adaptation of SRI practices*

The FPAR commenced with a rehearsal of the problem diagnosis. The common issues and interests expressed by farmers in both countries were to achieve higher yield with reduced costs of production by reducing input use for cost saving and for making rice cultivation more efficient and profitable. Using various group-dynamic tools such as sub-group discussion, visual tools, and brainstorming sessions, a range of options were selected for each of the target areas that revolved around the integration of a few SRI principles with existing conventional practices to be applied on a learning plot for location-specific adaptation, but also to have application of the full set of SRI principles on a demonstration plot which would serve as a "test site" to test and show the full potential of SRI methods at smallholder farmers' field level. For comparison purposes, the practices that were applied were categorized into:

(1) Conventional practices (CP) - the existing management practices generally followed in the target area as identified through the baseline survey.
(2) SRI-demonstration (SRI-D) where the full set of SRI practices was applied.

(3) SRI-transition (SRI-T) where a few principles of SRI were applied in combination with modified or existing conventional practices. The word "transition" was used because the practices are generally transitioning towards SRI with different degrees of SRI adoption and types. To gain further insight on the practices being applied by farmers, SRI-T was further broken down into: 1) SRI-innovation (SRI-I), where a few principles of SRI were integrated with modified conventional practices, i.e., practices that do not fall in either category of SRI or CP, but that are improved and better than CP, and 2) SRI-locally adapted practices (SRI-LAP) where a few principles of SRI were integrated with CP.

CP is taken as the baseline for purposes of comparison and evaluation. Details of the SRI-D, SRI-T, and CP alternatives are given in Table 2.

**Table 2. Crop management practices followed in SRI-demonstration (SRI-D), SRI-transition (SRI-T) and conventional management practices (CM).**

| Crop management practices | Conventional practices (CM)* | SRI-transition (SRI-T)** | SRI-D |
|---|---|---|---|
| Seedbed | Wet seedbed with high seeding rate (more than 150 kg/ha) | Wet seedbed with less seeding rate (20–30% less than CM) | Dry raised seedbed with less seed rate (5–10 kg/ha) |
| Seedling age | More than 30-day-old | 16–30-day-old | 8–15-day-old |
| Seed rate/if doing direct seeding/broadcasting | More than 200 kg/ha | 20–30% less than CM | 5–20 kg/ha or less than 5 kg |
| Transplanting spacing | Random/less than 10×10 cm | 10×15 cm–19×19 cm | 20×20 cm–30×30 cm |
| Planting/hill | >5–6 seedlings/hill | 4–5 seedlings/hill | 1–3 seedlings/hill |
| Soil condition | Flooded (or no effort in maintaining aerobic soil condition | Relatively aerobic soil condition with respect to CM either through shallow water level or through intermittent drying | Maintaining aerobic soil condition at least for a week during tillering stage |
| Compost application | Less than 5t/ha | 6–9 t/ha | More than 9 t/ha |
| Weed management | Chemical and manual | With rotary hoe 1–2 times | With rotary hoe more than 2 times |
| Pest management | Chemical | Apply IPM | Apply IPM with emphasis on plant environment management |

*Established by baseline survey; **SRI-T includes both: SRI-I and SRI-LAP

SRI-I: SRI innovation—few principles of SRI + *modified* conventional practices

SRI-LAP: SRI locally adopted practices—few principles of SRI integrated with existing conventional practices.

As a part of FPAR, on an average four training-cum-observation sessions were conducted during the entire crop growth stages, corresponding to the transplanting/sowing, tillering, flowering and harvesting stages of the crop cycle. The first session was 4–5 days, and the other three sessions were 2 days each.

Data were recorded at three stages: tillering, flowering, and harvesting, and were recorded at two levels: 1) at farmer trainer level, which was recorded using farmers' diaries (input use, yield and cost-benefit, number of sessions conducted, number of FPAR participants, number of women participants, number of landless) and was cross-checked during backstopping visits by researchers, and 2) at researcher level, by both national and regional researchers, with an objective to study the effects of applied management practices on yield and income and other socio-economic implications, and also to learn about the SRI adaptation responses from FPAR farmers in their own fields. For monitoring and learning on SRI adaptation/adoption patterns at FPAR farmers' field, participants of both CFPAR and FPAR were surveyed.

Final results of the field experimentation were discussed and deliberated at the provincial workshops organized at the end of the FPAR involving farmers, researchers, local ministries, national universities, and development professionals from international organizations/institutions. Final data were entered in the project database created for each FPAR site. Data were compiled at provincial, national, and regional levels for further analysis and for presentation and deliberations at national and regional workshops.

### *2.5. Data analysis*

The data were analyzed using Kruskal Wallis rank ANOVA first. Computed F values for SRI-D and SRI-T and CP for selected parameters, yield, fertilizer use efficiency, and economic productivity gain, are presented in Table 3. Followed to that Meta-analysis was conducted to test the trends of the following: how SRI-I, SRI-LAP and SRI-D respond to yield in comparison to CP across the region, and also specifically in rainfed environments by excluding the yield data from irrigated areas and data from SRI demonstrations.

For meta-analysis, initially fixed effects model was considered. In the fixed model, if value of Q (heterogeneity in effect size) was statistically significant, then a random effects model was used. The random effects model assumes that the studies were drawn from populations that differ from each other in ways that could have an impact on the treatment effect. It follows that the effect size will vary from one study to the next for two reasons: the first is random error within studies, and the second is true variation in the effect size from one study to the next. Further, comparative analyses were done to evaluate the economic productivity gain (net return/cost of cultivation) with SRI-T practices in rainfed and irrigated areas with respect to baseline.

In order to understand the adaptation response of farmers for SRI practices in FPAR groups, cluster analysis was performed. Clusters were defined according to five parameters: 1) seedling raising method, 2) seedlings/hill, 3) seedling age, 4) spacing, and 5) aerobic soil conditions at least for a week at vegetative stage. For all five variables, the SRI-D definition, presented in Table 2, was used.

Data are presented as means ± standard error (*s.e).* In most cases, the analysis was performed across the country; and in some cases it was performed by production system, comparing rainfed with irrigated systems.

## 3. Results

### *3.1. Productivity gains with SRI and SRI-T practices across the region*

The results across the region showed that in the SRI full demonstration plots (SRI-D), the average yield increment was 100% higher than with conventional practices (CP) while in SRI-T plots, it was 60% greater. This resulted in increased fertilizer use efficiency (kg grain produced/kg inorganic fertilizer applied), which was 46 and 36% higher in SRI-D and SRI-T, respectively, compared to conventional practices (CP).

The economic productivity gain (the ratio of net return in dollars/dollars spent per ha) was calculated using the local costs of production and the prices for produce, using the producer prices reported from all FPAR sites (US$0.30 and 0.43 per kg in Cambodia and Thailand, respectively). It was found that the economic productivity gain was 339 and 284% higher with SRI-D and SRI-T, respectively, compared to CP. There was no statistical difference between SRI-D and SRI-T.

**Table 3. Computed F values, degree of freedom (*df*) from analysis of variance (anova) of rice yield, fertilizer use efficiency and economic productivity in SRI demonstration (SRI-D), SRI-transition (SRI-T) and conventional practices (CP) across the five provinces of Thailand and Cambodia.**

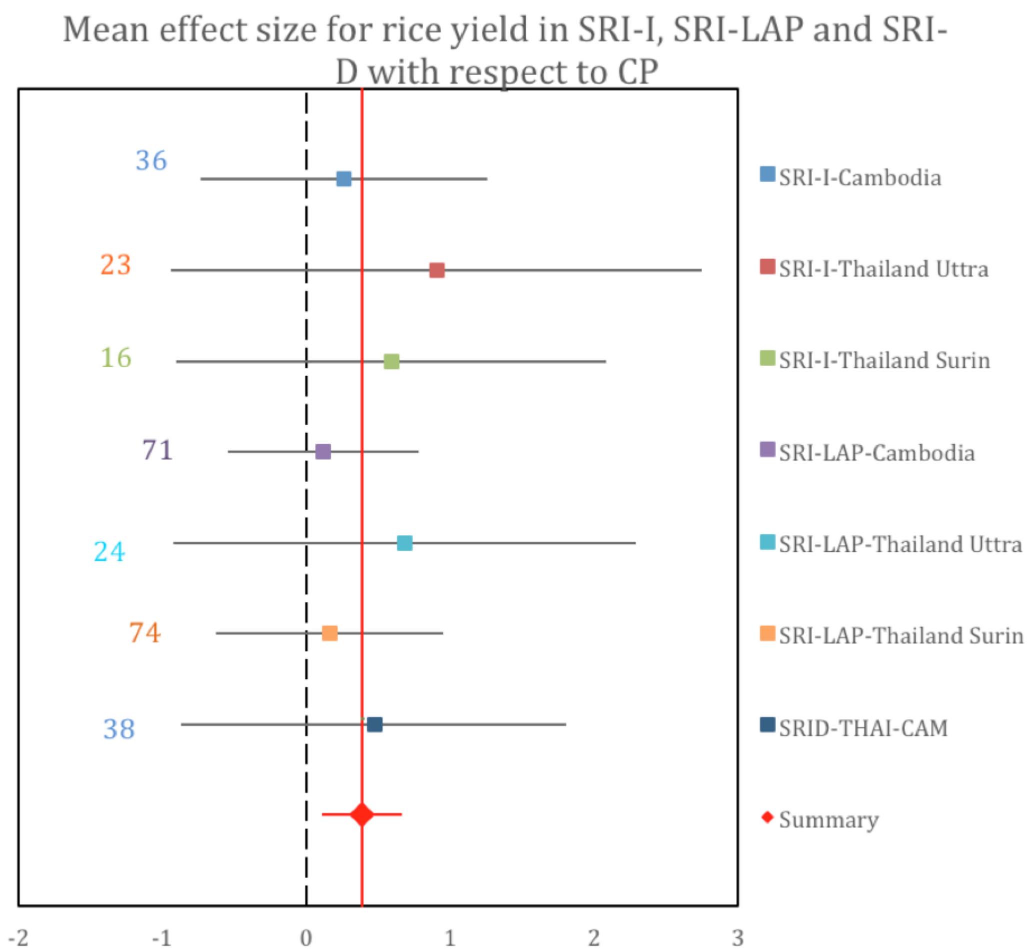
| | SRI-demonstration (SRI-D) | SRI-transition (SRI-T) | Conventional practice (CP) (baseline) |
|---|---|---|---|
| Rice yield (t/ha) | 6.41 ± 0.16 a | 5.02 ± 0.09 b | 3.14 ± 0.06 c |
| Fertilizer use efficiency (kg) | 40.46 ± 2.82 a | 37.68 ± 1.39 a | 27.66 ± 1.44 b |
| Economic productivity | 1.67 ± 0.11 a | 1.46 ± 0.07 a | 0.38 ± 0.03 b |
| *Rice Yield* | *F Value = 109.98** (df = 2, 299)* | | |
| *Fertilizer use efficiency* | *F value = 10.80** (df = 2, 299)* | | |
| *Economic productivity gain* | *F value = 52.25** (df = 2, 299)* | | |

Value in row shows mean ± standard error. Mean values sharing same letter in row are not statistically significant. **shows F value is significant at $p < 0.001$

### *3.2. Meta-trends of SRI-I, SRI-LAP and SRI-D yield with respect to conventional practice*

Data on SRI-I, SRI-LAP and SRI-D all indicated significantly higher yield benefits with respect to conventional practices. The overall effect size was positive and significant (Figure 2). The percentage of variation ($I^2$) across the studies due to heterogeneity (Q) was zero and therefore confirming the consistency of the studies and provides confidence in the trend obtained. Meta-trends were also observed to evaluate the yield gain or reduction in rainfed environments excluding yield data from the irrigated areas of two districts (Tron and Pichai in Thailand) and also excluding the yields from SRI demonstration plots (SRI-D) from both countries. Figures 3 shows the distribution of effect size across the studies for SRI-I and SRI-LAP, respectively under fixed model analysis. The results showed large effect size though with significant heterogeneity (Q) and variation ($I^2$) and so the data was further analyzed for random effects. Figure 4 shows the summary effect size for both SRI-I and SRI-LAP under random effects. An effect size of 0.2 is considered small, 0.5 moderate, and 0.8 large [14]. The overall effect size was large with insignificant heterogeneity (Q). Therefore, yield advantage under SRI-I and SRI-LAP with respect to CP can be confirmed.

Both SRI-I and SRI-LAP showed yield benefits with respect to CP. Positive and significant large effect sizes confirmed the benefit of applying SRI-T practices even in rainfed environments.




Summery effect size is 0.3886 with 95% Cl 0.1423 to 0.2790.

Heterogeneity test Q= 0.48 , df =6 , p=0.998 : $I^2$=0

The test of overall effect size: Z =2.730 (P=0.0063). Number next to error bars represent the number of replication used to calculate effect sizes in each category

**Figure 2. Standardized mean difference for rice yield in SRI-T (SRI-I and SRI-LAP) and SRI-D with respect to CP.** X axis shows the effect size. The effect size shows yield benefit in SRI-I, SRI-LAP and SRI D. Overall effect size is positive and significant.

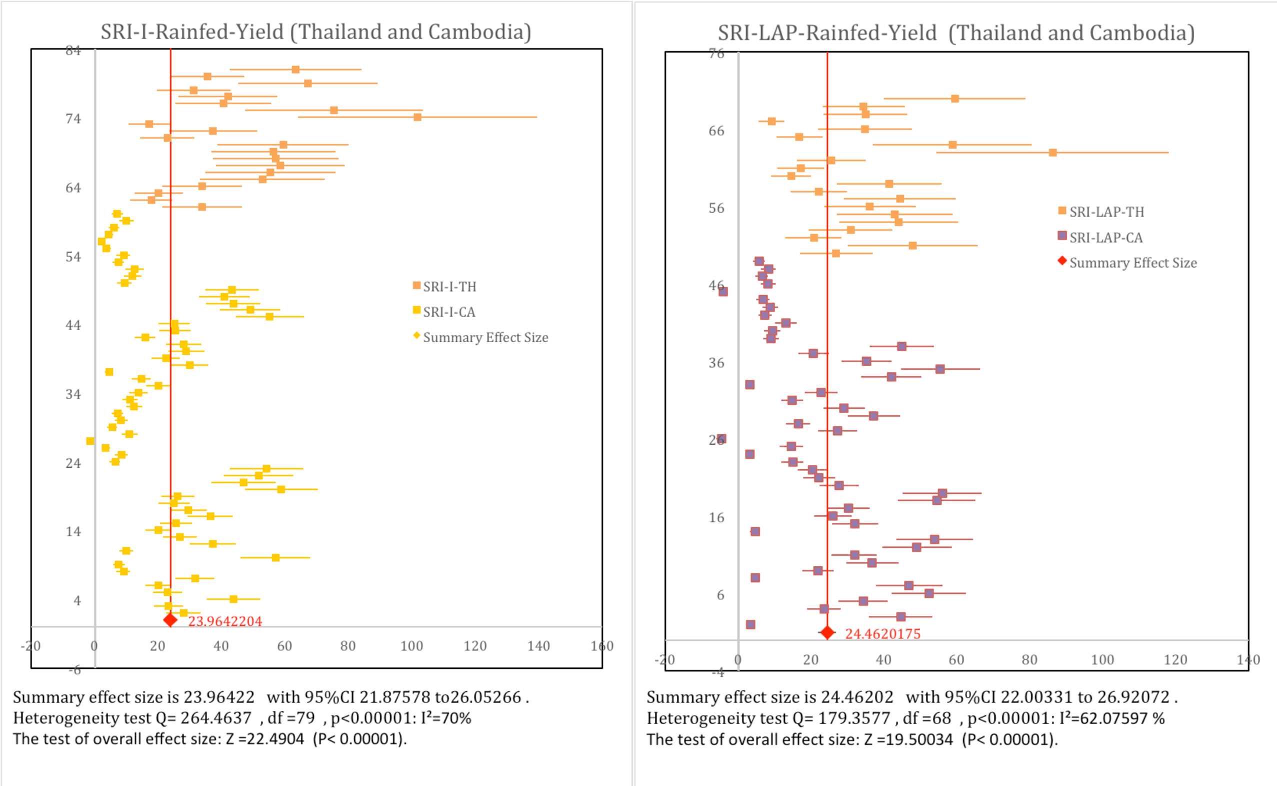



**Figure 3. Distribution of effect sizes across the studies measuring the effect of SRI-I and SRI-LAP practices in rainfed environment.** Effect sizes below zero indicate decrease in yield and above zero indicate increase in yield with respect to baseline yield (CP).

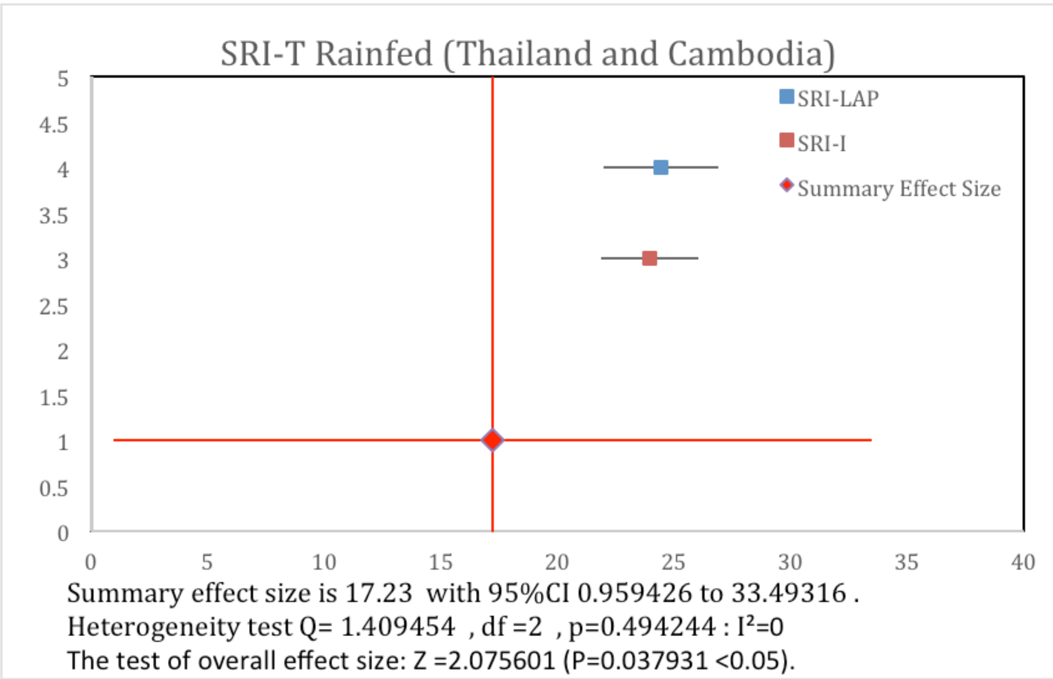



**Figure 4. Standardized mean difference for rice yields in SRI-T (SRI-I and SRI-LAP) in rainfed environment.** Effects sizes shows yield benefit in SRI-I and SRI-LAP with respect to baseline (CP). Overall effect size is positive and significant.

### 3.3. Economic implications of SRI-T practices

The economic productivity gains reflected in Table 3 were reported from FPAR sites. Further analyses of the economics of SRI-T were done for different scenarios utilizing the producer prices and domestic rice prices in both countries, and also the paddy seed price in Thailand since most of the FPAR farmers reported that they were able to sell their grain as seed at a higher price than for consumption. The input costs were also "actualized" based on the actual field conditions but also valued to get in-depth ideas on the factors involved and their cost that would affect micro-economics of rice cultivation.

Four different scenarios were considered as represented in Table 4. In the first scenario, the costs of all inputs were valued, including water cost and family labour, were considered. For rice price, the farmer's/producer's reported price was used, which was 0.30 and 0.43US$/kg in Cambodia and Thailand, respectively. With this scenario, it was found that overall economic productivity gain was more than three times higher in Thailand compared to Cambodia (Scenario 1a). This was due to the higher yield along with higher price of paddy.

Farmers of Thailand reported that SRI practices produced higher quality of grain that enabled them to sell their paddy as seed with a higher premium price. Accordingly, it was found that within Thailand, the economic productivity gain in rainfed areas was 28.5% higher compared to irrigated areas. Above all, in both countries and in both kinds of systems, both irrigated and rainfed, the productivity gain under SRI-T practices was much higher compared to baseline situation (CP).

In scenario 1b, we excluded the cost of labour for transplanting, weeding and harvesting in Cambodia as these operations are mostly done by family labour in the project areas (85–90%) and thus do not involve cash expenditure. In addition, we excluded the cost of water in Cambodian sites because all FPAR sites there are completely rainfed. Similarly, water cost was excluded from Surin province data in Thailand because the production system there is completely rainfed. In this scenario (scenario Ib), we found that productivity gain was highest in rainfed areas of Thailand compared to irrigated areas. Further, the economic productivity gains in rainfed areas of Cambodia and from irrigated areas of Thailand were similar.

In scenario 2a, we used the domestic rice price [15] for calculation. In this situation, when all inputs were valued, the productivity gain under SRI-T practices was again higher in the rainfed areas of Thailand compared to the irrigated ones. When we actualized the cost of inputs as reflected in scenario 2b, we found that the economic productivity gain was higher in rainfed areas of both countries compared to the irrigated areas of Thailand. Indeed, the productivity gains were again highest in Surin, a rainfed province of Thailand. Overall, this analysis showed that economic productivity gains were increased in both irrigated and rainfed system under SRI-T practices and were highest in rainfed areas compared to irrigated ones.

Further, as evident from Table 3, the gains under SRI-D were still more attractive given that the yield was 28% higher from SRI-D compared to SRI-T and 100% more than the baseline (CP). Accordingly, net profit was also higher in the SRI-D plots. The economic productivity gain was similar under SRI-D and SRI-T as shown in Table 3. The SRI-D's yield and profit showed the potential of SRI principles at the test sites when all practices were applied as recommended.

However, we have excluded these results from our discussion of productivity gains under SRI-D given that the field conditions of the SRI-D trials may or may not represent the actual field conditions under which farmers operate. Therefore, for our analysis, we focused on the results obtained from learning sites where farmers were encouraged to adopt and adapt SRI methods to develop their own technological options.

**Table 4. Computed F value, degree of freedom (*df*) from analysis of variance of economic productivity with SRI-T practices (dollar earn/dollar spent per hectare) in rainfed and irrigated rice production system of Cambodia and Thailand (value in rows show mean ± standard error).**

| | Economic productivity with SRI-T | Cambodia rainfed | Thailand rainfed | Thailand irrigated |
|---|---|---|---|---|
| Scenario 1a | With producer price (0.3 and 0.43US$/kg for Cambodia and Thailand respectively) when all inputs were valued | 0.769±0.03 c<br>(0.05±0.01) | 2.655±0.12 a<br>(0.4±0.01) | 2.066±0.08 b<br>(0.05±0.01) |
| Scenario 1b | With producer price (0.3 and 0.43US$/kg for Cambodia and Thailand respectively) when labour input for transplanting, weeding and harvesting cost were excluded from Cambodia and cost of water are excluded from Cambodia and Surin province of Thailand | 2.10±0.06 b<br>(0.66±0.04) | 2.9±0.13 a<br>(0.54±0.01) | 2.06±0.08 b<br>(0.05±0.01) |
| Scenario 2a | With domestic rice price (0.3 and 0.38US$/kg for Cambodia and Thailand respectively) when all inputs were valued | 0.769±0.03 c<br>(0.05±0.01) | 2.17±0.11 a<br>(0.40±0.01) | 1.79±0.08 b<br>(0.05±0.01) |
| Scenario 2b | With domestic rice price (0.3 and 0.38US$/kg for Cambodia and Thailand respectively) when labour input for transplanting, weeding and harvesting cost were excluded from Cambodia and cost of water excluded from Cambodia and Surin province of Thailand | 2.08±0.06 b<br>(0.66±0.04) | 2.4±0.12 a<br>(0.54±0.01) | 1.79±0.08 c<br>(0.05±0.01) |
| Average rice yield at FPAR sites | | 4.3±0.73 c | 5.82±1.29) b | 6.26±0.82 a |
| Scenario 1a | *F = 230.73** (df = 2, 184)* | | | |
| Scenario 1b | *F = 22.09** (df = 2, 184)* | | | |
| Scenario 2a | *F = 149.34** (df = 2, 184)* | | | |
| Scenario 2b | *F = 7.00** (df = 2, 184)* | | | |

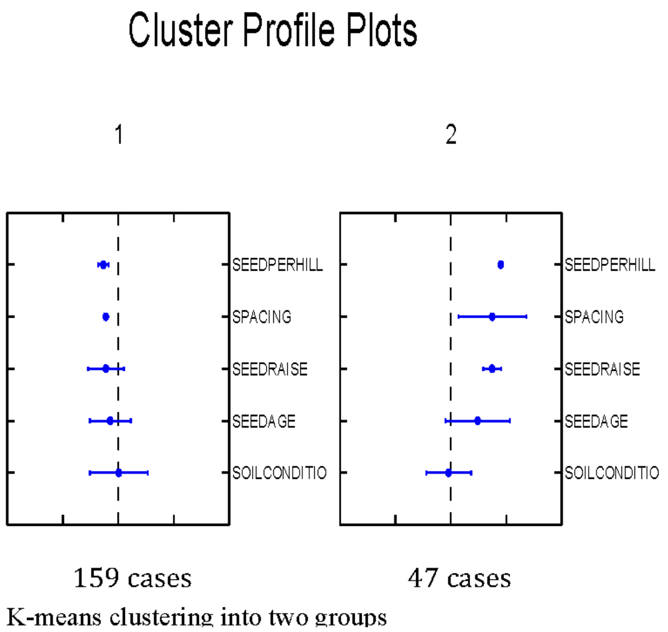
Mean value sharing same letter in row are not significantly different. Value in bracket shows baseline figures.

**Shows F value is significant at $p < 0.001$

Note: For baseline yield economy calculation, rice price US$3/kg is used for both countries as reported in the baseline survey.

### *3.4. Adaptation responses from farmers for SRI practices*

On farmers' responses to learning SRI practices, which was characterized as SRI in transition (SRI-T), it was found that single seedling transplant (1–2 seedlings/hill) and SRI spacing (20×20–30×30 cm) were the most preferred practices in both countries and were applied by almost 80% of FPAR farmers (Figure 6). SRI seedbeds (dry seedbed) and young seedlings (8 to 15-days-old) for transplanting were followed by relatively few farmers (only 15%). Keeping paddy soil aerobic for a week or so during the vegetative growth stage was least followed. However, most of the farmers responded that aerobic soil management was not followed as a part of their crop and soil management because this occurred naturally, given that they are working in a rainfed environment. Almost all FPAR districts experienced early drought last year due to a late monsoon. Farmers who followed aerobic soil conditions for some period were mainly from Tron and Pichhai districts where supplementary irrigation facilities were available. In those two districts, they reported 2–3 less irrigations with SRI compared to conventional practices.




| SRI practice | F ratio |
|---|---|
| Seedling/hill | 7307.98 |
| Spacing | 412.39 |
| Seedling raising method | 398.12 |
| Seedling age | 80.23 |
| Aerobic soil condition at least for a week in vegetative growth stage | 0.358 |

**Figure 6. Adaptation response on SRI practices by FPAR farmers in 15 districts of five provinces of Cambodia and Thailand.**

## 4. Discussion

### *4.1. Effectiveness of SRI management practices for achieving higher yield and profit with higher resource use efficiency at rainfed smallholder farms*

Various literatures have identified specific linkages between economic growth, poverty alleviation and political stability which have direct consequences on achieving food security [16,17]. The explanation given in these literatures is that greater stability in food economy contributes to faster economic growth and in turn to political stability. And greater stability contributes in turn to more equity and poverty alleviation by reducing the vulnerability of the poor to sudden shocks in food prices or availability. This occurs when economic growth raises the poor above a meaningful poverty line and when stabilization of the food economy prevents external shocks from threatening their food intake, which is not the case with smallholder farmers of this region. Therefore, for addressing food security concerns, it is important to increase the productivity of the poor farmers themselves so that they can protect themselves from external shocks.

It is evident that rice cultivation is the main farming occupation in both countries (Table 1). At macro level, both countries have achieved rice production sufficiency in terms of production, and Thailand has some surplus production even though this sufficiency and surplus is inadequate to achieve food sufficiency and security at the household level in many rural areas there. Particularly, smallholder rice farmers are more prone to this insecurity living in a rainfed areas.

The baseline figures (Table 1) show the average rice productivity in each province in pre-project scenario and also rice insufficiency and sufficiency status. It also reveals that the contribution from conventional rice farming to household income in Cambodia is not very significant compared to Thailand. In rainfed areas of Cambodia, rice farmer produces only 20% of the total household income from rice. This is mainly because in Cambodia, rice insufficiency is still a concern for the farmers (Table 1) and that is why most of the rice produced is stored for self-consumption.

In Thailand, the contribution of rice production to total household income is 49 and 77% in Surin and Uttradit, respectively. The reason is that a majority of the rice farmers in these parts of Thailand sell their produce after harvest and often depend on the market for their own food needs. It is also evident in both countries that food availability from the farm is linked mainly to rice production because of the limited diversification of farming activities since farmers do not grow many other crops. Although in Cambodia, livestock is another means for increasing household incomes, only 30-40% of households in project areas are engaged in livestock production (Table 1). This means that they need to rely on markets to meet their other food requirements.

Our results from five provinces of Cambodia and Thailand, involving approximately 3600 farmers, clearly demonstrated higher yield with SRI methods compared to the regional baseline yield of 3.14 t/ha. In the same districts and with the same farmers, the average yield with STI-T was 5.03 t/ha and with fuller use of SRI methods (SRI-D) it was 6.41 t/ha. The higher yield obtained under SRI management practices is in line with our previous research findings [9,10,13,18–20]. The scientific explanation for higher yield under SRI practices is already well established within the scientific domain and reviewed and researched by many [9,21,22] so there should not be any surprise.

The interesting results in this study was that in addition to higher yield, higher net returns and higher fertilizer use efficiency were also achieved with SRI methods. The economic productivity gain was higher with SRI-T compared to conventional systems in both countries, and with the both systems, rainfed and irrigated. Importantly, the gain was much higher in rainfed systems compared with irrigated ones.

Thus, SRI-guided practices can help smallholder farmers to increase their productivity and higher resource use efficiency with less input use. The productivity gains can ensure more income, almost double, from rice farming even with the existing market scenario. It can be further improved if better incentives are provided to them for the healthy (pesticide free) and higher-quality produce (bold and good filled grain) by ensuring a favorable market price for rice grown with agro-ecological approach, e.g., organic rice production.

### *4.2. SRI adaptation response from farmers in the context of existing bio-physical and socio-economic environment*

To gain more understanding of farmers' adaptation response, discussions were held with them on the agricultural practices and the factors that drive adaptation and adoption decisions for any new technology. The responses were different between the two countries.

In Cambodia, farmers operating in rainfed areas are very much dependent on favourable weather conditions for a good harvest. Often these households become food-insecure immediately if the weather is unfavourable. Although the extent of food insecurity is difficult to quantify and varies considerably from one area to another, and from one household to another, in areas where agricultural production has increased in recent years, a significant proportion of the incremental production has been consumed by the producing households, indicating continued significant inadequacies in meeting household food needs, as evident from baseline findings (Table 1).

Only twenty percent (20%) of household income in rural Cambodia comes from rice farming (Table 1), which is non-significant realizing that the rice is the only crop that they grow. This indicates that households are mainly growing rice to ensure sufficient food production for consumption by utilizing their own resources, mainly family labour and land under rainfed conditions. Working in rainfed and insecure environment makes subsistence farmers further insecure about making gains from farming, and therefore they do not want to expend cash and extra efforts in farming. Further, the farm-gate price of paddy in Cambodia is the lowest compared to other countries of the Lower Mekong River basin, which makes rice cultivation a relatively unattractive option to them compared to off-farm employment opportunities. So, increasingly most of them are being employed as construction labourers or in factories with higher wages rate, especially the young generation and male members of the farming community.

Further, in Cambodia as the prices of agriculture inputs are increasing, the costs of cultivation are generally becoming higher in recent years. Moreover, the opportunity (and risks) associated with rainfed farming have not been adequately addressed by government, and so the current policy by and large tends to favour agriculture in the irrigated areas. While the reach of micro-credit schemes has widened over the years in rainfed areas and farmers are taking loans as evident from our baseline study (Table 1), these loans are primarily used for physical construction and for social functions. This has resulted in increasing migration from rural to urban areas for better livelihood options, and it has changed the structure of agriculture. From the action research it became evident that more than 70% of the farmers in the project area are women, and a majority of them are older than 50 years [23].

Within the context of the existing bio-physical and socio-economic environment, we discussed with farmers SRI adoption in the project area. They are quite interested in increasing yield and reducing their costs of cultivation, especially for seeds and fertilizers, and in making higher profits. So there is a considerable increment in the adaptation rate for SRI-recommended practices that help them to get higher yield without any extra input cost.

Since manual transplanting is a common feature in most regions of Cambodia and given that family labour is fairly available, for which households do not need to pay, it turns out that the SRI-recommended practices of single-seedling transplants and transplanting with wider spacing are “taking root” in rice farming fairly easily. Younger seedling transplanting can enhance the yields with these other new methods even more, but due to early drought spells which is increasingly increasing in recent years, this practice has been difficult for farmers to follow unless there is some supplementary irrigation support available for the early growth stage of the rice crop.

This is also applicable with the SRI water management practice that is least adopted by FPAR farmers. Lack of assured water supply limits opportunity either for maintaining shallow water level with drying period for a week or draining excess water from the rice field, creating aerobic soil condition at least for a week during vegetative growth stage. Part of the higher yield from SRI-D was attributable to transplanting young seedlings as recommended, along with availability of supplementary irrigation water.

Discussion was also held on the matter of water availability and on the costs associated with it. It was found that in areas which are near to a canal, water can be pumped to the fields if this facility is available. The cost of pumping water is about US$48–50/ha. Further discussion was held on labour requirements. Regarding labour requirements with SRI, 40% of the FPAR farmers reported that their labour requirement was less, whereas 33% reported no effect (data not shown here). Three-quarters thus experienced no increase in their labor inputs or even had a reduction.

Results were also discussed with respect to the income for landless labourers that they could earn from rice employment. It was reported that currently in Cambodia the wage for labourers working in rice fields is much less than in Thailand, reflecting part the lower price received for rice in Cambodia. Landless labourers who work in rice fields thus reported that they get only 10% of their total household earnings from rice field labour [23]. Also, 85–90% of the labour inputs for smallholder production is available from family members, so hiring external labourers is not a part of rice cultivation. However, recently the increasing migration of male members to urban areas from rural areas has created a shortage of labour in the latter, and this has put an extra burden on women farmers. With increasing feminization and aging of agriculture society, these issues will become more prominent in the near future. Further research is warranted on this emergent trend in rice farming.

On the other hand, in Thailand, the situation is quite different. First, in rice-farming households, the share of net food-buying by households is higher among those with smaller landholdings and more particularly with rice-farming households. As can be seen from Table 1, a major proportion of household income comes from rice farming as the rice produced is not kept for self-consumption but rather is sold. About 87% of those who were affected by food poverty in 2007 were agricultural households, mainly in the north and northeastern parts of Thailand. If global food prices rise again as they rose in 2007–2008, this will induce a sharp increase in domestic food prices causing a high rate of overall inflation. For the poor farm households, food constitutes a considerable portion of their expenditure, and therefore any rise in food prices makes them food-insecure.

Smallholder farmers are hard-hit by soaring agriculture input prices and by rising production costs. So this kind of inflation is a big issue for them. For example, most chemical fertilizer used in Thailand is imported. Between 2003 and 2010, the cost of urea increased by 2.5 times. In general, agriculture input markets are free, although public policies on chemical fertilizer make fertilizer available at a reduced price. However, smallholder farmers often cannot benefit from this policy because they do not meet the eligibility requirements for subsidized fertilizer.

Another factor is that labour wages have been increasing many-fold, making the costs of production even higher. This is the reason why labour use in agriculture has declined from 392 man-hours per hectare in 1980 to less than 56 man-hours per hectare in 2008 [24]. The level of man-hours/ha has been further decreased after a further increase in labour wages in 2010–2011 following the 2011 flood.

Further, an unstable market for rice and price volatility at the time of harvesting further constrains farmers' marketing opportunities. In addition, many smallholders rent land, and the cost of renting land becomes higher when the market price for rice is high. Indeed, these forces in combination create an unfavorable environment for smallholders and put them on risk.

These are the driving forces for migration of farmers from rural to city areas, and they explain why mostly older people and women who are left behind in the villages to engage in rice cultivation (Table 1). In addition, more than 90% of farmers in both provinces of Thailand take out loans, and these loans are taken mainly for agricultural activity (Table 1). The amount of loans taken by farmers is more in irrigated areas than in rainfed area because the costs of production are higher in irrigated than in rainfed cultivation.

To address all these issues, farmers are seeking alternatives to reduce their cost of production by reducing labour, fuel and fertilizer inputs. That is also why direct seeding, broadcasting, and indigenous fertilizer production and application are all part of common rice cultivation practices in Thailand. Our survey report indicated that almost 90% of farmers in Thailand now follow broadcasting and direct-seeding in their rice cultivation, given labor shortages and wage costs for transplanting. However, for their SRI experimentation, almost 70% farmers agreed to go with transplanting (single seedlings and wider spacing, see Figure 6).

When we discussed the reasons for this, farmers informed us that with SRI practices they can get higher quality grain, and that grain can be sold as seed for almost double the price compared to the existing market price of rice. For expanding these practices in a larger area, they are seeking some substitute for labour. There is a considerable interest among farmers to experiment with SRI ideas used direct-seeding methods with reduced seed rate and to develop organic SRI production for better marketing opportunities. This is an area where further research is required, especially in rainfed areas where low seed rates increase weed infestation during the early vegetative growth stage, which coincides usually with an early drought spell in the region.

### *4.3. Potential of SRI for addressing food insecurity by actively involving smallholder farmers*

The above analysis showed that at ground level the situation for rice production and innovation is rather different in both countries, although the repercussions of these prevailing situations are the same, i.e., out-migration of farmers. Our learning shows that SRI can boost yield and income and resource use efficiency without any additional cost. Further, the productivity gain is higher in rainfed areas compared to irrigated ones. With favorable policy support—supplementary irrigation, market security and some crop insurance policy—the migration of farmers could possibly be reversed if rice farming would be made more attractive for them. SRI provides an opportunity to address these multiple issues, as this is not only a matter of bringing yield and income benefits to farmers. In rainfed systems which cover 60% of the rice growing area and where a majority of the smallholding poor farmers reside, only a small investment is needed to make the system more productive and resilient.

This also means that the resources of irrigated areas can be freed up for other agricultural activities. There is already considerable competition for water, land and other resources. A “business as usual” scenario will make this competition even tougher and will put further pressure on environmental resources. Additionally, even with sufficient production at the macro level, food insecurity still is common in rainfed areas. Therefore, instead of trying to achieve food security through entitlement and distribution mechanisms, bringing poor smallholding farmers more directly into the process of economic growth can offer more hope at both micro and macro levels.

With respect to contribution towards food security, our results confirm that with SRI adoption, food availability, at least the staple food, can be increased substantially with increased production without an increase in the costs of cultivation, indeed with reduced cost of cultivation in most cases and with higher resource use efficiency. Greater purchasing power of poor farmers stimulated by more profitable rice production (Table 4) will improve the diversity and quality of food intake by rural households.

To cope with market uncertainty, which might threaten food stability and so security, it is important for poor farmers to save their produce for self-consumption. This is particularly relevant for Thailand's smallholder farmers. With SRI practices, they can have better yield, as evident in Table 2. A part of this increased production can be saved for self-consumption, and the rest can be sold to market.

It is to be noted that the rainfed production system is already a fragile production environment where farmers are operating with limited resources. Increasing climate change variability will further deteriorate it and will increase further pressure on them. Indeed, they need a smarter approach and low cost solution to become productive and resilient. With SRI, which is based on agro-ecological principles and practices with less input use and which encourages to feed the soil to feed the plant, production systems can become more stable and resilient.

Therefore, development efforts that raise productivity and incomes for the broad population of smallholders without further deteriorating the environment should be supported by incentives which will not only stimulate rural growth and address food security concerns, but will also influence the macroeconomic performance of the region in positive ways.

## 5. Conclusion

Results from over 120 sets of field-level experiments spread across 5 provinces of Cambodia and Thailand have demonstrated higher yield and resource use efficiency with SRI-T practices, as well as SRI-D management, which more fully utilized the recommended methods. The net profit achieved with SRI-T management was almost double, due to the higher yield coupled with reduced costs of inputs and also due to the higher quality of the grain produced, which commanded a higher market price. The productivity gain was even much higher with SRI-D where yield gain was 28% and 100% greater than SRI-T and CP respectively.

Surprisingly, economic gains for farmers attainable with SRI rice crop management were higher in rainfed areas compared to the irrigated areas because the cost of production was significantly lower in the rainfed areas compared to the irrigated one. Efforts to make SRI knowledge and practices available on a wider scale can raise productivity and incomes and in turn can address food insecurity of the broad population of smallholders without further deteriorating the environment, if supported by favourable and appropriate policies. Further research is warranted on the subject of higher yield and its implication on rice price either benefitting or burdening farmers and consumers. The research should take into account the current trend of increasing farmer out-migration. Finally, research is required for better location-specific adaptation of SRI practices involving smallholders.

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## Conflict of interest

All authors declare no conflicts of interest in this paper.

## References


1. Matsuo K (2002) Development of upland cropping systems for Crop-Animal integrated farming systems in Northeast Thailand. Report of Japan International Research Centre for Agricultural Sciences (JIRCAS), Department of Agriculture (DOA) and Khon Kaen University (KKU), Thailand.
2. MAFF (2008) Report on Activities of Agriculture, Forestry and Fisheries. Workshop on National Achievement in 2007-2008 and Planning for 2008-2009. Ministry of Agriculture, Forestry and Fisheries, Phnom Penh, Cambodia, 2-3 April 2008 (in Khmer).
3. FAO (2004) FAOSTAT. Available from: http://faostat.fao.org/default.aspx
4. Kirby M, Mainuddin M (2006) Water Productivity Assessment: Mekong River Basin Approach, BFP Working Paper 4. In: *An advance edition of a working paper on the assessment of water productivity from the approach of the Mekong River Basin*. Available from: http://www.waterandfood.org/fileadmin/CPWF_Documents/Documents/Basin_Focal_Projects/BFP_Publications/MekongBasinWaterProductivityBFPwp04Draft02.pdf
5. UN Population Division (2006) World Population Prospects: The 2006 Revision. Available from: http://www.un.org/esa/population/publications/wpp2006/wpp2006.htm
6. Nesbitt HJ (2005) Water Used for Agriculture in the Lower Mekong Basin. MRC Technical paper No 11, Mekong River Commission, Vientiane.
7. Molle F, Wester P, Hirsch P, et al. (2007) River basin development and management. In: *Water for Food Water for Life, A Comprehensive Assessment of Water Management in Agriculture*. Molden, D. (Eds.). London Earthscan. 585-625.
8. Behera D, Chaudhary AK, Vutukuru VK, et al. (2013) Enhancing agricultural livelihoods through community institutions in Bihar, India, In: *South Asia rural livelihoods*. Series 3 note no. 1. Washington D.C., The Worldbank.
9. Mishra A, Whitten M, Ketelaar JW, et al. (2006) The system of rice intensification (SRI): a challenge for science, and an opportunity for farmer empowerment towards sustainable agriculture. *Int J Agri. Sustain* 4: 193-212.
10. Mishra A, Kumar P, Noble A (2013) Assessing the potential of SRI management principles and the FFS approach in Northeast Thailand for sustainable rice intensification in the context of climate change. *Int J Agric Sustain* 11: 4-22.
11. Uphoff N, Randriamiharisoa R (2002) Possibilities for reducing water use in irrigated rice production through the Madagascar System of Rice Intensification, In: *Water-Wise Rice Production*. Bouman B et al. (Eds.). Los Banos, Philippines: International Rice Research Institute. 71-88.
12. Kabir H, Uphoff N (2007) Results of disseminating the system of rice intensification with farmer field school methods in Northern Myanmar. *Exp Agric* 43: 463-476.
13. Mishra A, Salokhe VM (2008) Growing More Rice with Less Water in Asia: Identifying and Exploring Opportunities through System of Rice Intensification, In: Agricultural Systems: Economics, Technology and Diversity. Oliver, W. Castalonge (Eds.). Hauppauge, New York: Nova Science Publishers. 173-191.

14. Cohen J (1992) Statistical power analysis. *Curr Dir Psychol Sci* 1: 98-101.
15. FAO Rice Market Monitor (2015) Volume XVIII, Issue No 2, July 2015. Available from: http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Rice/Images/RMM/RMM_JUL15_H.pdf
16. Birdsall N, Ross D, Sabot R (1995) Inequality and growth reconsidered: lessons from East Asia. *World Bank Econ Rev* 9: 477-508.
17. Dawe D (1996) A new look at the effects of export instability on investment and growth. *World Dev* 24: 1905-1914.
18. Mishra A, Salokhe VM (2010) The effects of planting pattern and water regime on root morphology, physiology and grain yield in rice. *J Agron Crop Sci* 196: 368-378.
19. Mishra A, Salokhe VM (2011) Rice root growth and physiological responses to SRI water management and implications for crop productivity. *Paddy Water Environ* 9: 41-52.
20. Mishra A, Uphoff NT (2013) Morphological and physiological responses of rice root and shoots to varying water regimes and soil microbial densities. *Arch Agron Soil Sci* 59: 705-731.
21. Horie T, Shiraiwa T, Homma K, et al. (2005). Can yields of lowland rice resume the increases that they showed in the 1980s? *Plant Prod Sci* 8: 251-272.
22. Thakur AK, Uphoff NT, Stoop WA (2015) Scientific underpinnings of the System of Rice Intensification (SRI): What is known so far? *Adv Agron* 135: 147-179
23. Mishra A, Kumar P (2015) Sustaining and Enhancing the Momentum for Innovation and Learning around the System of Rice Intensification (SRI) in the Lower Mekong River Basin. *Regional Review and Planning Workshop Report*. 40p. Available from: http://www.sri-lmb.ait.asia/country/doc/Regional%20Review%20and%20Planning%20Workshop-REPORT%20(02-03%20June%202015).pdf
24. Isvilanonda S, Kao-ent S (2009) Dynamics of Thailand Rice production economy and future outlook. A paper presented to Thailand Research Fund, Bangkok.