博士論文（要約）

Why Farmers in the Rainfed Rice Regions of Southern Cambodia Adopt the System of Rice Intensification (SRI)

（カンボジア南部天水稲作地域の農家が

集約稲作農法(SRI)を採用するのはなぜか）

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Abstract

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Why Farmers in the Rainfed Rice Regions of Southern Cambodia Adopt the System of Rice Intensification (SRI)

Chapter 1. Introduction

Cambodia is a small country located in the Mekong region between Thailand and Vietnam, and has a total population of over 15 million, of which the majority (79.7%) lives in rural areas. Across the past 35 years, there has been more-than twofold increase in wet-season rice yield from just over 1.19 t ha^{-1} in 1980 to 2.82 t ha^{-1} in 2015, growing by 2.9%. Although rice yield has thus increased, Cambodia's rice harvest still comes mostly from rainfed lowland fields, and has year after year been threatened by natural disasters, such as floods and drought.

The System of Rice Intensification (SRI) was established in the early 1980s by Fr. Henri de Laulanie, S. J in Madagascar. Over the past 30 years, many researchers have demonstrated that SRI in comparison with conventional practices increased rice yield by 20-40% with 20-50% less water use and 50-70% reduced seed cost in irrigated as well as rainfed fields.

In recent years, adoption of the SRI is spreading in most Asian countries, and more recently in some two dozen countries in Africa and Latin America. Cambodia is one of the Asian countries with high adoptions of SRI. Even though SRI would increase rice yield in irrigated paddies where shallow water level can be maintained, the water constraint in rainfed fields could negate the yield increase by SRI. In rainfed fields, the water level can be hardly controlled.

In my thesis, I found the possibility of SRI in improving rice farming under the water constraint of rainfed lowland fields of Cambodia. Therefore, I took field science approach including interview surveys and on-farm experiment to better understand the farmers' adoption of SRI and thereby to contribute to a securer livelihood among the small holder farmers in rainfed region of Cambodia.

Chapter 2. Rice yield increase by SRI with dependency on supplementary water availability in rainfed lowland fields of southern Cambodia

I conducted an interview survey with the farmers in Popel commune of Tram Kak District of Takeo Province. Tram Kak district was selected for its higher rate of SRI adoption among the farmers than other districts. The study area rice farming is done mostly in wet season.

I interviewed with 106 smallholders of southern in 2015 and asked about characteristics of their rice fields, such as soil properties and topography, and their agronomic practices including SRI practices in the wet season rice of 2014, when the fields were hit by a severe drought early in the season. The results indicated a clear difference in rice yield between SRI and Non-SRI fields with mean rice yield in SRI fields being 3.95 t ha^{-1} as compared with 2.77 t ha^{-1} in Non-SRI fields. The results further showed that the yield increase by SRI was associated with the planting of young seedlings at lower density. More importantly, the SRI-induced rice yield increase was dependent on supplementary water availability to the fields: there was no rice yield increase by SRI in the fields without the availability of supplementary water. The rice harvest in SRI fields without water supply was delayed due presumably to severer drought which caused delayed heading than those in Non-SRI fields.

Chapter 3. Assessing the acceptance of SRI among rice farmers in a rainfed lowland area of southern Cambodia

With the same fields and interview survey design as in chapter 2, I addressed, in this chapter, the acceptance of SRI by farmers in various environmental conditions including supplementary water availability. I also analyzed the farmers' recognition of positive and negative aspects of SRI intending to understand the determinants of the farmers' adoption (or rejection) of SRI. Better understandings of farmers' adoption of SRI will clarify the prospect of SRI in promoting rice production under the natural and socioeconomic environments of rural Cambodia.

The temporal change in SRI adoption exhibited two timings of the rapid increase. However, I also found the period of increased SRI discontinuation which coincided with the declining trend of wet-season rainfall since 2011. It is evident that availability of supplenmentary water is among the major determinants of the farmers' decision on SRI adoption. Another constraint against SRI adoption was the difficulties at transplanting, i.e. the hardships of using transplanting rope and meeting the labor requirement for SRI. The latter constraint could be ameliorated by experiences to some extent, the former constraint, i.e. lack of supplementary water to the fields, cannot be ameliorated by experience but needs increased source of water supply.

Chapter 4. On-farm evaluation of the effects of SRI on rice growth and yield in rainfed fields of southern Cambodia

I conducted on-farm experiment to investigate the effects of SRI on rice growth and yield in the farmers' fields in rainfed region of southern Cambodia. The study was undertaken in rainfed lowland fields of Popel commune of Tram Kak District in Takeo Province during the wet seasons in 2012, 2013, and 2015. The on-farm experiments were conducted in a total of 26 fields during the wet seasons for three years of 2012 (7 fields), 2013 (8 fields), and 2015 (11 fields).

Across the three years of study, SRI produced significantly greater plant biomass and grain yield than Non-SRI. The yield increase was mostly ascribed for the increased number of grains per land area, which was due to the increased number of spikelet per panicle rather than the number of panicles per land area. With no significant difference between SRI and Non-SRI with respect to seedling age, the greater number of grains per panicle was accounted for by the reduced planting density and increased amount of manure application in SRI than Non-SRI fields. It was found that the greater manure application has increased soil nitrogen content in SRI and Non-SRI fields. While SRI did not increase the number of panicles per land area, it did increase the number of panicles per hill.

Chapter 5. General discussion

Synthesizing the findings in the preceding chapters, I conclude that SRI increases rice yield in rainfed lowland fields of Cambodia by planting young seedlings in the fields where supplementary water is available, and by planting the seedlings at lower density in combination with increased application of farmyard manure.

The yield increase by SRI have made a good reason for the farmers to adopt SRI, however, many farmers could not do so due to the lack of supplementary water in their fields. Some farmers have once adopted SRI, but discontinued it later due likely to the lack of supplementary water. Some other farmers, who have fields at more than one location managed to perform SRI in some of their fields with supplementary water availability. Another reason for the farmers for not adopting SRI was the difficulties at transplanting according to the SRI principles. The ongoing urbanization and increasing opportunities of off-farm jobs raise the labor cost for transplanting and make the labor-intensive SRI practices less feasible for the farmers.

I would rather argue that SRI must be adapted for lower labor requirement along with a higher yield. Such improvement could take advantages of the labor-saving components of SRI: lower number of seedlings planted per land area and utilization of the tillering capacity of the young seedlings to compensate for the lower planting density. With the reduced labor requirement as an additional target, the adapted SRI may not be simply called a system of rice *intensification* any more, however.

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Chapter 1. Introduction

1.1. Background

1.1.1. Cambodia and its agriculture

Cambodia is located in the Indochina Peninsula at latitudes between 10° and 15° N and longitudes between 102° and 108° E having total landmass of 181,035 km^2. It is bordered by Laos to the north, Thailand to the northwest, and Vietnam to the east. Cambodia has a total population of over 15 million, of which the majority (79.7%) lives in rural areas.

The agricultural sector is an important part of the country's economy accounting for 28.6% of GDP in 2015, and, moreover, this sector takes up the largest share (45.3%) of employment in the country (CSES, 2014). Within the agricultural sector, crops and fisheries are the most important sub-sectors contributing to 60% and 22%, respectively, of agricultural GDP, followed by livestock (11%) and forestry (7%) sub-sectors. As such, the growth of Cambodian agricultural sector has been led by crop and fish productions (MAFF, 2016).

1.1.2. Rice production in Cambodia

Agricultural development, particularly the dominant position of rice-based farming systems, has a long history in Cambodia (Mak, 2001). Rice (*Oryza sativa* L.) is grown by over 80% of Cambodian farmers and produces 60% of the subsistence need (Yu and Fan, 2011). Rice cropping in Cambodia is done mostly in rainfed environment, and dominated by the wet season rice, which is cultivated from May to December, whereas the dry season rice is grown from December to March.

Recovering from the huge devastations by Khmer Rouge through to the end of 1970s, Cambodian rice production showed an increasing trend across the 1980-2015 period. For the past 35 years, there has been more-than twofold increase in wet-season rice yield from just over 1.19 t ha^{-1} in 1980 to 2.82 t ha^{-1} in 2015, growing by 2.9% (MAFF, 2016). The rapid increase in the rice yield has been due to the rehabilitation and construction of the irrigation facilities, dissemination of improved varieties, as well as the adoption of improved cropping technologies among the farmers (MAFF, 2015) (Fig. 1.1). In 2015, the total planted area was 3,051,412 ha, of which 2,561,957 ha was for wet season rice and 489,455 ha was for dry season rice. Although improved varieties of rice are grown in the dry season for cash income purpose, rice farming in the wet season with traditional varieties is the mainstream with a share of 75% of the national rice production. The rice yield of Cambodia (3.01 t ha^{-1}) is still low among the countries in the Mainland Southeast Asia as compared with Thailand (3.01 t ha^{-1}), Myanmar (3.89 t ha^{-1}), Laos (4.18 t ha^{-1}), and Vietnam (5.75 t ha^{-1}) (http://faostat.fao.org). In this thesis, I focus on the wet season rice for its importance to the peoples' subsistence and food security.

1.1.3. Drought impacts on rice production in Cambodia

Cambodia has plenty of water resources such as Mekong River, Tonle Sap Lake, Tonle Sap River, and the tributaries, but has only a limited area of irrigated land. Ministry of Water Resources and Meteorology (MOWRAM) in Cambodia has rehabilitated and constructed small and large scale irrigation schemes throughout the country in the last 5 years enabling to irrigate 387,907 ha (296,000 ha in wet season rice, and 91,907 ha in dry season rice) of agricultural area (MOWRAM, 2015). Yet, the irrigated land area is only 15.2% of the national land area for rice production.

Due partly to the limited coverage of irrigation systems, rice production of Cambodia has year after year been threatened by natural disasters, such as floods and droughts (Fukai and Ouk, 2013). Drought has the highest impact on rice fields, which has destroyed

969,292 ha from 1994 to 2015, and, in 1994 and 2004, it destroyed almost 200,000 ha of rice fields (MAFF, 2016). Drought-induced rice yield loss has ranged from 12 to 46% under irregular rainfalls (Ouk et al., 2006). The monthly rainfall is usually high from May to October, but sometimes there occurs dry spell that lasts for about 2 to 3 weeks between July and mid-October, and causes damages to the livelihood of smallholders of rainfed lowland paddies.

1.2. The System of Rice Intensification (SRI)

1.2.1. History and background

The System of Rice Intensification (SRI) was established in the early 1980s by Fr. Henri de Laulanie, S. J in Madagascar. In 1990s, together with a number of Malagasy colleagues, Fr. Laulanie established an indigenous non-governmental organization (NGO), named Association Tefy Saina, to work with farmers and other NGOs. In 1994, Tefy Saina began working with the Cornel International Institute for Food Agricultural and Development at Cornell University in Ithaca, N.Y. They provided SRI with the farmers living in the peripheral zone around Ramayana national park as the alternative to their slash –and-burn agriculture. Later on, the adoption of SRI spread among most Asian countries, and more recently in some two dozen countries in Africa and Latin America (hittp://sri.ciifad.cornell.edu/).

SRI primarily targets at increasing rice harvest for smallholder farmers using considerably less water and seeds, without relying on external inputs such as chemical fertilizers. Over the past 30 years, many researchers of SRI demonstrated increased yields by 20-40% with 20-50% less water, and 50-70% reduction of seed cost under SRI in comparison with conventional practices in irrigation and rainfed lands (Ceesay et al., 2006; Sinha and

Talati, 2007; Menete et al., 2008; Stoop et al., 2009; Adusumilli and Bhagya Laxmi, 2011; Styger et al., 2011; Ndiiri et al., 2013; Islam et al., 2014; Thakur et al., 2016). Another study has reported water saving of 40-50% with no reduction in yield, which is an increase of water productivity by 40-50% (Senthilkumar et al., 2008).

Despite the reports of dramatically higher yield by SRI, its technological efficacy and feasibility are still under controversy (Sheehy et al., 2004; Latif et al., 2005; Stoop & Kassam, 2005; McDonald et al., 2006; Glover, 2011; Berkhout et al., 2015).

1.2.2. Benefits of SRI with its component techniques

Recommended SRI management practices for irrigation condition are to plant (1) very young seedlings, 8 and 12 days old (at the 2 leaf-stage); (2) one plant per hill instead of 3-4 together to avoid root competition, (3) in wider spaces to encourage greater root and canopy growth with a square grid pattern (more than 25 × 25 cm); along with (4) water management to intermittent flooding and darning of the rice fields rather than continuously flooded during the vegetative growth period; (5) frequent weeding; and (6) refrain from chemical fertilizers in favor of farmyard manure. SRI practices cause the large change in the morphologic characteristics of rice plants, in their roots, tillering, and canopy, as compared with the plants grown under continuous flooding (Uphoff, 2014; Thakur et al., 2015a). The component techniques have been shown to have beneficial effects on the rice plant growth as follows.

Transplanting young seedling is advantageous in faster recovery from transplanting stress than aged seedling (Horie et al., 2005). Another advantage of early transplanting is that younger seedling has higher tiller production potential than aged seedling. The tillering ability of rice plants is seen in the number of phyllochrons of growth that they complete before entering the reproductive phase (Horie et al., 2005; Thakur et al., 2015b). The above-ground biomass becomes greater during the vegetative growth phase as a result of the increase in tillers (Uphoff, 2014). However, young seedling is hardly possible to ascertain whether transplanting at a particular seedling age is likely to increase either productive tillers or grain yields compared with old seedlings (Debal, 2011).

Wide space planting with single seedling per hill; one of the components of SRI practice is relationship in rice yield. Many researchers tested the effects of planting density on rice yield. Takeda and Hirota (1979) showed that grain yield was unchanged between planting densities from 10 to 100 hills per m^2. However, wide space planting of single seedling per hill reduced competition and helped to minimize the shading effect on lower leaves. This permits prolific tillering and associated root development, along with increased grain development that can more than compensate for reduced plant populations on an area basis (Thakur et al., 2015b). The high chlorophyll content with lower planting density was attributed to higher and longer period of root oxidizing activity (Horie et al., 2006; Toriyama and Ando, 2011). These results indicate that rice has a wide adaptability to planting density through regulation of panicle number, number of spikelets per panicle and grain-filling percentage, according to the environments (Horie et al., 2005).

Intermittent irrigation and delayed flooding is similar to the alternate wetting and drying (AWD), while there are still debates on whether these water-saving techniques will increase or decrease rice yields (Bouman et al., 2007). However, SRI is an effective water-saving technology in rice production with increased rice yield, and improved root development (Wu et al., 2009; Zhang et al., 2009; Thakur et al., 2015a). Moreover, an increased root biomass, root oxidation activity, and cytokinin contents in roots are all necessary to develop an increased number of panicles and spikelets per panicle (Thakur et al., 2015b). Thus, intermittent irrigation and delayed flooding reduce the adverse effects of low redox potential on rice roots and allow them to penetrate deeper into the soil, but such effects of on rice yield depend on availability of nitrogen (Horie et al., 2005). Organic manure application under AWD has been shown to increase significantly the uptake of N, P and K, causing a significant increase in filled grains per panicle, 1000-grain weight, and grain yield. N-containing molecules in the soil are also available for uptake by plant roots (Thakur et al., 2015b). The incorporation of organic manure into soil can bring beneficial effects to root growth by improving the physical and chemical environments in which roots grow (Mishra et al., 2006). The beneficial effect of an integrated fertilizer strategy has been significant for grain yields also under waterlogged condition. Soil organic matter contents and the soil moisture regime will be important factors influencing N availability for uptake by plant roots (Thakur et al., 2015b). SRI practices create more favorable soil-water-plant-rhizosphere relationships than are possible under conventional wetland rice production. With the conventional system, fields are continuously flooded leading to hypoxic soil conditions, and rice plants grow under crowded above- and belowground environment (Thakur et al., 2015b).

As mentioned above, although SRI has been rapidly disseminated in Asian countries (Kabir and Uphoff 2007; Uphoff, 2014), some studies have reported that partial adoption, discontinuance, and continued rejection of SRI are common place (Moser and Barrett, 2003; Moser and Barrett, 2006; Senthilkumar et al., 2008; Noltze et al, 2012; Takahashi, 2013).

1.2.3. SRI in Cambodia

SRI was first introduced to 20 farmers across 18 villages in Cambodia by Cambodian Center for Study and Development in Cambodia (CEDAC) in 2000 (Yang, 2002). In 2012, number of farmers who adopted SRI increased to about 149,657 with the average rice yield being about 3.9 t ha^{-1} (SRI-LMB project, 2013), which is much higher than the national average yield for wet-season rice as noted above.

In the early of 2006, SRI was included in the MAFF's National Strategic Development Plan (NSDP) and policy frameworks for 2006-2010 to improve rice production and contribute to poverty reduction of farmers in Cambodia (MAFF, 2015).

In Cambodia, previous studies have shown that SRI increased rice yield and reduced uses of chemical fertilizer and seeds in rainfed lowland fields (Anthofer, 2004; Ches et al., 2012; Ly et al., 2012; Ly et al., 2016). None of these studies on SRI in Cambodia has however investigated how the yield increase by SRI was attained in interaction with the water constraint and other determinants of rice yield.

Even though SRI would increase rice yield in irrigated paddies where shallow water level can be maintained, the water constraint could negate the yield increase by SRI in rainfed fields where the water level can be hardly controlled.

1.3. Objectives of This Study and Thesis Outline

1.3.1. Objective of study

One of the major challenges in Cambodia is to increase rice production under the water constraint of the rainfed paddies, and I focus in this study on SRI as a possible solution to the challenge.

The main objective of this study is to find possibilities of SRI in improving rice farming under the water constraint of rainfed lowland rice of Cambodia. To this end, I conducted interview surveys, on-farm experiment as well as numerous field visits while staying in Phnom Penh, the capital of the country for the period of 56 months in total between 2011 and 2016.

With the interview surveys, I tried to see whether SRI increased rice yield in rainfed low land fields of southern Cambodia. I also tried to understand how the farmers view advantages and disadvantages of SRI and make the decision on the acceptance or rejection of SRI against the huge variability of natural, agronomic and societal environment.

The on-farm experiment was conducted to augment and hopefully substantiate the findings in the interview surveys. I observed the farmers' performance and the rice plant growth and yield under SRI and Non-SRI practices in rainfed fields of southern Cambodia. At the same time, I monitored climatic and soil regimes in the fields, and also analyzed soil properties to place the SRI-induced changes, if any, of rice growth and yield against the climatic and edaphic constraints.

By conducting the interview survey and the on-farm experiment in the farmers' rainfed fields, I aimed at better understandings of the farmers' adoption of SRI in the rainfed fields and thereby contributing to a securer livelihood among the small holder farmers, who is the main target of SRI.

1.3.2. Thesis structure

This thesis is organized as follows. Following **this chapter** for presentation of background and the introduction to the objectives of study, **Chapter 2** analyzes the efficacy of SRI on rice yield as reported by the rainfed rice farmers in southern Cambodia in an interview survey. **Chapter 3** focuses on the farmers' adoption of SRI to elucidate factors that determine the adoption and rejection of SRI among the rainfed rice farmers, who were subjected to the interview survey. The yield gain by SRI reported in the interview survey was investigated with on-farm experiments along with environmental monitoring in SRI and Non-SRI fields, and the results of the investigation are presented in **Chapter 4. Chapter 5** provides a synthesis of findings in previous chapters and discusses roles of SRI for the future of rainfed lowland rice production in Cambodia.

Chapter 2 Rice yield increase by the System of Rice Intensification with dependency on supplementary water availability in rainfed lowland fields of southern

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Chapter 3 Assessing the acceptance of system of rice intensification (SRI) among rice farmers in a rainfed lowland area of southern Cambodia

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Chapter 4 On-farm evaluation of the effects of SRI on rice growth and yield in rainfed fields of southern Cambodia

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Chapter 5. General discussion

The main objective of this study is to find the possibility of SRI in improving rice farming under the water constraint of rainfed lowland rice of Cambodia. To this end, I conducted interview surveys and on-farm experiment along with numerous field visits.

With the interview surveys, I tried to see whether SRI increased rice yield in the rainfed lowland fields, and to understand the farmers' view on advantages and disadvantages of SRI and reasons for their decision on acceptance or rejection of SRI. I also conducted the on-farm experiment to substantiate the findings in the interview surveys. I observed the farmers' practices and the rice plant performances in the SRI and Non-SRI fields under the rainfed condition. I also analyzed climatic records and soil properties to place the SRI-induced changes of rice growth and yield against the climatic and edaphic constraints.

In this chapter, I first synthesize the findings in the interview surveys and the on-farm experiment as described in the preceding chapters to better understand the farmers' adoption of SRI in the rainfed fields. I then argue ways to utilize SRI for better security of the livelihood of the smallholder farmers in the rainfed lowlands of Cambodia.

5.1. The efficacy of SRI on rice yield improvement in rainfed lowland fields

Rainfed lowland rice areas lack water supply and/or water control for irrigation. As a result, they are more prone to flooding and drought than their counterparts in irrigated production areas (IRRI, http://www.knowledgebank.irri.org/).

Although the water management is one of the key components of SRI, it is hard to practice for rainfed rice farmers in Cambodia. Tsurui et al. (2010) reported low rate of adoption by farmers of some SRI components including keeping shallow water levels, raised nursery bed, and transplanting young seedlings in the rice fields of Cambodia. On the other hand, the farmers practiced other SRI components such as planting only one or two plants per hill, wider spacing at transplanting, and higher rates of farmyard manure (Tsurui et al. 2010). In the SRI fields of the present study also, the farmers did not perform the shallow water management, but adopted other SRI components, i.e. use of young seedlings for transplanting, reducing the number of seedlings per hill and the planting density, and applying farmyard manure. The respective components should have contributed to the increased rice yield in the farmers' SRI fields as discussed below.

A. Young seedlings for transplanting

As reported in Chapter 2, the interview survey indicated that the high grain yield in SRI as compared to Non-SRI is associated with early planting of young seedlings into the fields with availability of supplementary water. Previous studies have also shown that younger seedlings recovered from transplanting shock faster than aged ones, and that they produced higher number of tillers and dry matter production leading to the greater rice yields under favorable field conditions (Pasuquin et al., 2008; Thakur et al., 2013; Hidayati et al., 2016). In the fields without supplementary water, however, SRI did not increase grain yield, but delayed the harvest date, which may be an indication of severer drought stress in the seedlings after transplanting. In 2014, there was a very severe drought during the wet season (Fig. 2.4), and the grain yield in SRI fields without supplementary water (Table 2.5) was even lower than that in Non-SRI fields in a bumper year of 2012 (Table 4.7). A similar result showing 12-46% yield reduction due to water shortages was reported by Ouk et al, (2006) in artificially induced drought conditions in Cambodia. The effects of supplementary water on rice yield and the SRI-induced yield increase was not evident in the on-farm experiment (Table 4.7), however, due presumably to the limited number of field studied (Table 4.1), higher rainfall during the wet season for the three years than 2014 (Figs. 2.3b and 2.4), and the lack of difference in the seedling age between the SRI and Non-SRI fields (Table 4.4).

B. Planting at lower density

In the on-farm experiment as reported in Chapter 4, the rice yield was increased with no significant difference in seedling age between SRI and Non-SRI fields. It has been reported that performance of individual hill was significantly improved with wider spacing in terms of root growth and xylem exudation, tiller and panicle number, and grain number per panicle (Thakur et al., 2010). Such was also the case in the on-farm experiment in this study, where the number of panicles per hill was increased (Table 4.8) to compensate for the lower planting density while the number of spikelets per panicle was increased leading to the yield increase (Tables 4.7 and 4.8). The increased grain yield was related to the greater amount of nitrogen accumulation in plants (Fig. 4.2) and, more closely, to the increased number of spikelets per land area (Fig. 4.3).

C. Increased application of farmyard manure (FYM)

It must be noted that the increased plant N uptake and grain number (Figs. 4.2 and 4.3) were made possible with the greater amount of FYM application in the SRI fields particularly in the non-drought years (Table 4.5). The greater availability of soil nitrogen (Table 4.6) in SRI fields in association with the lower planting density should have led to the higher nitrogen content in the plants, which should have led to the greater number of spikelets per panicle (Kobayasi & Horie, 1994) and consequently higher rice yield.

The above findings could be summarized that rice yield can be increased by SRI even in rainfed lowland fields in Cambodia by combining the reduced planting density with increased manure application, and that the grain yield could also be increased by planting young seedlings where supplementary water is available.

5.2. Farmers' adoption and rejection of SRI

The higher rice yield with lower planting density should make very good reasons for the farmers to adopt SRI. They did mention the higher yield and lower seed requirement among the major reasons for the SRI adoption (Fig. 3.2). However, most of the farmers whom I interviewed continued the rejection of SRI or discontinued once adopted SRI, since a majority of them had no water supply in their fields (Fig. 3.4b). The linkage between supplementary water availability and SRI practices was clearer on the field-to-field basis (Fig. 2.6), where more than 70% of the fields had no availability of supplementary water. Some farmers who had their fields at two or more locations could perform SRI in some of the fields (category PA in Fig. 3.4), whereas others with fields at only one location and without supplementary water had to discontinue SRI (category DA in Fig. 3.4). It thus appears that the farmers have realized the dependence of SRI-induced yield increase on supplementary water availability as indicated earlier.

Besides the lack of supplementary water, this study has identified difficulties of transplanting according to the SRI principle as the major reasons why the farmers do not adopt SRI. A labor peak comes at transplanting time, and the farmers in neighborhood help out each other via labor exchange. The planters with no SRI experiences would perceive the planting at regular spacing especially troublesome. It must also be noted that SRI dictates the farmer to plant seedlings earlier than the conventional practice, and that securing the planting labor at an earlier timing is quite difficult particularly with the increasing opportunities to earn income from off-farm sources, e.g. factories.

Although previous studies have pointed out that SRI requires intensive manpower than conventional practices in weed control and water management (Moser and Barrett, 2003;

Barret et al., 2004; Takahashi, 2013; Islam et al., 2014), these were not mentioned by the farmers as the reasons for not practicing SRI. Such intensive management may be impossible or even unnecessary in the rainfed environment at the study site.

5.3. Adapting SRI for better livelihood of small holder farmers in rainfed lowlands of Cambodia

This study showed that the yield-gain in SRI by planting younger seedlings requires supplementary water sources. Increasing small-scale water sources, e.g. ponds and pumps, would facilitate the earlier planting and the rice yield increase with SRI. It must be noted, however, that, in Cambodia, a rapid urbanization is occurring, and that nearly one in four households has at least one working-age member to emigrate to cities. This makes the shortage of transplanting labor severer and may make SRI less feasible for many farmers. As shown before, the difficulties at transplanting according to SRI principle have been mentioned as a reason for not practicing SRI by many farmers.

From the on-farm experiment, an yield gain can be expected from reducing planting density when it is combined with increased manure application. The reduced planting density may not necessarily require the regular-grid planting, which causes troubles for the planters as mentioned above. Considering the little needs for weeding at the study site, the regular-space planting may not have to be followed as long as the planting density can be reduced from the conventional one. It would however be necessary to increase the soil nitrogen supply via increased manure application to compensate for the reduced planting density and to increase the number of grains per land area. It appears that availability of manure is not a major constraint at this moment, but its availability could become limiting when SRI were to be adopted at a large scale in the future.

A more basic question would be if the rice yield increase by SRI contributes to improved livelihood of smallholder farmers in rainfed rice regions of Cambodia. Indeed, as mentioned above, there are increasing opportunities of diversifying income sources for many farming households. This may make the labor shortage at the transplanting time even severer and adoption of SRI less attractive for many farmers. It must be noted, however, that some components of SRI are labor saving. The reduced number of seedlings per hill and lower planting density would save the seeds as well as the time for collecting and planting the seedlings, although only a small fraction of farmers acknowledged the labor-saving benefit of SRI (Fig. 3.2).

According to my observations across rainfed rice regions of Cambodia, farmers are indeed trying to save planting labor by reducing the number of seedlings per hill, although they may not recognize it as partially performing SRI. The rising labor cost for transplanting is a challenge for both SRI and Non-SRI farmers. I would therefore argue that adaptation of SRI must be sought out for lower labor requirement along with a higher yield. Such improvement could take advantages of the labor-saving components of SRI: lower number of seedlings planted per land area and utilization of the tillering capacity of the young seedlings to compensate for the lower planting density. With the reduced labor requirement as an additional target, the adapted SRI may not be simply called a system of rice *intensification* any more, however.

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