Cost – Benefit Analysis of Different Rice Cropping systems in Thailand

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Arayaphong, S., 2012: Cost – Benefit Analysis of Different Rice Cropping systems in Thailand. *Master thesis in Sustainable Development at Uppsala University*, No. XX, YY pp, 30 ECTS/hp

Abstract: System of Rice Intensification (SRI) has been introduced and practiced throughout Thailand. However, the conventional transplanting system is well-accepted among Thai farmers over the country. This paper quantifies and compares costs and benefits of SRI and the conventional system of rice cultivation in Thailand to find the best system for a farmer, the environment and a society. The scope of this paper includes a farmer's profit, the environmental damages and a society's net benefits categorized in clay soil and sandy loam conditions. The farmer's profit consists of a production cost and income. The amount of fertilizer application, level of lethal dose and climate change cost are regarded as environmental damage components. The society has concerned over the farmer's profit and the environmental cost in a decision. The study uses cost-benefit analysis to investigate mean and variation of profit and cost in monetary term. Monte Carlo simulation is utilized for quantifying risk in each scenario. The study finds that SRI saves the production input and increases yield gain significantly. The most impressive results are a reduction in water consumption and number of seeds. Also, the environmental damage caused by this system is lower due to less amount of chemical fertilizer and pesticide applications as well as a low rate of methane gas emission. Sensitivity analysis shows that SRI has better performance under best and worst case scenarios for both types of soil (clay soil and sandy loam). However, the system contains the highest risk of the farmer's profit. In conclusion, SRI is more beneficial and efficient than conventional system. Still, risk aspects should be considered in decision making. This study can be employed as a framework for government or any parties, who are interested or have willingness to conduct a field study of SRI and the conventional rice cropping system or for the further study about the integrated system (a combination between SRI and conventional system).

Keywords: Sustainable Development, Rice cropping system, SRI, CBA, Risk analysis, Thailand

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Summary: Thailand is an agro-based country, where almost half of the agricultural area is devoted to rice cultivation. Many Thai farmers over the country apply the conventional transplanting system as their fundamental rice cropping system. However, the innovative system named System of Rice Intensification (SRI) has been introduced and practiced in many parts of Thailand. The significant differences between the conventional system and SRI are a number of seedlings per hill, an irrigation system, the transplanting space, and the amount of chemical fertilizer and pesticide applications. From the core concept of sustainable development, not only economic aspect should be concerned, but also environmental and social aspect has to be considered in order to meet the goal of sustainability. Thus, the objective of this paper is to quantify and compare costs and benefits of SRI and the conventional system in Thailand in order to find the best system for a farmer, the environment and a society. The scope of this paper includes a farmer's profit, the environmental damages and a society's net benefits categorized in clay soil and sandy loam conditions. In Thailand, there are two main soil types for growing rice, which are clay soil and sandy loam. Clay soil is stickier and has higher water storage capacity than sandy loam condition. The study focuses on four main regions in the country; northern, northeastern, central and southern part, where clay soil is assumed to represent soil condition in northern and central part while sandy loam represents northeastern and southern part. The farmer's profit consists of the production cost (seed, labour, irrigation, fertilizer and pesticide) and income (yield gain). The amount of fertilizer application, level of lethal dose of each type of pesticides (LD_{50}) and climate change cost are regarded as the environmental damage components. The society has concern over the farmer's profit and the environmental cost (the climate change cost) in a decision. The study uses cost-benefit analysis to investigate mean and variation of the profit and costs in monetary term. Since all parameters in this study are diverse, so the Monte Carlo simulation is utilized for quantifying risk in each scenario of different cropping systems and soil types by performing 1,000 random simulations to calculate the standard deviation and the effect of each input towards the profit. The study finds that SRI saves the production input and increases yield gain significantly. The most impressive is a reduction in water consumption and a number of seeds. Also, an environmental damage caused by SRI is lower than the conventional system because of less amount of chemical fertilizer and pesticide applications as well as a low rate of methane gas emission. With a wider transplanting space and wet and dry system help and enhance the rice plant to absorb more nutrients, sunlight and water as well as prevent pests and diseases (the aeration in the rice field can flow better and the sunlight can reach the soil surface). Hence, there is no need of intensive chemical fertilizer and pesticide under SRI. Methane gas generally emits under flooding condition; therefore, SRI with wet and dry system has lower methane gas emission comparing to continuous flooding from conventional system. Moreover, the system has better performance under best (maximum income with minimum cost) and worst (minimum income with maximum cost) case scenarios for both soil types because the core concept of less input with more output enhances the resilient ability of the system. The farmer's profit is higher, while the environmental cost is lower under SRI. Hence, the society gains higher profit from the system than the conventional system. However, SRI contains the highest risk of the farmer's profit, which means that the variation of the profit is really various. The SRI farmer has a chance to reach the highest profit, but at the same time has a possibility to get the lowest profit. In conclusion, SRI is more beneficial and efficient for a farmer, the environment and a society than conventional system. Still, risk aspects should be considered in decision making. This study can be employed as a framework for government or any parties, who are interested or have willingness to conduct a field study of SRI and the conventional rice cropping system or for the further study about the integrated system (a combination between SRI and conventional system).

Keywords: Sustainable Development, Rice cropping system, SRI, Cost-benefit analysis, Risk analysis, Thailand

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1. Introduction

Thailand is an agro-based developing country in South East Asia, where about 41% of the land is devoted to an agricultural sector. Rice cultivation is the main crop in the sector covering 50% of the agricultural area (around 2 ha/household) (Office of Agricultural Economics, 2011). Rice is the staple food for every household in rural and urban areas. Approximately 353 gram of rice is consumed per day (for a Thai person with an age above 3 years old) (National Bureau of Agricultural Commodity and Food Standards, 2010). Besides, 36.54% of total labour force lives in a rural area and involves in agricultural activities, where rice production is the main source of income (Bank of Thailand, BOT, 2011a). Since the Green Revolution in 1960s, Thailand started becoming an outstanding rice producer and exporter in the world market. The country exported 10.6 million tons in 2011, and is expected to reach 20 million tons by 2012 (United States Department of Agriculture, 2012). Accordingly, rice cultivation plays a key role in economy, society and household's food security in Thailand.

Several cropping systems are applied variously all over the country, but the transplanting system is the most famous among Thai farmers. In the past, a purpose of producing rice is to maintain household's food security, and sell the rest to neighbors. Later on, population and economic growth accelerated demand of rice, so a farmer had to intensify rice production in order to meet increased demand. Intensive fertilizer and pesticide application substantially become a preferred option for a local farmer to gain more yields. However, using more inputs leads to higher production cost, which means that a farmer has to produce more to cover the cost. In addition, an escalation of rice production brings negative impacts on the environment, ecological system and humankind. Chemical substances are widely used among Thai farmers resulting in contamination of toxicity and pollution on nature. Furthermore, natural resources such as water and soil nutrients are exploited for massive rice cultivation.

As sustainability becomes a vital issue nowadays, the cropping system is improved and developed to meet the core concept of sustainable development, which is the development that meets the need of present generation without compromising the ability of future generations to meet their needs (Rist, 2002) as shown in the report Our Common Future. Accordingly, System of Rice Intensification (SRI) is initiated with a principle of less input, more output. The system originated in Madagascar by Fr. Henry de Laulanie in 1980's, who developed a new concept of single seedling transplantation and intermittent irrigation (World Bank, 2008). The new innovative techniques allow a rice plant to utilize biological power and solar energy for greater yield capacity with less input and chemical usage. Currently, many countries apply and experience the system, such as Bangladesh (Muazzam, 2004; Rahman and Roy, 2006), India (Geethalakshmi, 2011; Barah, 2009; Sivanagaraju, 2006), Cambodia (Uphoff, 2004; Suon, 2007; Anthofer, 2004), Sri Lanka (Uphoff, 2004), China (Li, et. al., 2004), Philippines and Vietnam (World Bank, 2008). In the case of Thailand, SRI is initiated since 2000, and conducted the first experimental field in Chiang Mai provinces by Multiple Cropping Center (MCC) in 2001 (SRI-Rice, 2011). After that, several farmers and researchers learn and study the new system in many parts of the country.

Rice cultivation depends mainly on uncontrollable factors such as weather and market. As an example, flooding and drought cause serious yield loss while fluctuated market price affects production cost and income. Therefore, riskiness should be considered in decision making. Besides, not only a farmer is an important actor in sustainable rice cultivation, but also the environment and the society should be considered in the study according to the concept of sustainable development.

The main purpose of this study is to investigate two different rice cropping systems; the conventional system and SRI, in order to find the best rice cropping system that is suitable for a farmer, the environment and a society in Thailand. Accordingly, cost-benefit analysis (CBA) is employed to quantify and compare costs and benefits. Likewise, the study employs Monte Carlo simulation to evaluate and analyze expected profit and risk of both systems. Furthermore, this study can be employed as a framework for government or any parties, who are interested or have willingness to conduct a field study of SRI and the conventional rice cropping system.

The entire study is divided into seven sections including this section as an introduction. The following section is literature review, where previous studies and researches are shown. The third section gives general information on rice cultivation containing an overview of rice production in Thailand and a general background of conventional system and SRI. The forth section is a theoretical framework, where involved actors, scenarios and project choices are explained. The fifth section is devoted to data presentation showing how all data and numbers are retrieved and calculated. Next section presents results of this study, and the last section consists of discussion, overall results summary and conclusion.

2. Literature review

As stated in the introduction part, SRI is a new technical system with a concept of less input, more output. The system is widespread around the world. Still, not every farmer is willing to change from the conventional system to the new innovative system as SRI. Several studies investigate and compare costs and benefits of SRI and non-SRI systems in order to prove beneficial advantages of SRI. Most of the studies show that a local farmer gains more benefit from SRI in reduced input use and increased yield gain than non-SRI systems[1]. In general, the production input mainly consists of seed, labour, irrigation, fertilizer and pesticide, whereas yield is a farmer's income.

Barah (2009) quantifies economic and ecological advantages of SRI and the conventional system in Tamil Nadu, India to identify and evaluate impacts of reduced production input and influent factors on SRI adoption. The results show that the production cost of SRI is lower than non-SRI, whilst a SRI farmer gains more yields. Accordingly, the benefit-cost ratio of SRI is higher than non-SRI. However, more labour and time are consumed under SRI because some processes such as transplanting process is a tender and detailed task. Similarly, Rahman and Roy (2006) examine potentials of SRI by comparing the cost of seed, labour, irrigation, fertilizer and pesticide with income of yield gain. They conclude that SRI in overall has the greater potential and benefit-cost ratio than conventional system. Still, transplanting single seedling requires more time and labour. Also, intermittent irrigation is difficult to manage especially for a farmer, who is lack of water resource accessibility. Furthermore, a study from Sivanagaraju (2006) employs "*farm management cost concept approach*" to categorize the production cost into 4 groups. Cost A_1 consists of seed, labour, irrigation, fertilizer and pesticide. Cost A_2, Cost B and Cost C add land rental cost, rental value of owned land and interest on owned fixed capital, and value of family labor to Cost A_1, respectively. The result shows that SRI has all costs slightly higher than conventional system, but the gross return is dramatically higher. Accordingly, the net benefit of SRI is greater than conventional system.

On the other hand, Uphoff (2004) finds that SRI practice in some areas is not successful because of labour requirement. In Madagascar, labour cost increases during the first period due to required skill and detailed task. Nonetheless, several farmers in China regard SRI as labour-

[1] More studies and field researches in various countries show that SRI can improve rice production and economic return in a sustainable way (Mishra, et al, 2006; Mishra and Salokhe, 2008; Uphoff and Mishra, 2009).

saving method; nevertheless, most of them apply herbicides instead of hand weeding. In a case of Cambodia, SRI is regarded as "*labour neutral*" although the production process requires more time and labour use than conventional system. Time and labour constrains can be overcome by proficient management. Water control is also a serious constraint of SRI because the process is complicated and detailed, which is not suitable for a farmer who has difficulty in water resource accessibility. Besides, a farmer needs to be trained and educated about new innovative method, which is also a constraint and cost for a farmer as well.

Apart from a farmer's perspective, the environmental impact is also studied in several papers. A field experiment is conducted by Khosa, et al. (2010) to find the best water management practice to mitigate methane gas emission from the rice field. Continuously flooded condition creates higher rate of CH_4 emission. Conversely, CH_4 leakage is reduced to almost half of previous amount when the rice field is applied intermittent irrigation. Moreover, Shin, et al. (1996) evaluates the effects of water management and rice straw application on CH_4 emission in Korea. The result reveals that intermittent irrigation reduces CH_4 emission by 36% compared to a continuous flooding system. Sass (1996) studies CH_4 emission from different water sources; irrigated, rainfed and deep water area in many parts of Thailand and other countries. The study concludes that an irrigated area in overall has the highest emission. In the same year, Kroeze (1996) conducts research surveys in several countries around the world including Thailand about CH_4 leakage from the rice field under different irrigation systems. Continuous flooding system is still the main source of CH_4 emission.

Further interesting point is risk-preference of a local farmer. As mentioned in the introduction, an agricultural yield gain depends on an uncontrollable factor, which means that a farmer has to take responsibility of riskiness by him- or herself. Therefore, risk analysis is also an important factor in decision making. Fox, et al. (2005) studies economic viability for water harvesting system (WH) implementation with supplemental irrigation (SI) for a small-holder farmer in semi-arid Burkina Faso and Kenya. Costs and benefits of WH are estimated and compared among different treatments to find expected yield for risk analysis. The result shows that SI generates economic and sustainable benefits to a farmer's household, but an investment in the technology is higher than the normal system. Variations in labour cost and interest rate are the main constraint obstructing a farmer to change WH pattern. The authors conclude that the government or policy maker should facilitate the credit system for a farmer's motivation.

SRI principles and practices are introduced in Thailand since 2000 by Klaus Prinz of McKean Rehabilitation Center (MRC), who participated in International Institute for Rural Reconstruction (IIRR), a SRI workshop, in Philippines. The information is passed to Multiple Cropping Center (MCC) of Chiang Mai University, initiating the first experimental study of SRI during year 2001 (SRI-Rice, 2011). The study is conducted during wet and dry season in Chiang Mai province (northern part), where the rice field is under sandy loam condition. The result shows that land preparation under SRI is critical because the process of transplanting (non-flooded condition) is totaling different from the conventional system (flooded condition). The study concludes that yield gain under conventional system is higher than SRI because local farmers are not familiar with new water management as a wet and dry system. Besides, an irrigation system in this area is based on a community or a group, which means that an individual farmer, who applies a different irrigating pattern will affect working schedule of the community or the group. Consequently, the farmer cannot reach the optimum benefits from a wet and dry system. On the other hand, production input use in SRI is lower as a number of seeds in SRI are only 10 kg/ha whereas a conventional farmer spends almost 65 kg/ha (Gypmantasiri, 2002).

Even though the first experiment is not successful, MCC, MRC, NGOs and other groups continue the SRI experiment in several areas in northern and northeastern province, and formalize the national SRI network for sharing and discussing experiences and obstacles of SRI (SRI-Rice, 2011). An experiment in northeastern region shows that local farmers have more knowledge and better comprehension about SRI and a wet and dry system; hence, the farmer achieves an optimal benefit of SRI. Tillers are much more than usual, and roots system is developed, and becomes longer and stronger. Also, yield gain increases by 30% - 60% in many areas (MCC, 2003).

Since 2003, more researches and experiments about SRI are conducted in several areas around Thailand. One of important experiments is the SRI project held in northeastern region (from 2006 to 2007) with an attempt to overcome water resource constraint and fluctuated weather. The result finds that younger seedling has better performance compared to 30 days old seedling. Besides, intermittent irrigation saves the cost more than a continuous flooding system without reducing yield gain. Weed is the only problem from SRI, but farmers grow local plants to control weed growth instead of applying chemical herbicides (Mishra and Salokhe, 2006;2007). However, an experiment in Chachoengsao province (clay soil condition) shows that yield gain is not much different between intermittent irrigation and a continuous flooding system. The study regards young seedling and single seedling as an important factor of increased yield gain. This convinces local farmers to reduce the amount of chemical fertilizer application (Nieuwenhuis, et al., 2008). Mishra and Salokhe (2011) reveal that younger seedling enhances a rice plant to prolong vegetative period, leading to increased root length density. Greater root length density enhances storage capacity of root zone, and a deeper root system helps a rice plant to absorb more water from soil.

In addition, plant spacing such as 25x25 cm, 30x30 cm and 40x40 cm has an effect on yield capacity as studied in a SRI experiment conducted in Phattalung, a province in southern part. The result reveals that wider plant spacing increases an amount of yield gain. The reason is that wider transplanting space enhances the rice plant and its roots to absorb more nutrients, sunlight and oxygen, resulting in more tillers, panicles and grains (Panomjan, et al., 2009), and avoid shading effects (Mishra and Salokhe, 2011). It can be seen that SRI practice and knowledge are promoted and developed throughout the country; however, the system is not well-accepted for all Thai farmers. Several studies above inspire the purpose of the study, which is to study cost-benefit and risk of rice cropping systems in the perspective of a farmer, the environment and the society.

3. General information about rice cropping in Thailand

Two main cropping periods in Thailand are wet (rainy) season or in-season (June - December) and dry (winter) season or off-season (February - June); however, the period depends on the climate in each year (Department of Agriculture, 2011). A farmer generally grows different rice species, which are categorized into two main types; strong and less sensitivity to photoperiod. Rice with strong sensitivity to photoperiod is grown during wet season whilst dry season is suitable for rice with less sensitivity to photoperiod (Rice Department, 2006).

This study focuses on four main regions in Thailand namely northern, central, northeastern and southern region. Climate and soil types are diverse among these regions, resulting in different production input usage and yield gain. Northern, central and northeastern region have almost the same amount of annual rainfall. Significantly, southern region has the highest annual rainfall and humidity because the area is surrounded by oceans (Thai bay and Pacific Ocean) and forests. Average temperature in central region is the highest whereas northern and northeastern region have the most decent temperature.

As said by the Land Development Department (2006), rice fields in Thailand are under clay soil and sandy loam conditions (clay soil is stickier and its water storage capacity is better than sandy loam). Based on the soil map of Thailand, most of areas in northern and central region contain clay soil while northeastern and southern region are under sandy loam condition (Boonsompopphan, et al., 2010). Hence, presented data in this study is categorized by two cropping systems (conventional transplanting system and SRI), and two soil conditions (clay soil and sandy loam) (for general information about the rice plant, see *Appendix A*)

Generally, there are three main rice cropping systems in Thailand; transplanting method, seed broadcasting or direct seeding method, and seed drilling method. Only transplanting method has similar cultivating processes to SRI, and can be improved if needed, whereas other methods; broadcasting and drilling method, have totaling different processes. Accordingly, this transplanting method is chosen to be one of the alternatives of this study (see *Appendix B* and *Appendix C* for broadcasting and drilling cropping system). Transplanting method is also called "*low-land rice cultivation*", and considered as a labour intensive method. Seedlings are raised in prepared plots (*Picture 1*) during the nursery period until reaching 25 – 30 days old for photosensitive rice and 20 – 25 days old for non-photosensitive rice (Bureau of Rice Research and Development, 2011a). Then, a farmer irrigates a rice field with 5 – 10 cm height, and keeps it flooding until a few days before the harvesting time for a purpose of weed control (*Picture 1*) (Wongwutsaroj, 2006). A farmer transplants 3 – 4 seedlings[2] per hill[3] with a transplanting space of 20x20 cm for non-photosensitive rice and 25x25 cm for photosensitive rice (ibid).

Picture 1: Nursery plots and continuous flooding system

Nursery plots (Seedbeds)

Transplantation with continuous flooding

For SRI, a farmer disassembles seedlings with 8 - 12 days old (2 leaves stage) and transplants only one seedling per hill (single seedling). A transplanting space between hills is 25x25, 30x30 or 40x40 cm depending on soil's fertility (World Bank Institute, 2008). Low fertile soil should have less wide space. In Thailand, clay soil is more fertile than sandy loam, so an appropriate space is 30x30 and 40x40 cm for clay soil, and 25x25 and 30x30 cm for sandy loam (Gypmantasiri, 2001; Sivanagaraju, 2006). Wider transplanting space makes it more convenient to use rotary weeder in the rice field. For an irrigation system, a farmer applies a wet and dry system, where a core concept is to irrigate the rice field with a water level of 5 cm and let it dry until a water level drops to 15 cm below the soil surface (*Picture 2*), which takes about 7 – 10 days before starting a new round, depending on soil and climate conditions (World Bank Institute, 2008; Gypmantasiri, 2001; Sivanagaraju, 2006; Kürschner, 2010).

Picture 2: Wet and dry system

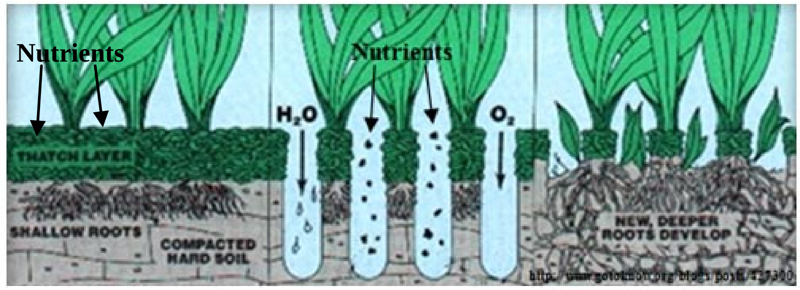
The system reduces the amount of water used in the rice field. Moreover, rice roots can absorb oxygen and nutrients directly through soil cracking, benefiting root length density, and growth of roots and shoots (*Picture 3*) (World Bank Institute, 2008; Mishra and Salokhe,

[2] Some farmers spend up to 8 seedlings in each hill
[3] Hill is a hole, where a farmer put a seedling in the rice field

2006;2007; Vial, 2007). Since the rice field is kept dry, weeds grow more quickly. A farmer usually uses a rotary weeder to control and get rid of weeds about 3 times or 18 – 25 days/ha/cropping season (World Bank Institute, 2008; Gypmantasiri, 2001; Sivanagaraju, 2006). With rotary weeder, weeds are mixed in the soil that enhances soil aeration and fertility.

Picture 3: Rice field under SRI method and wet and dry system

Rice field under SRI method



Wet and Dry system

There are four main differences between the conventional system and SRI. Firstly, a number of seedlings per hill for SRI (single seedling) are different from the conventional system (3 – 4 seedlings). Secondly, an irrigation system of SRI is a wet and dry system, while the conventional system applies a continuous flooding system. The transplanting space is the third difference between SRI (25 – 30 - 40 cm) and the conventional system (20 - 25 cm). Lastly, the amount of chemical fertilizer and pesticide applications in SRI is less than the conventional system[4].

[4] For a number of labour, SRI has more processes, so it depends on an individual household to manage time and labour. Some spends less time, but some needs more labour to complete all the processes.

4. Theoretical Frameworks of Cost-Benefit Analysis

This study aims to quantify and compare costs, benefits, expected profits and risks between the conventional system and SRI by using CBA basis and Monte Carlo simulation. According to Broadman, et al. (2006), a few steps are taken in a CBA; specifying alternatives or scenarios of the project, identifying key players (who will be affected by the project), collecting, and measuring costs and benefits. To begin with standings identification, a farmer is the main actor who is affected directly from rice production through a profit and production cost. The second actor is the environment because nature and ecological system are impacted by toxicity and exploitation of resources from rice production. Lastly, a society is regarded as third actor because an impact on a farmer and the environment also affects the society. Life time span of this study is one cropping year (two cropping seasons; wet and dry season) at the present period. Besides, a scale perspective is small to medium farms with an average size of 2 ha. The conventional system (transplantation with a continuous flooding system) and system of rice intensification or SRI (transplantation with a wet and dry system) are alternatives specification of rice cultivation. In the following, the symbols in *Table 1* are employed to present the CBA approach.

Table 1: Abbreviation and definition

Abbreviation	Meaning	Abbreviation	Meaning
i	Cropping system (Conventional system or SRI)	P	Amount of pesticide use
h	Soil type (Clay soil or sandy loam conditions)	p^S	Price of seed
s	Society	w^L	Wage of labour
Π	Profit	p^{IR}	Price of irrigation
p^R	Price of rice grain	p^F	Price of fertilizer
Q	Amount of grain yield	p^P	Price of pesticide
C (Q)	Costs of rice production	p^m	Price of climate change
S	Number of seeds use	e	Environmental damage (F, LD_{50} and m)
L	Amount of labour use	m	Climate change cost
IR	Amount of irrigation use	LD_{50}	Level of lethal dose 50 of each pesticide
F	Amount of fertilizer application	M	Amount of methane gas emission

4.1 Farmer's profit

One part of the CBA shows how a decision is made by a farmer. A profit gain under the conventional system (Π^C) has to be higher than or equal to zero ($\Pi^C \geq 0$), so a farmer can continue the production. In certain situations, SRI is the preferable choice, when the profit is

(Π^{SRI}) comparatively higher than the conventional system (Π^{SRI} - $\Pi^{C} \geq 0$). Otherwise, the farmer will not have the motivation to change his/her cropping system.

In order to evaluate and analyze the best cultivation system, costs and benefits of rice production under each system are calculated. The production input consists of seed (S), labour (L), irrigation (IR), fertilizer (F) and pesticide (P). These inputs are diverse depending mainly on cropping and irrigating method while other production components such as a milling machine and land rental vary from external factors not from the different cropping systems and irrigating method. Total production cost [$C(Q^{i,h})$] at the cropping system i and the soil type h is the sum of production input's costs (3). Yield ($Q^{i,h}$) is a benefit component, generating a farmer's income ($p^R*Q^{i,h}$). A farmer's profit ($\Pi^{i,h}$) of each cropping system and soil type is calculated by subtracting the production cost [$C(Q^{i,h})$] from the farmer's income ($p^R*Q^{i,h}$), which is written as

$$\Pi^{i,h} = p^R*Q^{i,h} - C(Q^{i,h}) \quad ---------- \quad (1)$$

$$Q^{i,h} = Q^{i,h}(S^{i,h}, L^{i,h}, IR^{i,h}, F^{i,h}, P^{i,h}) \quad ---------- \quad (2)$$

$$C(Q^{i,h}) = p^S*S^{i,h} + w^L*L^{i,h} + p^{IR}*IR^{i,h} + p^F*F^{i,h} + p^P*P^{i,h} \quad ---------- \quad (3)$$

4.2 Environmental damage

Rice production causes many negative effects on the environment through the applications of fertilizer and pesticide as well as methane gas emission. Chemical fertilizer's runoff and leakage create imbalanced terrestrial and aquatic ecosystems. Additionally, soil quality is destroyed and exploited by chemical substances such as Nitrogen (N), Phosphorus (P) and Potassium (K) (Choudhury and I. R. Kennedy, 2005; Zhao, et al., 2011). Pesticide is the most injurious factor causing severe damages on the environment, nature and human. Herbicide, insecticide, mollussicide and fungicide are mainly used among Thai farmers, where each type of pesticide has different toxicity level (lethal dose 50). Methane gas emission is one of the global warming gases, resulting in climate change phenomena such as flooding and drought.

Therefore, the environmental damage (e) consists of an amount of fertilizer application (F), a level of lethal dose 50 of each pesticide (LD_{50}) (see *page 23*), and climate change cost (m). Owing to the limitation of data, the environmental costs of fertilizer and pesticide cannot be monetized. This study only compares the quantity of them. On the other hand, climate change cost expresses the environmental cost of CH_4 emission by multiplying the price of climate change (p^m) with the amount of CH_4 emission ($M^{i,h}$) as written in (5).

$D^{i,h} = D(m^{i,h})$ ---------- (4)

$D(m^{i,h}) = p^{m} * M^{i,h}$ ---------- (5)

4.3 Society's net benefit

A society contains a farmer and the environment, so costs and benefits of both actors are further added in the society's decision making. For conventional system, a farmer's profit (Π^{C}) subtracts by the environmental damage cost (D^{C}) must be higher than or at least equals to zero ($\Pi^{C} - D^{C} \geq 0$). Conversely, a profit of SRI (Π^{SRI}) subtracts by a damage cost (D^{SRI}) has to be higher or equals to conventional system ($\Pi^{SRI} - D^{SRI} \geq \Pi^{C} - D^{C}$). Any system that has the highest profit is a preferable system for the society (6).

$\Pi^{SRI} - D^{SRI} \geq \Pi^{C} - D^{C} \geq 0$ ---------- (6)

4.4 Risk of profit and environmental damage

After specifying probability distributions or a range of possible results (minimum and maximum value), the mean and variance of expected value are employed in Monte Carlo simulation to assess and analyze risk. Minimum and maximum values in this study are obtained from various sources including the author's calculation. Therefore, the cost of each input and income are presented in a range of minimum and maximum values, where price and quantity vary within the range. The reason is to quantify the variance as a measurement of risk. Then, the study performs random simulations by running the numbers between the range (for 1000 random simulations) to get the variance and observe the effect of each input on the profit.

As explained by Markowitz (1959), variance (Var) refers to an average variation in a group of numbers, which indicates the level of risk. The lower variance regards a lower risk. Since all parameters in this study are stochastic, total variance of a farmer's profit [Var ($\Pi^{i,h}$)] is the summation of the random of all parameters of cropping system i and soil type h. Total variation of environmental damage [Var ($D^{i,h,e}$)] is the sum of both amount and cost of environmental damage in the cropping system i and the soil type h. For total variance of society's profit [Var ($\Pi^{i,h,s}$)], a variation of a farmer's profit and climate change cost are added together. The paper assumes that there are no co-variances among the stochastic variables. A uniform probability distribution is assumed where every outcome between the minimum and maximum values has the same equal possibility. The variances are then written as,

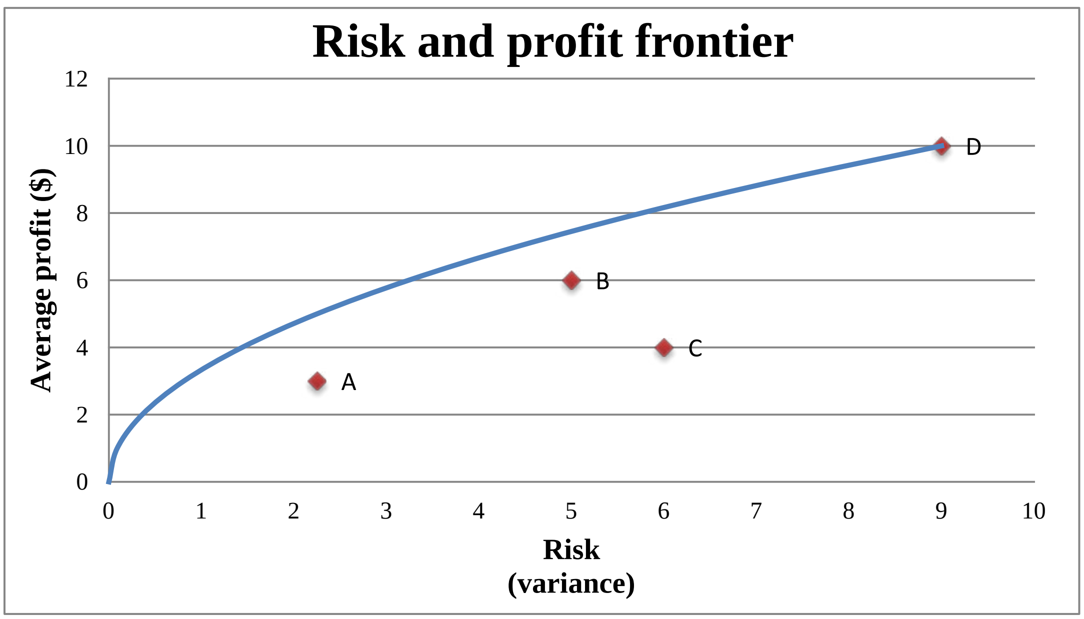
$$\text{Var}(\Pi^{i,h}) = \text{Var}(p^R) + \text{Var}(Q^{i,h}) + \text{Var}(S^{i,h}) + \text{Var}(L^{i,h}) + \text{Var}(IR^{i,h}) + \text{Var}(F^{i,h}) + \text{Var}(P^{i,h}) + \text{Var}(p^S) + \text{Var}(w^L) + \text{Var}(p^{IR}) + \text{Var}(p^F) + \text{Var}(p^P) \quad \text{----------} \quad (7)$$

$$\text{Var}(D^{i,h,e}) = \text{Var}(F^{i,h}) + \text{Var}(LD_{50}{}^{i,h}) + \text{Var}(p^m) + \text{Var}(M^{i,h}) \quad \text{----------} \quad (8)$$

$$\text{Var}(\Pi^{i,h,s}) = \text{Var}(\Pi^{i,h}) + \text{Var}(D^{i,h,m}) \quad \text{----------} \quad (9)$$

After obtaining the average value and standard deviation, both values are plotted in the risk and profit frontier to analyze the relation between average value or expected value and risk. In general, higher profit creates higher risk in return, which is illustrated in *Figure 1*. A risk averse farmer probably prefers to gain less profit, but also less risk at point A. Comparing between point B and C, point B clearly has better performance than point C due to higher profit and lower risk. At point D, even though the average profit is the highest, the level of risk is the highest too. Therefore, a farmer has to take the risk aspect into the consideration before making a decision.

Figure 1: Risk and profit frontier



5. Data Presentation

Data for the analysis of risk, including cost – benefit estimation of conventional system and SRI are mainly obtained from secondary data; previous experiments, researches and surveys, gathered and studied by academic and official institutes and organizations both domestic and international. Some statistical data are further adjusted and calculated by the author. The minimum and maximum values on each cost and benefit component in this study are obtained from the literatures, which are used to calculate the average profit for the farmer and the society.

Due to lack of data availability, assumptions have to be made. Some specific details such as an individual irrigation system and local organic fertilizer or pesticide, which have different prices and required quantity, are excluded from this study. Moreover, economic and social assessment of the environmental damage from rice cultivation is difficult to accurately measure and obtain. Instead, the study compares the amount of fertilizer application, the level of LD_{50} of each pesticide and the climate change cost of the two cropping systems.

In this section, data and information of price and quantity of every parameter in the theoretical part are presented. Prices of all parameters are based on year 2011, except for labour wage that is converted from year 2010 to year 2011 due to lack of data availability. Consumer price index (CPI) is employed to adjust collected data from year 2010 to year 2011 (based year) with 3.51 and 3.65 dollars of CPI, respectively (International Monetary Fund, 2011). The value of production cost and income depends on inflation, which devalues money when time passes. From Boardman, et al. (2006), the targeted price is computed by;

$$Price\ 2011 = \left(\frac{Price\ 2010}{CPI\ 2010}\right) x\ CPI\ 2011$$

The currency used in this study is based on an exchange rate of 1 dollar = 30.79 baht as of 01 February, 2012 (Bank of Thailand, 2012a). Since a farmer's household in Thailand generally is a small-holder, who owns approximately 5 - 10 rai of rice fields (OAE, 2009), all calculation are converted from rai to hectare with a rate of 6.25 rai = 1 hectare.

5.1 Farmer's cost

A farmer's cost consists of seed cost, labour cost, irrigation cost, fertilizer cost and pesticide cost.

5.1.1 Seed cost

The number of seeds is, in fact, diverse depending on the soil type and quality in each area. However, this study excludes human error[5] and bases data on Bureau of Rice Research and Development (2011a), who publicizes that a proper number of seeds for the conventional transplanting method should be around 25 - 31.25 kg/ha (clay soil) and 31.25 – 43.75 kg/ha (sandy loam).

For SRI, total number of seeds is calculated by dividing total area with transplanting space, and then multiplying with seed weight[6]. For example, a space of 25x25 cm equals to 0.0625 sqm, which is used to divide the total area (1 ha = 10,000 sqm) to get the number of hills[7]. In this case, total hill is 160,000 hills/ha (10,000/0.0625), which will be the total number of seeds because only one seedling is transplanted per hill. Then, multiplying the total number with seed weight to get a range of seed use; 160,000x0.027 and 160,000x0.030, which is 4,320 – 4,800 g (converting to kg; 4.32 – 4.80 kg/ha). Accordingly, a number of seeds for a transplanting space of 25x25, 30x30 and 40x40 cm is 4.32 – 4.80, 3.00 – 3.33 and 1.69 – 1.88 kg/ha, respectively. Grouping the numbers into soil types; clay soil and sandy loam, following Gypmantasiri's study (2001). A proper space for clay soil is 30x30 and 40x40 cm, so the range of seed use is from minimum and maximum values of the combination of both seed use ranges (30x30 and 40x40) so as to sandy loam condition. Therefore, total number of seeds under clay soil condition is 1.69 – 3.33 kg/ha. For sandy loam, it requires a space of 25x25 and 30x30 cm, so total number of seeds is 3.00 – 4.80 kg/ha.

There are two types of rice seed; photosensitive and non-photosensitive, which the price of rice seed can be different in some years. As the year 2011 (based year), the rice seed price is 0.81(photosensitive for wet season) and 0.75 (non-photosensitive for dry season) $/kg (Bureau of Rice Seed Multiplication, 2011). A discount price, which some retailers may offer for their customers, is not included. See *Appendix D* and *Appendix E* for total number and cost of seed.

[5] Some farmers in Suphan Buri and Patumthani spend around 25 – 31.25 kilograms/ha (Isvilanonda, 2009; Pisanwanich, 2011). With similar soil type, some farmers in Chiang Mai, Chiang Rai and Prae spend up to 112.5 kilograms (Tohong-Ngam, 2010). For farmers in north-east areas such as Roi-Et, Khon Kaen and Nakhon Ratchasima (Khorat), number of seeds reaches 187.5 kilograms/ha (Mishra and Salokhe, 2006; Isvilanonda, 2009: Nantanok and Nambomrung, 2005).
[6] One rice seed has weight about 0.027 - 0.030 grams (Vergara, 1992)
[7] Hill is a small hole in the rice field, where a farmer put a seedling in it.

5.1.2 Labour cost

Transplantation has six main steps namely seed treatment and nursery, land preparation, transplantation, fertilizer application, pesticide application and weeding. The amount of labour use is calculated in hours[8], which vary in each step and cropping system. Because data about labour cost in Thailand is difficult to obtain, labour and time requirement in each cropping system and soil type are based on three following studies. The first study is a case study in West Bengal, India, which compares labour requirement in each step of transplantation between conventional and SRI method (Sinha and Talati, 2007). The SRI process in India and Thailand are similar. The second study is a research survey conducted at the same province by National Bank for Agriculture and Rural Development (NABARD, 2010), including soil types in the analysis. Lastly, Isvilanonda (2009) studies labour and time requirement of conventional transplanting rice cultivation in many parts of Thailand, and also analyzes differences of the results of each soil type.

Calculations based on these research studies[9], show that land preparation, transplantation and weeding process are three main processes, requiring most time and labour. Reduced fertilizer and pesticide applications help a SRI farmer to save time and labour consumption. From *Appendix F*, total time consumption of SRI under clay soil is lower than sandy loam (406.49 and 1,207.00 hrs/ha), whereas the conventional method under clay soil consumes time more than sandy loam (563.53 and 399.33 hrs/ha). The average wage for agricultural labour in the farming sector is 0.45, 0.64, 0.43 and 0.72 $/hrs for north, central, northeast and south, respectively[10] (BOT, 2011b;c;d;e), which are grouped into clay soil and sandy loam conditions to be 0.45 – 0.64 and 0.43 – 0.72 $/hrs. See *Table 8* and *Table 9* for total labour cost, and *Appendix G*, *Appendix H* and *Appendix I* for details of wage rate and labour cost in each cropping process.

5.1.3 Irrigation cost

Commonly, a farmer irrigates a rice field for 86 days during one cropping season. An amount of water consumption in northern, central, north-eastern and southern parts depends on

[8] In general, a farmer works 8 hours a day, so an amount of labour use under each method can be calculated by dividing total required hours with working hours (8 hours)

[9] Machinery is excluded from labour aspect because of a limitation of information accessibility (since there are various kinds with different prices of agricultural machinery in Thailand). Consequently, labour cost can change more or less if machinery cost is included.

[10] The numbers are adjusted with CPI deflator from 2010 to 2011, which converted from day wage to hour wage by the author.

evapotranspiration (ET)[11] and water intake by rice plants[12] of each region (*Appendix J*)[13]. Under conventional system, a rice field should be kept flooding with a level of 5 – 10 cm height (equals to 80 – 160 m^3) throughout the irrigation days (86 days) (Wongwutsaroj, 2006). Additionally, puddling[14] and seedling[15] processes require a large amount of water with 2,750 and 1,312.50 m^2/ha (440 and 210 m^3/ha) (ibid). In calculation, ET and water intake represent water loss per day during rice's life time. To keep water at the same level, a farmer needs to irrigate a rice field with the same amount as water loss. Therefore, total amount of water consumption (TW) under conventional system (*Appendix L*) equals to;

TW (Continuous flooding) = [(ET + Water intake) x 86 days] + Amount of water kept flooding in rice field + Amount of water use in puddling and seedling process

On the other hand, a wet and dry system has more complicated processes. Firstly, total dates of irrigation are calculated from the amount of water consumption in each period. During rice's life time, tillering, panicle and flowering stages are three main irrigation periods. The tillering stage covers 30 – 50 days (World Bank Institute, 2008). Irrigation normally starts at date 10 after transplantation (Gypmantasiri, 2001). Thus, irrigation days in this stage are about 20 – 40 days (30 – 50 days deducted by 10 days). However, a rice field under this system is irrigated with a level of 5 cm height (or 80 m^3), and then let it dry until reaching 15 cm under the soil surface (as illustrated in *Picture 2*), which takes around 7 – 10 days to reach that level (ibid). Accordingly, total irrigation time is calculated by dividing irrigation days with drainage days since a farmer has to wait until the water level reaches 15 cm depth before starting next irrigation. As a result, total amount of water consumption in the tillering stage is 1,000 - 2,857.14 m^3/ha as calculated from;

$$TW_{(Tillering\ stage)} = \left(\frac{Irrigation\ days}{Drainage\ days}\right) x\ Amount\ of\ water\ irrigated\ (80\ m^3)\ per\ each\ irrigation$$

For example, if the irrigation day is 20 days and drainage day is 7 days, the farmer will have to irrigate the rice field every 7 days. This means the irrigation occurs 3 times in total

[11] Evapotranspiration (ET) = Transpiration (loss of water from plants) + Evaporation (loss of water from grounds) (Miller and Spoolman, 2008)
[12] Amount of water intake by rice plant includes infiltration rate of 1.5 mm/day
[13] The calculation of total water amount use in each system excludes percolation and runoff because of information lacking
[14] Puddling process is a process of land preparation in which rice field is irrigated until soil is saturated (Vergara, 1992).
[15] Seedling process is a process of growing seedlings in seedbeds (Vergara, 1992).

$\left(\frac{20\ days}{7\ days}\right)$. The amount of water irrigated each time is 80 m^3, so total amount of water consumption in this example is 240 m^3.

Panicle stage takes 35 days to form panicles for future rice grain (World Bank Institute, 2008). During the period, the rice field should be kept flooding with 1 – 2 cm (equals to 16 – 32 m^3) (Gypmantasiri, 2001); therefore, total amount of water consumption in the panicle stage (*Appendix K*) equals to;

$$TW_{(Panicle\ stage)} = [(ET + Water\ intake) \times 35\ days] + Amount\ of\ water\ kept\ flooding\ in\ rice\ field$$

Flowering stage is a vital period for producing rice grain, covering 30 days (World Bank Institute, 2008). The rice field is kept flooding 5 cm (or 80 m^3) and let it dry 15 cm, which the process is repeated until 14 – 20 days before harvesting period, when the rice field needs to be drainage and kept dry (Gypmantasiri, 2001). As a result, total irrigation days are 10 – 16 days, which is divided by drainage days to get total irrigation time. So, total amount of water consumption in the flowering stage is 500 - 1,142.86 m^3/ha as calculated from;

$$TW_{(Flowering\ stage)} = \left(\frac{Irrigation\ days}{Drainage\ days}\right) \times Amount\ of\ water\ irrigated\ (80\ m^3)\ per\ each\ irrigation$$

Apart from three stages, puddling and seedling process are further added to water consumption with 2,750 and 1,312.50 m^3/ha, respectively (Wongwutsaroj, 2006). Therefore, total amount of water consumption in a wet and dry system (*Appendix L*) equals to;

$$TW_{(Wet\ and\ dry)} = TW_{(Tillering\ stage)} + TW_{(Panicle\ stage)} + TW_{(Flowering\ stage)} + Amount\ of\ water\ use\ in\ puddling\ and\ seedling\ process$$

As stated previously, clay soil represents north and central regions whereas sandy loam represents northeast and south regions. Thus, all numbers are adjusted into soil conditions as presented in *Table 2*;

Table 2: Total amount of water use under conventional and SRI system for 1 season (m^3/ha).

	Conventional system		SRI	
Soil types	Min.	Max.	Min.	Max.
Clay soil	15,054.50	16,844.50	9,932.50	13,057.50
Sandy loam	15,054.50	17,033.70	9,932.50	13,134.50

Remark: From author's calculation, based on Wongwutsaroj, 2006; World Bank Institute, 2008, and Gypmantasiri (2001)

Cost of irrigation is divided into two types; irrigating and pumping cost. Rural areas in Thailand are either inside or outside irrigated areas. For an irrigated area, an irrigation price is 0.02 – 0.03 $/m^3$ (Royal Irrigation Department, 2011). Conversely, an outside area (rainfed area) farmer has to be responsible for his/her own irrigation, where the pumping cost is the main cost of irrigation in this area. With an amount of 240 – 320 m^3, the cost is 12.18 $/ha and 12.18 – 60.90 $/ha for a rice field located near a pump station and remote rice field, respectively (Mishra and Salokhe, 2006). Hence, the pumping price is 0.01 – 0.04 $/m^3$, which is estimated from a price of gasoline spent in pumping, and excluded cost of individual pump or pump station, and installation cost, which probably have an impact on the pumping cost.

Actually, local farmers have several irrigation methods. Some farmers have their own small pool in the rice field, while some farmers build a big pool in the village that everyone can use and share the cost. Thus, irrigation cost varies in each household, community and location. To make the report less complicated, cost of irrigation is based on only irrigating price and pumping cost. *Table 2* shows that the amount of water use under clay soil is lower than sandy loam for both cultivation systems. *Table 8* and *Table 9* in the result section show the similar result that a SRI farmer pays less irrigation cost than conventional farmer.

5.1.4 Fertilizer cost

Table 3 shows an amount of chemical fertilizer application under the conventional system and SRI (BRRD, 2011b; Rice Department, 2011). Only significant substances that a farmer usually applies; 16-20-0, 16-16-8, 15-15-15, 13-13-21, 46-0-0 (Urea) and 21-0-0 or 20-20-0 (Ammonium sulfate) (Sanwong, et al., 2008) are presented in this study[16]. Office of Agricultural Economics (OAE, 2012a) reveals the local retail price (2011) for above fertilizers with 0.49, 0.28, 0.52, 0.58, 0.63, 0.49 $/kg, respectively.

Table 3: Average amount of fertilizer application under conventional system and SRI (kg/ha)

Conventional system		**Amount of fertilizer use during wet season**				**Amount of fertilizer use during dry season**			
Soil types	**Fertilizers**	Period 1*		Period 2*		Period 1*		Period 2*	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Clay soil	16-20-0	125	156.25	125	156.25	156.25	218.75	156.25	218.75
	21-0-0	125	156.25	62.5	125	156.25	218.75	125	250
	46-0-0	-	-	31.25	62.5	-	-	62.5	125
Sandy loam	16-16-8	125	156.25	125	156.25	156.25	218.75	156.25	218.75

[16] These are the formula of chemical fertilizer, which is a mixture of Nitrogen (N), phosphorus (P) and potassium (K).

	15-15-15	125	156.25	125	156.25	156.25	218.75	156.25	218.75
	13-13-21	156.25	187.5	156.25	187.5	187.5	281.25	187.5	281.25
	21-0-0	-	-	62.5	125	-	-	125	250
	46-0-0	-	-	31.25	62.5	-	-	62.5	125
SRI									
Clay soil and Sandy loam	21-0-0	125	156.25	62.5	125	156.25	218.75	125	250
	46-0-0	-	-	31.25	62.5	-	-	62.5	125

Remark: From author's calculation, based on Sanwong, et al., 2008 and OAE, 2012a

*There are two times of fertilizer application; during seedling and flowering stages (BRRD, 2011b)

Under SRI method, a farmer generally applies an organic fertilizer and only little amount of chemical fertilizer. With a wet and dry system and new transplanting method, rice plants and roots are benefit from absorbing oxygen and nutrient directly, which improves roots length density and growth of roots and shoots. For this reason, there is no requirement to apply intensive chemical fertilizers like the conventional system. There are a variety of organic fertilizer, which price and quantity are differ in fertilizer types and individual's or community's knowledge. Accordingly, only Ammonium sulfates (NH4) (21-0-0) and Urea (46-0-0) are assumed to be used by a SRI farmer (*Table 3*) (Gypmantasiri, 2001; Mishra and Salokhe, 2006). See *Table 8* and *Table 9* in the result section for the fertilizer cost of both systems.

5.1.5 Pesticide cost

In conventional rice field, several harmful rice plant diseases such as rice blast, bacterial bright, bacterial leaf streak and root-knot nematode are often found. These diseases grow very well when a rice field is too dense and less ventilation (BRRD, 2011c). Besides, golden apple snail is a damaging pest, destroying a rice plant severely. Consequently, a farmer often uses chemical pesticides to control and get rid of weeds, diseases and pests from the rice field. Thai Crop Protection Association (TCPA, 2009a;b;c;d), Bureau of Rice Research and Development (BRRD, 2011d) and Department of Plant Science (2008) reveal an amount of pesticide use in the rice field. Only popular and famous types of herbicide, insecticide, mollussicide and fungicide are presented. A price of each pesticide is based on an import price shown by the office of Agriculture Regulation, Department of Agriculture (ARD, 2011). Without subsidization and tariffs, a producer normally sets the price higher than an import price. From an observation on three famous chemical companies in Thailand, Akesuphan Enterprise Corporation, P.Chemitech

Company Limited and Chia Tai Group, a retail price is in average two times higher than an import price. Therefore, a domestic price each pesticide is assumed to be an import price multiplied by two.

Total amount and price of each type of pesticides are presented in *Appendix M*, *Appendix N*, *Appendix O* and *Appendix P*. Price and quantity of herbicide vary. For instance, Fenoxaprop-P-Ethyl has the highest price (46.55 $/kg), but required amount is the lowest (0.08 – 0.09 kg/ha), so an average cost of applying this herbicide is lower than others such as Glufosinate Ammonium, where the price is not high (15.92 $/kg), but requires the largest amount (12.89 – 25.78 kg/ha) (BRRD, 2011d). Niclosamide Ethanolamine Salt and Metaldehyde are used to kill and control golden apple snail, so represent mollussicide. With an assumption that a farmer prefers insecticide, which can prevent and kill more than four types of insect, Carbofuran, Cartap Hydrochloride, Chlorpyrifos, Carbaryl and Triazophos are chosen to represent insecticide. As claimed by Department of Plant Science (2008), Hexaconazole and Propiconazole + Difenoconazole are mainly used in many areas, thereby representing fungicide. In contrast, SRI is against a pesticide application, so a SRI farmer generally uses nature to control pest and weed such as growing flowers or plants that have special capacity in insect control (World Bank Institute, 2008). Due to lacking of data about local knowledge and technique, only chemical pesticide is presented in this study (*Appendix Q*).

5.2 Farmer's benefit

5.2.1 Income

Normally, a rice plant with high ability in tillering can produce higher yield (Vergara, 1992). With suitable transplanting space, a rice plant can tiller better than crowded rice field. The rice plant with normal space (10x10 or 20x20 cm) usually has 3 – 15 tillers, but the rice plant with wider space (more than 20x20 cm) has approximately up to 33 tillers (Prasuth, 1991). Several studies and experiments conducted in many parts of Thailand evaluate and compare yield capacity between SRI and conventional system (see *Appendix R* for details). The result shows that the cropping system, soil condition and water management affect an amount of yield significantly (Gypmantasiri, 2002; Isvilanonda, 2009; Nieuwenhuis, 2008; Mishra and Salokhe, 2007; Komson, 2007; Panomjan, 2009). *Table 4* shows the amount of yield categorized into soil types for conventional system and SRI. Rice grain price at farm gate is different between wet and dry seasons. For dry season, the price of rice grain is 0.26, 0.28, 0.27, and 0.43 $/kg for north, central, northeast and south, respectively. For wet season, the price of rice grain is 0.29, 0.31, 0.27, and 0.24 $/kg for the same order. All prices are obtained from Office of Agricultural Economics (OAE, 2012b) and Bank of Thailand (BOT, 2012b;c).

Table 4: Total amount of yield gain under conventional and SRI system (kg/ha/cropping year).

	Conventional system		**SRI**	
Soil types	Min.	Max.	Min.	Max.
Clay soil	7,280.00	12,137.50	6,000.00	12,275.00
Sandy loam	5,625.00	7,400.00	4,502.11	11,391.84

Remark: From author's calculation, based on Gypmantasiri, 2002; Isvilanonda, 2009; Nieuwenhuis, 2008; Mishra and Salokhe, 2007; Komson, 2007; Panomjan, 2009; OAE, 2012b, and BOT, 2012b;c

Not only yield, but also production input has a significant impact on a farmer's profit. As showed in *Table 8* and *Table 9* in the result section, the irrigation and labour cost are the major production factor of both cropping systems and soil conditions. For conventional system, clay soil is a preferable condition because of a higher yield and lower production cost. Moreover, there is a slight difference between irrigated and rainfed area. SRI has better performance in reducing production input use and increasing yield gain. Least number of seeds and pesticide use are the main reasons of having lower cost. However, income of SRI has wider range than conventional system, which means that a SRI farmer not only gain higher profit than conventional farmer, but also has a chance to reach the lowest yield gain at the same time.

5.3 Environmental damages

Leakage of methane gas from a rice field and chemical substances from fertilizer and pesticide are a harmful factor affecting the environment and ecological system in several ways.

5.3.1 Fertilizer application

Nitrogen (N), phosphorus (P) and potassium (K) are fundamental substances of chemical fertilizers. Nitric and nitrous oxide cause pollutions on the atmosphere, resulting in the green house effect, global warming and acid rain that affect human health, crops, the environment and ecological system (Choudhury and Kennedy, 2005). Furthermore, phosphorus leakage and runoff flow to downstream aquatic ecosystem causing eutrophication, which is a situation when water resource contains too much enrichment of nutrients. The effect brings an explosion of algae and aquatic plants, leading to a reduction in dissolved oxygen at the bottom level, which means that water cleanness ability decreases (Miller, 2008). Likewise, Ammonium sulfate emitted from the rice field is blown to downwind water resource causing the same problem as phosphorus (Matson, et al., 1997). Due to limitation of gathering precise statistical data of the environment cost of chemical fertilizer leakage in Thailand, this study, instead, compares the amount of fertilizer application of both systems (See *Table 3* in the fertilizer cost section).

5.3.2 Pesticide application

All chemical pesticides destroy not only natural and ecological system, but also human health. Herbicides, insecticides, mollussicides and fungicides are widely used in many rice fields around Thailand. Each type of pesticides has different level of toxicity. LD_{50} refers to lethal dose of pesticide, and the subscription 50 indicates the quantity that can kill a half of tested animals. It is estimated in milligrams per 1,000 grams of tested animal's weight. To illustrate, LD_{50} of 100 is a dosage of 100 mg of pesticide per 1,000 g of; for example, rat's weight. Therefore, a pesticide that has low level of lethal dose contains less toxicity (Pirone, 1978; EPA, 2009). Level of LD_{50} of each pesticide is obtained from several literatures (EPA, 1997; Fishel, 2006; Hock, 2005; Dikshith and Diwan, 2003; IUPAC, 2012; EPA, 2004; Pirone, 1978; WHO, 2002; Siriwat, 2010) with criteria that only the rat test and level of oral toxicity on mammal are considered in this study.

LD_{50} is sometimes displayed in three signals; Danger, Warning and Caution, depending on a toxic level of pesticide's inhalation, oral and dermal intake (EPA, 2009). For oral toxic level, LD_{50} = 0 - 50 mg/kg is "*Danger*". LD_{50} = 50 – 500 mg/kg is "*Warning*". LD_{50} = 500 and up mg/kg is "*Caution*" (Hock, 2005; Siriwat, 2010). From *Appendix T*, LD_{50} of insecticide is in danger category while mollussicide and some herbicides are in the middle group between warning and caution stage. Most of fungicides are in caution stage.

Table 5: Level of LD_{50} in each type of pesticides under conventional system (mg/kg).

	LD_{50} (mg/kg)		
Pesticides	Min	Max.	Mean
Herbicides	283,00	5 000,00	2 641,50
Mollussicides	630,00	5 000,00	2 815,00
Insecticides	8,00	850,00	429,00
Fungicides	1 453,00	1 752,00	1 602,50

Remark: From author's calculation, based on EPA, 1997; Fishel, 2006; Hock, 2005; Dikshith and Diwan, 2003; IUPAC, 2012; EPA, 2004; Pirone, 1978; WHO, 2002, and Siriwat, 2010

From *Table 5*, insecticide seems to be the most hazardous pesticide on human and mammal creatures. Although other pesticides have low oral toxicity on mammal, the environment and ecosystem are affected in other ways. For instance, Niclosamide Ethanolamine Salt is a famous mollussicide for killing golden apple snail, which has low toxicity on human and some animals like bird and rabbit. However, this mollussicide is highly toxic to fish and other aquatic creatures (WHO, 2002). As seen, *Appendix U*, bird loss represents a significant negative impact of pesticide leakage on wildlife. Reduced natural enemies and increased pesticide resistance accelerate a need for a farmer to apply more and stronger pesticide to control and protect their crops. This leads to more hazardous and severe impacts on the environment, nature and humankind. Furthermore, the government and organization have to employ financial, human and capital resource to protect, prevent and recover all damages. On the other hand, lacking of data availability and time constraint make an environmental and social cost of pesticide use in Thailand are difficult to obtain. Thus, the lethal dose level of each type of pesticides is, instead, presented in this study.

5.3.3 Climate change cost

Methane gas emission from a rice field is one of the serious environmental problems in rice cropping sector. Flooded rice field is regarded as a significant source of greenhouse gas; methane gas (CH_4) (Neue and Boonjawat, 1998; Gon, 2000; Li, et al., 2002; Yan, et al., 2009). The rate of CH_4 emission depends on a growth of rice plant and availability of carbon substrates in soil (Neue, 1993; Neue, et al., 1996). Improved water productivity and crop management are an alternative for reducing CH_4 emission (Molden, 2007; Mishra and Kumar, 2011). Some studies show that most of CH_4 emission in the rice field is leaked from rice plants through oxidization, which a development of the root system under intermittent water management is a preferable option that compromises CH_4 emission mitigation and yield productivity (Mishra and Salokhe, 2011; Conrad, 2007; Neue 1993; Yan, et al., 2009; Kern, et al., 1997).

A leaching in CH_4 produces carbon dioxide equivalent causing the climate change phenomena such as severe flooding and drought. Amount of CH_4 emission under conventional system is gathered and adjusted from IPCC Guidelines and summarized in *Table 6.* Methane gas is emitted differently under irrigation systems and soil conditions. An amount of CH_4 emission under irrigated and rainfed area is based on Sass (1996), whilst Kroeze (1996) observes and compares an amount of CH_4 leakage between clay soil and sandy loam conditions. For SRI, an experiment in South Korea explores a mitigation option for CH_4 emission from a rice field (Shin, et. al., 1996). The outcome shows that SRI farm reduces CH_4 emission by 36% due to intermittent irrigation system. Therefore, the amount of CH_4 emission under SRI is calculated by subtracting total amount of CH_4 emission from a conventional rice field with 36%.

Table 6: Amount of CH_4 emission rate under conventional and SRI system (kg CH_4 /ha/season) (2011).

	Conventional system			SRI		
Criteria	Min	Max	Mean	Min	Max	Mean
Irrigated	326.80	619.20	473.00	209.15	396.29	302.72
Rainfed	17.20	387.00	202.10	11.01	247.68	129.34
Clay soil	66.05	877.20	471.62	42.27	561.41	301.84
Sandy loam	33.02	505.68	269.35	21.14	323.64	172.39

Remark: From author's calculation, based on Sass, 1996); Kroeze, 1996, and Shin, et. al., 1996

To estimate the environmental cost of CH_4 emission, carbon dioxide (CO_2) equivalence is required. From Greenhouse Gas Equivalencies Calculator created by U.S. Environmental Protection Agency (EPA, 2011), one kg of CH_4 is equivalent to 21 kg of CO_2. The CO_2 equivalent is employed to compute the climate change cost (Stern, 2008), which represents the environmental cost of CH_4 emission. One ton of CO_2 has a cost about 30 Euro (ibid). In reality, the cost is probably higher or lower than presented number, depending on specific level of environment and nature damage in each area. Still, *Table 7* presents climate change cost under each circumstance, which are based on Stern's report, and adjusted with an exchange rate (Euro and Dollar[17]), and measurement unit (ton to kg). Hence, one kg of CO_2 has a cost about 0.04 $.

Table 7: Cost of climate change under conventional and SRI system (dollar/ha/season) (2011).

	Conventional system			SRI		
Criteria	Min	Max	Mean	Min	Max	Mean
Irrigated	268.20	508.18	388.19	171.65	325.23	248.44
Rainfed	14.12	317.61	165.86	9.03	203.27	106.15
Clay soil	54.21	719.92	387.06	34.69	460.75	247.72
Sandy loam	27.10	415.01	221.06	17.35	265.61	141.48

Remark: From author's calculation, based on Stern, 2008

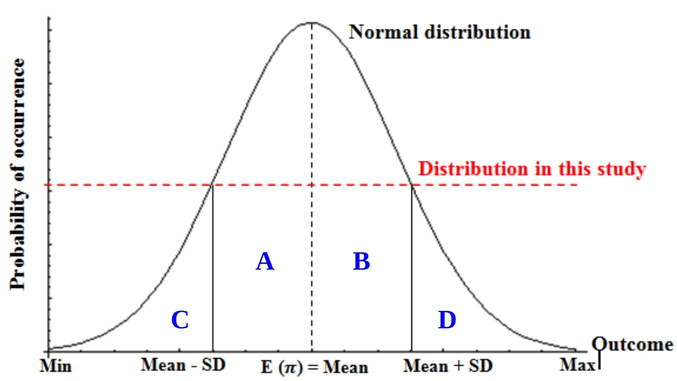
[17] Bank of Thailand (BOT): An exchange rate as of 01 February, 2012 (1 Euro = 1.30 $)

5.4 Risk in profit and environmental damages

With the purpose of investigating and examining an impact from statistical observations, uncertainty should not be neglected from analysis. Commonly, several assumptions are made by analysts and researchers especially when required data is difficult to obtain or evaluate. Consequently, analytical results can have errors and bias hiding inside. Monte Carlo simulation is a method to analyze variability and uncertainty of the outcome, and also assess an impact of possible risk. This method is a mathematical computer-based technique, generating a range of possible outcome, known as probability distributions from a random simulation of inputs. All costs and benefits for a farmer and the environment in this study depend on a variety of prices and quantities; therefore, outcomes have to be sampled at random in order to address the uncertainty and risk of each parameter. Normally, the Monte-Carlo method is simulated thousands of times for reliability. This study completed 1,000 random simulations in the estimation for each parameter between the minimum and maximum values presented in Tables 2 - 7 in Section 5 and in Appendixes D – S to find expected profit (average profit). As explained in previous part, variance is used to investigate risk from which standard deviation (SD) (equals to square root of variance) is employed in the calculation to show a variation of each number and mean value. The lowest value of standard deviation means the lowest risk.

The *Figure 2* shows normal probability distribution, which is usually a bell shape. Most of probability distribution is around mean, whereas minimum and maximum numbers have the lowest amount of probability distribution. Area A and B indicate a variation of numbers that are away from mean, and distribute within a range of SD (mean $\pm$ SD). However, this probability distribution is assumed to be the same amount for all numbers (min, max and mean) because of lacking of standard deviation data.

Figure 2: Normal probability distribution



6. Results

This study aims to find the best cropping system for a farmer, the environment and a society. In this section, the conventional system and SRI are investigated by comparing actual profit of the systems, analyzing best-worst case scenarios, and examining risk-profit of every scenario. Also, the result is presented in three perspectives; a farmer's profit and risk, the environment's damage and risk, and a society's profit and risk.

6.1 Farmer's profit and risk

All costs and benefits of conventional system and SRI are showed in *Table 8* and *Table 9*. Total cost and profit are categorized into irrigated and rainfed areas, and clay soil and sandy loam conditions. As well, minimum, maximum and mean value of every cost and income are examined to observe a range of profit of both systems and soil types. For conventional system, irrigation cost is the largest amount comparing to other cost components. There is a slightly difference between irrigated and rainfed areas, where irrigating cost is higher than pumping cost for both soil types. An average income under clay soil condition is higher, whereas an average total cost is lower than sandy loam condition. Thus, a conventional farmer gains more profit if the rice field is under clay soil condition.

Table 8: Costs and Benefits of conventional system ($/ha/cropping year) (2011).

	Conventional system					
	Clay soil			Sandy loam		
Production costs	Min	Max	Mean	Min	Max	Mean
Seed	38.97	48.72	43.85	48.72	68.20	58.46
Labour	250.96	361.43	306.19	173.42	288.32	230.87
Irrigating cost	488.94	1,094.15	791.55	488.94	1,106.44	797.69
Pumping cost	183.35	1,367.69	775.52	183.35	1,383.05	783.20
Fertilizer	125.26	367.08	246.17	191.95	590.70	391.32
Pesticide	34.06	556.02	295.04	34.06	556.02	295.04
Income	2,015.89	3,605.77	2,810.83	1,448.04	2,595.65	2,021.84
Total cost (Irrigated area)	938.19	2,427.40	1,682.80	937.09	2,609.68	1,773.38
Total cost (Rainfed area)	632.60	2,700.94	1,666.77	631.50	2,886.29	1,758.89
Profit (Irrigated area)	1,077.70	1,178.37	1,128.04	-14.03	510.95	248.46
Profit (Rainfed area)	1,383.29	904.83	1,144.06	-290.64	816.54	262.95

Remark: From author's calculation

Not only irrigation cost, but also labour cost plays the major role on total cost of SRI. Different from the conventional system, irrigating cost of SRI is lower than pumping cost.

Because a wet and dry system of SRI has more details, so a farmer in rainfed area has to pay high cost of pumping; however, the difference between the two areas is not significant. Similar to the conventional system, a farmer gains an average income under clay soil condition slightly higher than sandy loam condition. Comparing both results, SRI has better performance in overall. Reduced input use is the main benefit from this system, which a number of seeds and amount of pesticide use are a significant factor of lower production cost. Even though SRI has the maximum income higher than conventional system, the system has a probability to reach the lowest income as well.

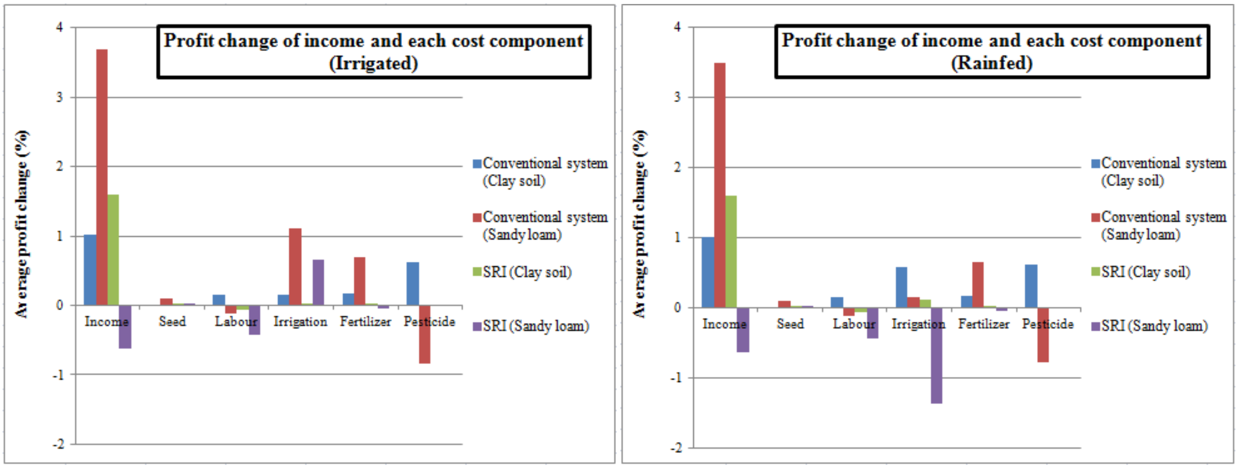
Table 9: Costs and Benefits of SRI ($/ha/cropping year) (2011).

	SRI					
	Clay soil			Sandy loam		
Production costs	Min	Max	Mean	Min	Max	Mean
Seed	2.63	5.20	3.91	4.68	7.48	6.08
Labour	181.02	260.71	220.86	524.18	871.45	697.81
Irrigating cost	322.59	848.16	585.38	322.59	853.17	587.88
Pumping cost	120.97	1,060.21	590.59	120.97	1,066.46	593.71
Fertilizer	125.26	212.41	168.84	125.26	212.41	168.84
Pesticide	-	-	-	-	-	-
Income	1,661.45	3,646.62	2,654.03	1,158.97	3,995.84	2,577.41
Total cost (Irrigated area)	631.50	1,326.48	978.99	976.71	1,944.51	1,460.61
Total cost (Rainfed area)	429.89	1,538.52	984.20	775.09	2,157.80	1,466.44
Profit (Irrigated area)	1,029.94	2,320.14	1,675.04	182.26	2,051.33	1,116.80
Profit (Rainfed area)	1,231.56	2,108.10	1,669.83	383.88	1,838.04	1,110.96

Remark: From author's calculation

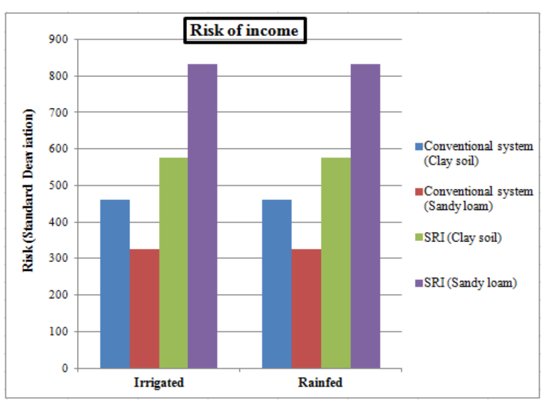
As said in the theory section, all parameters in this study are stochastic, and a simple way to acknowledge underlying uncertainty is to perform sensitivity analysis. Based on Boardman (2006), partial sensitivity analysis is employed to examine the most influential factor affecting a profit. The method is to run random simulation with one factor, while keep other factors constant at an average value. For example, simulating seed cost to observe standard deviation value, whereas other production costs and income are fixed at an average value. *Figure 3* shows how individual cost component affects a change in a farmer's profit. The figure is calculated by subtracting changed profit with referenced profit in *Table 8* and *Table 9*, and computed in percentage. Irrigation cost plays the most influent role on the farmer's profit in all circumstances. Besides, the cost of fertilizer and pesticide are also the second influent factor towards the profit. Under sandy loam condition, labour cost has a possibility to be considered as the second influent factor as well. (See *Appendix V, Appendix W, Appendix X* and *Appendix Y* for sensitivity analysis of a farmer's cost and profit under conventional system and SRI for clay soil and sandy loam).

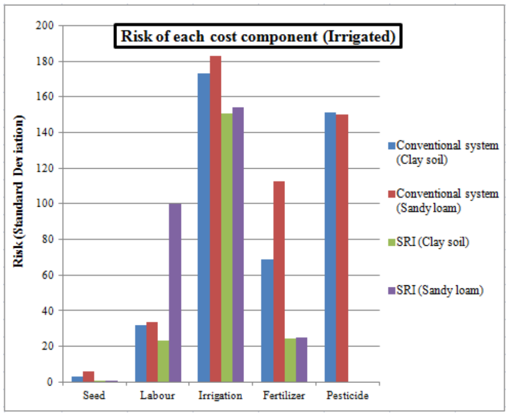
Figure 3: Average profit change of income and each cost component for all systems and soil types

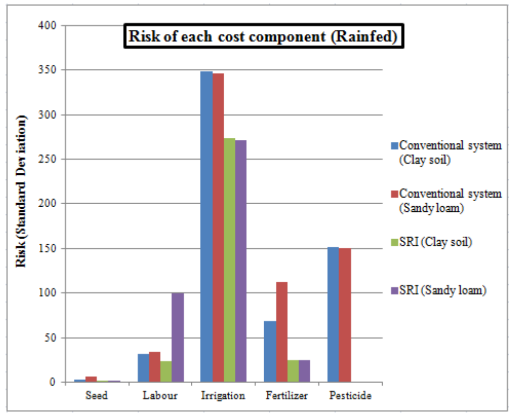


For *Figure 4*, the Monte Carlo simulation is employed to estimate the risk of income and each cost component under all circumstances. The income from SRI clearly has higher risk than conventional system for both irrigated and rainfed areas. The different is that SRI with sandy loam condition has higher risk than clay soil condition, but it works in the other way around for conventional system. Even though the price of rice grain under sandy loam condition is higher, but the amount of yield gain under clay soil condition is higher enough to offset the gap of differences in prices. Therefore, the conventional farmer's income is based on the amount of yield gain under individual condition.

Figure 4: Risk of income and each cost component for all systems and soil types







Comparing among cost components, irrigation cost seems to have the highest risk, where pesticide cost is in the second rank. This can be explained that irrigation and pesticide are difficult to control the amount use. Since sandy loam needs more management especially for irrigation, the possibility of SRI under this condition to increase labour cost is higher than others. On the other hand, SRI requires less fertilizer use, leading to lower risk comparing to the conventional system.

6.1.1 Best and worst case scenarios analysis

On an account of uncertainty, a situation of having maximum cost, at the same time, gaining minimum benefit can happen, when an assumption is radically changed such as climate change phenomena and a slump in market price (worst case scenario). Another situation is when a farmer gains maximum yield with minimized production cost (best case scenario). This is an effective incentive for a farmer to make or not to make any changes.

From *Table 10*, SRI has better performance under best case scenario, comparing to the conventional system, in which SRI (sandy loam) has slightly higher than SRI (clay soil). Even though the amount of yield gain under clay soil condition is higher, but the price of rice grain in the southern part is higher than other parts. Therefore, the price of yield gain under sandy loam condition is higher, which leads to higher maximum value of the income. However, the income of SRI (sandy loam) is based on the market price, which can is fluctuated, so that the risk of this condition is higher than others as seen in *Table 9* that the minimum income from sandy loam condition is lower than clay soil condition, meaning that there is a possibility for SRI farmer to reach the lowest income comparing to other conditions. Only conventional system (sandy loam) has poor profit gain.

On the other hand, SRI (clay soil) is the only one that has positive profit gain under worst case scenario. Because of the lowest production cost, this condition can resist to the unpredictable case when the production cost is maximum, while the income is minimum in the range. Besides, SRI (sandy loam) has worse result than the conventional system (clay soil) in this scenario since the minimum income of SRI (sandy loam) is lower than others. Nonetheless, the conventional system (sandy loam) has the worst performance under both extreme scenarios.

Table 10: Producer's profit of best and worst case scenario under conventional and SRI system ($/ha/cropping year) (2011)

		Conventional system		**SRI**	
Scenarios	**Irrigating systems**	Clay soil	Sandy loam	Clay soil	Sandy loam
Best scenario	Irrigated area	2,667.58	1,658.56	3,015.12	3,019.13
	Rainfed area	2,973.17	1,964.15	3,216.73	3,220.75
Worst scenario	Irrigated area	-411.51	-1,161.64	334.97	-785.53
	Rainfed area	-685.05	-1,438.25	122.93	-998.82

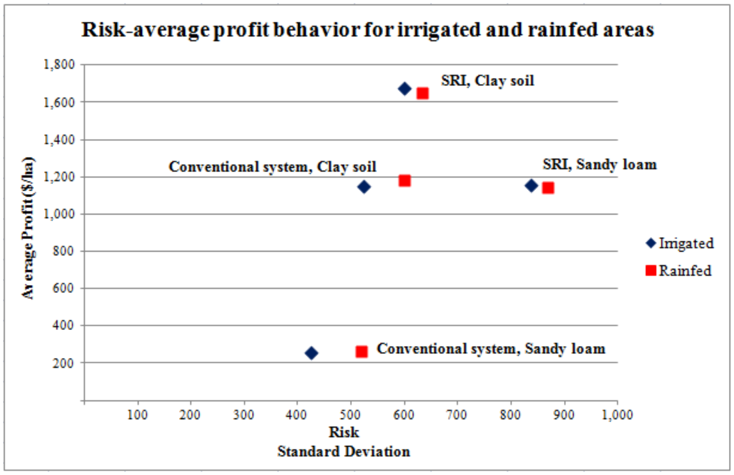
Remark: From author's calculation

6.1.2 Risk and profit analyses

As stated above, all parameters in this study are stochastic, so it is necessary to account for risk of both systems. From *Figure 5*, SRI has an average profit more than the conventional system under both soil conditions; however, this system also has higher risk. A variety of yield gain and sale price is a key factor of having high level of risk under SRI especially under sandy loam condition. On the other hand, the risk level of SRI and the conventional system under clay soil condition is not significantly different compared to the difference in the average profit of both systems. Therefore, SRI can be implied to have more motivation for the farmer to apply this system to the rice field under clay soil condition.

Profit under irrigated area has slightly lower risk than rainfed area because the irrigated area is more manageable. Nevertheless, a farmer perceives risk depending on the individual risk preference. A risk-averse farmer may apply a conventional system to avoid a dramatic change (i.e. under sandy loam condition) meanwhile a risk-neutral or risk-lover farmer probably prefers SRI because they have an opportunity to gain a better profit.

Figure 5: Producer's average profit and risk under conventional and SRI system ($/ha/cropping year) (2011)



Remark: From author's calculation

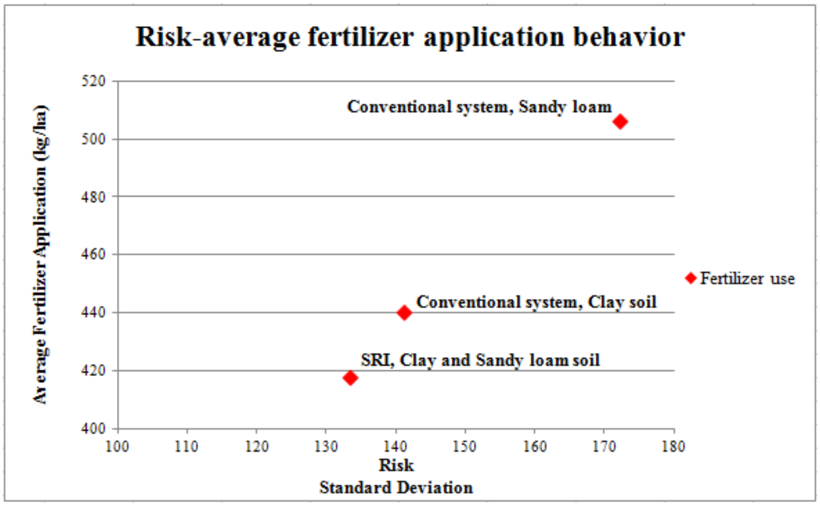
6.2 Environment's damage and risk

Rice cultivation both conventional system and SRI affect the environment negatively. The amount of chemical fertilizer application, level of lethal dose (LD_{50}) of each type of pesticides and climate change cost are investigated in this section.

6.2.1 Fertilizer application

Since the environmental cost of chemical fertilizer application is difficult to find, this study chooses to compare the quantity used in both systems as seen in *Figure 6*. Under conventional system, sandy loam requires the largest amount of fertilizer application to enrich nutrients in soil. Conversely, clay soil has greater performance in nutrient storage, so the amount of fertilizer requirement is lower than sandy loam. For SRI, a wet and dry system and single seedling method improve soil quality. Accordingly, the amount of chemical fertilizer applying to the rice field under both soil conditions is not different. Comparing between the systems, a SRI farmer applies chemical fertilizer less than a conventional farmer especially for sandy loam. The more fertilizer applied in the rice field, the more possibility of chemical substances leaking to the environment. Additionally, a variation of fertilizer use in the conventional system is more diverse than SRI, referring to higher risk on the environment. Hence, SRI is a better option for the environment.

Figure 6: Average amount of fertilizer application and risk under conventional and SRI system (kg/ha/cropping year) (2011)

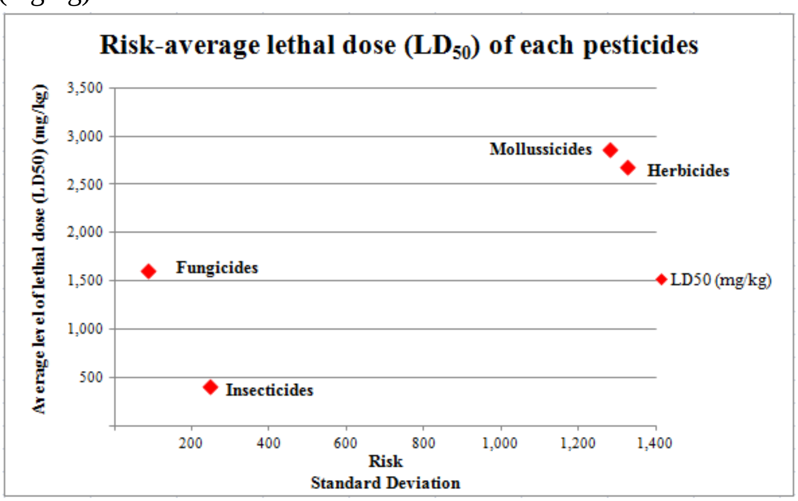


Remark: From author's calculation

6.2.2 Level of lethal dose (LD_{50}) of pesticide

Similar to fertilizer, the environmental cost of pesticide application is difficult to obtain precisely. Moreover, SRI is against the chemical pesticide application. Thus, LD_{50} level and risk of every type of pesticide application under conventional system is evaluated and compared.

Figure 7: Average level of LD_{50} in each type of pesticide and risk under conventional system in both soil conditions (mg/kg)



Remark: From author's calculation

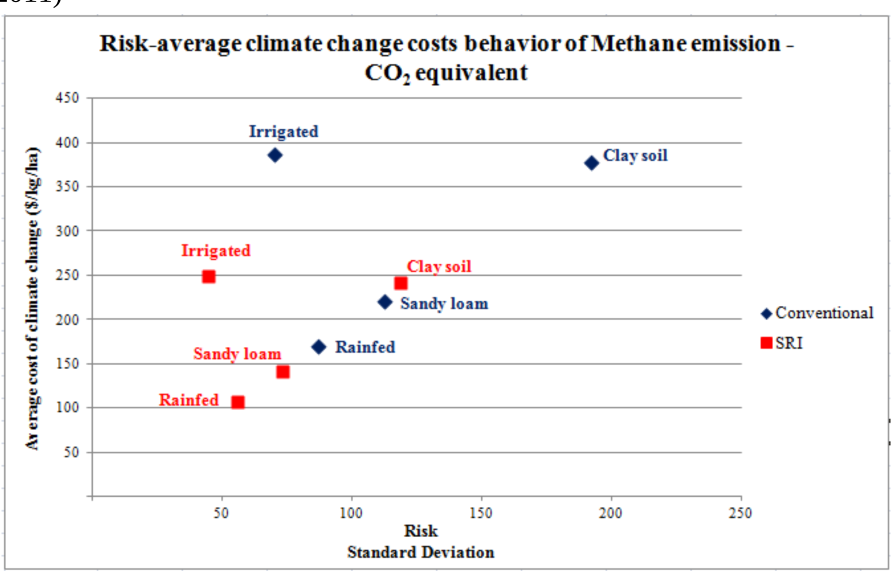
Figure 7 shows that insecticide is the most dangerous pesticide with the lowest level of LD_{50} (low LD_{50} means high toxicity). Surprisingly, mollussicide and herbicide have less harm on mammal than fungicide. However, some types of mollussicide and herbicide such as

Metaldehyde and Paraquat Dichloride contain high toxicity. This shows that a variation of LD_{50} level of these two pesticides is more diverse. Therefore, risk of mollussicide and herbicide is higher than others. Conversely, risk of insecticide is comparatively low, although the LD_{50} level is really high.

6.2.3 Climate change cost

Methane gas emission (CH_4) is one of the greenhouse gas emissions, causing climate change phenomena. In *Figure 8*, climate change cost is computed from carbon dioxide equivalent of CH_4 emission from the rice field. The cost is categorized in conventional system and SRI under two soil conditions (clay soil and sandy loam) and irrigation areas (irrigated and rainfed). Clearly, the conventional system creates larger amount of CH_4 emission, and has higher risk than SRI for all conditions. The possible reason is that SRI has better water management (a wet and dry system) than conventional system (a continuous flooding system). Methane gas usually emits very well under flooding condition. An amount of CH_4 leakage from clay soil and irrigated area is almost the same, but totally different in risk level. Clay soil has higher risk because the soil condition is an uncontrollable factor while an irrigation system is more manageable. Rainfed area is more difficult to control irrigation system, so risk is higher than irrigated area although the amount of CH_4 emission is lower.

Figure 8: Average climate change cost and risk under conventional and SRI system ($/kg/ha/cropping year) (2011)



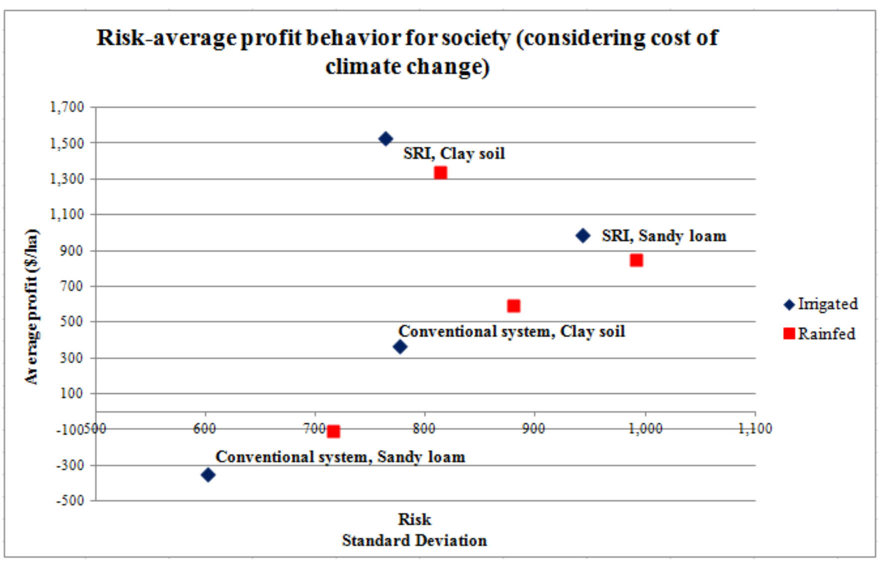
Remark: From author’s calculation

6.3 Society's profit and risk

A farmer's profit is a benefit of the society whereas the environmental damage is regarded as a cost. This calculation includes only climate change cost because the environmental costs of fertilizer and pesticide applications are not computed in monetary term. Risk of the society's profit is the summation of producer's profit and climate change cost. From *Figure 9*, SRI has a benefit on the society higher than conventional system for both soil conditions and irrigation areas. With climate change cost, the conventional system has very low profit especially under sandy loam condition, where the profit is a negative value. Since the irrigation cost under SRI is lower than pumping cost, the profit of SRI under irrigated area is higher than rainfed area. Even though the environmental cost of CH_4 emission under irrigated area is higher, the proportion of the farmer's profit is larger than the climate change cost. Accordingly, the SRI society gains more profit from irrigated area than rainfed area.

On the other hand, cost of irrigation for the conventional system (irrigated area) is higher than rainfed area, so the profit of conventional system (irrigated area) is lower. With lesser cost of climate change, the society gains more profit from the conventional system (rainfed area) than irrigated area. The risk between SRI and conventional system under clay soil condition is not much different, so that SRI is the preferable choice for the society. Although risk under SRI (sandy loam) is considerably higher than conventional system (sandy loam), the society should not choose the conventional system due to the negative profit gain.

Figure 9: Society's average profit and risk under conventional and SRI system ($/ha/cropping year) (2011)



Remark: From author's calculation

7. Discussion and Conclusion

This study shows that the System of Rice Intensification (SRI) has significant economic and environmental benefit for a farmer, the environment and the society. The system has better performance in generating profit even under worst case scenario. Less amount of input requirement and high yield capacity are the major reasons, enhancing the system's performance in a sustainable way. Single seedling method helps an individual rice plant to absorb adequate nutrients, water and oxygen. Thus, a rice plant can fully tillering, and develop a root system and root length density to be stronger. Then, the rice plant will have more panicles, leading to more amount of grain yield at flowering stage. Furthermore, a wet and dry system enhances growth of roots and shoot of a rice plant because every root has to expand itself to reach the water level under soil surface. Additionally, sunlight and aeration protect and prevent a rice plant from a disease and pest, so chemical fertilizer and pesticide are not necessary for the rice field. As a result, a rice plant of SRI has higher yield capacity and lower input use comparing to conventional system.

In addition, SRI gives a benefit to the environment and society more than conventional system. The biological power and solar energy are utilized by the system, resulting in lower demand in the chemical fertilizer and pesticide applications. Accordingly, ecological system can continue the processes; for example, a predator of a rice pest can complete its duty efficiently. Also, soil quality and water resource are not exploited or contaminated. The amount of chemical fertilizer application and level of toxicity of pesticide use show how the environment is affected by chemical substances, which the actual cost of environmental damage is difficult to obtain in this study. Moreover, methane gas is one of the global warming gases, emitting from the rice field. It creates severe negative impacts such as climate change phenomena on the environment, ecosystem and humankind. The rice field with a continuous flooding system emits a large amount of CH_4 comparing to intermittent irrigation like a wet and dry system. Comparing a farmer's profit and climate change cost, SRI still is a preferable option for the society under all conditions.

Incidentally, soil types and irrigation areas are an important factor for the rice production as well because each condition has different outcomes. For both conventional system and SRI, clay soil is more preferable for rice cultivation than sandy loam because the soil has a higher capacity in water and nutrient capture, leading to lower requirement of input use, and higher yield gain. Under conventional system, an irrigated area has higher cost of irrigation compared to pumping cost in rainfed area. Surprisingly, pumping cost of SRI is higher than irrigation cost in irrigated area. This can be explained by the fact that a wet and dry system requires a farmer to control irrigation more than a continuous flooding system. Therefore, an area within irrigation facility has lower cost than an outside area, where a farmer has to pay for pumping cost several times to control the irrigation.

From sensitivity analysis, it can be concluded that the most influential factor on a farmer's profit is the irrigation cost. Besides, the cost of fertilizer and pesticide also has a significant impact on the profit. For the rice field under sandy loam condition, labour cost is considered as the second influent factor towards the profit.

On the other hand, SRI has higher risk than conventional system. Although SRI has a benefit in less input, more output concept, a variation in production cost and profit is more diverse. To illustrate, a SRI farmer can reach the greater maximum expected profit; however, an expected profit can be downward to the minimum value, which is lower than conventional system, at the same time. Clay soil and rainfed area has higher risk than sandy loam and irrigated area because clay soil and rainfed conditions are more difficult to control. Only SRI (sandy loam) has the higher risk level than clay soil due to the price of rice grain. Nevertheless, an individual risk preference is a considerable factor in a decision making. A risk averse farmer probably prefer a conventional system to SRI because of its lower risk. Conversely, a farmer who can accept the risk, probably choose to apply SRI in order to gain higher benefit.

Since there is a limitation of the CBA, not all the costs and benefits are included in this study. Apart from the limitation stated in Section 5, a transformation from conventional system to SRI has an important hidden cost that is limited to express in monetary term. Changing from a conventional system to SRI has a high cost and risk. During the beginning period, a farmer has to pass unpredictable losses from trials and errors because the system consists of detailed and complicated processes. The irrigation system is an example that a farmer has to control water level and a number of irrigation in the rice field, which sometimes is difficult to manage. Likewise, knowledge and skills are an important factor for a farmer to invest time and capital in order to achieve a success. Last but not least, being different in a rural society (especially in Thailand) has direct and indirect cost on a farmer. In rural areas, changing or breaking the belief or conventional pattern of the society brings a big trouble to that person, and involved people.

For instance, most of Thai farmers cultivate rice together for labour saving purpose. Changing to a new cropping system may not be accepted by neighbors, which means that a farmer has to hire external labour or machine, and result in an increase of production cost. Another example is that a rice field surrounded by chemical pesticide and intensive fertilizer is a preferable place for pests and insects. Also, chemical substances' runoff and leakage cause a negative effect on surface and ground water resources, soil quality and ecosystem for all farmers around the area.

In conclusion, it can be clearly seen that SRI is the best system for a farmer, the environment and a society even though the system has higher risk. Clay soil is more suitable condition for rice cultivation for both cropping systems. A rice field in rainfed area finds more difficult to control the irrigation, so irrigated area is an appropriate condition for SRI more than rainfed area. Further study can be in an area of an integrated cropping system, which is a combination between a conventional system and SRI. As low risk diversification in a rice plant loss, single seedling method of SRI may have higher risk than 3 – 4 seedlings/hill of conventional system. Still, water management of SRI has a benefit on a rice plant better than conventional system. Therefore, more technical experiments and researches should be done to observe, improve and investigate a new integrated cropping system.

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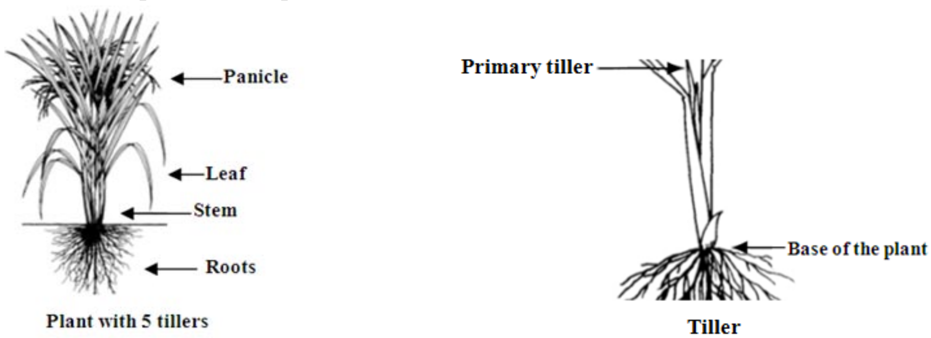
9. Appendix

Appendix A: General information about rice plant

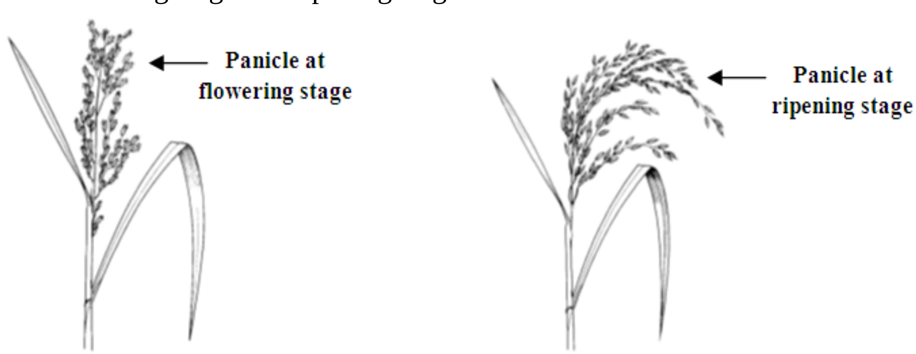
Growth stages of rice plant consist of vegetative phase, reproductive phase and ripening phase. During the vegetative phase, Seedling stage and tillering stage are the main stages in this phrase. Seedling stage or nursery stage is a process that a farmer grows seedlings in a seedbed before moving to the rice field. Tillering stage is a process that a shoot (tiller) has roots, stem, and leaves, which probably have or not have a panicle (Vergara, 1992). The process starts after seedlings are transplanted in the rice field about 10 days. One rice plant can have many tillers depending on the strength of a seedling, which normally reaches the maximum number of tillers around 50 – 60 days after transplanting (ibid).

Picture 4: Rice plant and important components



Reproductive phrase is a process that the first panicle starts forming until it reaches flowering stage. The ripening phase is a process that grain starts filling and developing in which nutrients and water are transported from one part of the plant to another. When filled grains turn hard and yellow, it is a time for harvesting (Vergara, 1992; Rice Knowledge Bank, 2009).

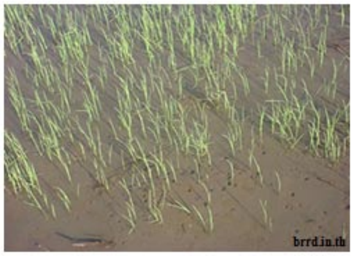
Picture 5: Panicle at flowering stage and ripening stage



Appendix B: Seed broadcasting or direct seeding method

Many farmers prefer this method because of time and labour saving. In general, there are two types of this cropping method; dry seed broadcasting and wet direct seedling.

Picture 6: Seed broadcasting or direct seeding method



Dry seed broadcasting is a way that farmers broadcast seeds in the rice field before raining period. Approximately 94 kilograms of seeds are used per hectare. Differently, farmers use pre-germinated seeds under wet direct seedling method. With this way, less number of seeds are used, 50 – 75 kilograms per hectare. Water kept in rice field should not exceed 10 cm. heights after tillering stage (BRRD, 2011e).

Appendix C: Seed drilling method

Seed drilling method is preferable in an area that faces a problem with fluctuated raining period especially sand soil area like upland in some Northern and North-Eastern areas. This method requires about 50 – 60 kilograms/hectare (Boonkerd and Teaumroong, 2011; BRRD, 2011f). Agricultural Research Development Agency (ARDA, 2011) explained major steps of seed drilling method. Starting with land preparation, using a stick to make a small hole where seed is put and sowed into the soil before covering all seeds with thin layer of soil, and waiting for raining period to come.

Picture 7: Seed drilling method

Appendix D: Total number and cost of seeds in wet and dry seasons under conventional system (2011).

Conventional system	Total numbers of seeds (kg/ha)		Total cost of seeds ($/ha) Wet season			Total cost of seeds ($/ha) Dry season		
Soil types	**Min.**	**Max.**	**Min.**	**Max.**	**Mean.**	**Min.**	**Max.**	**Mean.**
Clay soil	25	31.25	20.30	25.37	22.84	18.67	23.34	21.01
Sandy loam	31.25	43.75	25.37	35.52	30.45	23.34	32.68	28.01

Remark: From author's calculation

Appendix E: Total number and cost of seeds in wet and dry seasons under SRI system (2011).

SRI	Total numbers of seeds (kg/ha)		Total cost of seeds ($/ha) Wet season			Total cost of seeds ($/ha) Dry season		
Soil types	**Min.**	**Max.**	**Min.**	**Max.**	**Mean.**	**Min.**	**Max.**	**Mean.**
Clay soil	1.69	3.33	1.37	2.71	2.04	1.26	2.49	1.88
Sandy loam	3.00	4.80	2.44	3.90	3.17	2.24	3.59	2.91

Remark: From author's calculation

Appendix F: A number of labour use in each step of transplanting method (hrs/ha/cropping year).

<table>
<tr><th></th><th colspan="2">Conventional system</th><th colspan="2">SRI</th></tr>
<tr><th>Rice cropping steps</th><th>Clay Soil</th><th>Sandy Loam</th><th>Clay Soil</th><th>Sandy Loam</th></tr>
<tr><td>Seed treatment and Nursery raising</td><td>28.00</td><td>12.83</td><td rowspan="4">375.60</td><td>41.00</td></tr>
<tr><td>Land Preparation</td><td>92.00</td><td>28.17</td><td>224.00</td></tr>
<tr><td>Transplantation</td><td>323.67</td><td>221.00</td><td>740.00</td></tr>
<tr><td>Fertilizer application</td><td>14.00</td><td>107.67</td><td>16.00</td></tr>
<tr><td>Pesticide application*</td><td>17.42</td><td>18.17</td><td>-</td><td>-</td></tr>
<tr><td>Weeding</td><td>88.44</td><td>11.50</td><td>30.89</td><td>186.00</td></tr>
<tr><td>Total</td><td>563.53</td><td>399.33</td><td>406.49</td><td>1,207.00</td></tr>
</table>

Remark: From author's calculation

*Under SRI method, there is no use of pesticide

Appendix G: Wage rates in different regions ($/hrs) (2011)

Regions	Soil types	Min.	Max.
North	Clay soil	0.45	
Central	Clay soil		0.64
North-East	Sandy loam	0.43	
South	Sandy loam		0.72

Remark: From BOT (2011b;c;d;e)

Appendix H: Cost of labour under conventional system ($/ha/cropping year) (2011).

	Clay Soil			Sandy Loam		
Rice cropping steps	**Min.**	**Max.**	**Mean.**	**Min.**	**Max.**	**Mean.**
Seed treatment and Nursery raising	12.47	17.96		5.57	9.27	
Land Preparation	40.97	59.01		12.23	20.34	
Transplantation	144.14	207.59		95.98	159.56	
Fertilizer application	6.23	8.98		46.76	77.73	
Pesticide application*	7.76	11.17		7.89	13.12	
Weeding	39.39	56.73		4.99	8.30	

Total Costs	**250.96**	**361.43**	**306.19**	**173.42**	**288.32**	**230.87**

Remark: From author's calculation

Appendix I: Cost of labour under SRI system ($/ha/cropping year) (2011).

	Clay Soil			**Sandy Loam**		
Rice cropping steps	**Min.**	**Max.**	**Mean.**	**Min.**	**Max.**	**Mean.**
Seed treatment and Nursery raising	167.27	240.90		17.81	29.60	
Land Preparation				97.28	161.73	
Transplantation				321.37	534.28	
Fertilizer application				6.95	11.55	
Weeding	13.76	19.81		80.78	134.29	
Total Costs	**181.02**	**260.71**	**220.86**	**524.18**	**871.45**	**697.81**

Remark: From author's calculation

Appendix J: Amount of evapotranspiration (ET) and water intake by rice plants (m^3/day).

Regions	**Amount of evapotranspiration**	**Amount of water intake by rice plants**	
		Min.	Max.
North	8	11.52	12.8
Central	8.48	12	13.44
North-East	8.64	12.256	13.632
South	8	11.52	12.8

Remark: Royal Irrigation Department (RID) (2009a;b;c;d)

All numbers were adjusted from millimeter (m^2) to cubic meter (m^3)

Appendix K: Amount of water use in panicle stage under SRI system per season (m^3/ha).

Regions	**Amount of water use in panicle stage**	
	Min.	Max.
North	4,370.00	4,750.00
Central	4,580.00	4,995.00
North-East	4,671.00	5,072.00
South	4,370.00	4,750.00

Remark: From author's calculation

Appendix L: Amount of water use in each region under conventional and SRI system per season (m^3/ha).

	Conventional system		**SRI**	
Regions	Min.	Max.	Min.	Max.
North	15,054.50	16,242.50	9,932.50	12,812.50
Central	15,570.50	16,844.50	10,142.50	13,057.50
North-East	15,794.10	17,033.70	10,233.50	13,134.50
South	15,054.50	16,242.50	9,932.50	12,812.50

Remark: From author's calculation

Appendix M: Amount and Price of herbicides application per season (2011)

Common names of Herbicides	**Amount of herbicides application (kg/ha)**		**Price ($/kg) *****
	Min.	Max.	
Paraquat Dichloride (28%) *	1.88	3.13	4.11
Glyphosate (48%) *	2.19	3.75	3.69

Glufosinate Ammonium (15%) *	5.00	10.00	15.92
Butachlor (60%) **	-	1.00	8.20
Pretilachlor (30%) **	-	0.50	21.52
Oxadiazon (25%) **	-	1.00	22.55
Propanil + Butachlor (27.5% + 27.5%) **	-	0.75	11.00
Fenoxaprop-P-Ethyl (8%) **	0.08	0.09	46.55
2, 4-D Sodium Salt (95%) **	-	1.00	6.02
2, 4-D Isobutyl Ester (79%) **	-	1.00	4.11

Remark: *Thai Crop Protection Association (TCPA), 2009a
**Bureau of Rice Research and Development (BRRD), 2011d
***From author's calculation

Appendix N: Amount and Price of mollussicides application per season (2011)

Common names of Mollussicides *	Amount of mollussicides application (kg/ha) *		Price ($/kg) **
	Min.	Max.	
Niclosamide Ethanolamine Salt (96%)	0.31	0.63	48.29
Metaldehyde (5%)	3.13	6.25	2.48

Remark: *Thai Crop Protection Association (TCPA), 2009b
**From author's calculation

Appendix O: Amount and Price of insecticides application per season (2011)

Common names of Insecticides *	Amount of insecticides application (kg/ha) *		Price ($/kg) **
	Min.	Max.	
Carbofuran (3%)	50.00	62.50	1.37
Cartap Hydrochloride (4%)		25.00	1.62
Chlorpyrifos (40%)		0.50	7.43
Carbaryl (85%)		0.13	342.32
Triazophos (40%)		1.00	6.37

Remark: *Thai Crop Protection Association (TCPA), 2009c and Department of Plant Science, 2008
**From author's calculation

Appendix P: Amount and Price of fungicides application per season (2011)

Common names of Fungicides *	Amount of fungicides application (kg/ha) *		Price ($/kg) **
	Min.	Max.	
Hexaconazole (5%)	0.00	0.19	15.76
Propiconazole + Difenoconazole (15%+15%)	0.06	0.09	33.12

Remark: *Thai Crop Protection Association (TCPA), 2009d and Department of Plant Science, 2008
**From author's calculation

Appendix Q: Cost of pesticide application under conventional system ($/ha/cropping year) (2011).

	Total cost of pesticide		
Pesticides	Min	Max.	Mean
Herbicides	6.98	318.49	162.74
Mollussicides	15.51	60.36	37.93
Insecticides	7.43	170.96	89.19

Fungicides	4.14	6.21	5.18
Total Costs	**34.06**	**556.02**	**295.04**

Remark: From author's calculation

Appendix R: Amount of yield gains under conventional and SRI system (kg/ha/season) (2011).

		Conventional system		SRI	
Soil types	**References**	Min.	Max.	Min.	Max.
Clay soil	Northern (Gypmantasiri, 2002)	3,640.00	4,810.00	3,000.00	4,760.00
	Suphanburi (Isvilanonda, 2009)	4,118.75	5,312.50	-	-
	Chachoengsao (Nieuwenhuis, 2008)	3,918.75	6,068.75	4,387.50	6,137.50
Sandy loam	North-eastern (Mishra and Salokhe, 2007)	2,812.50	2,981.25	3,318.75	5,306.25
	Surin (Komson, 2007)	2,812.50	3,125.00	4,000.00	4,500.00
	Konkean (Isvilanonda, 2009)	3,006.25	3,700.00	3,281.25	5,625.00
	Phatthalung (Panomjan, 2009)	-	-	2,251.05	5,695.92

Remark: From author's calculation

Appendix S: Amount of methane emission rate under conventional and SRI system categorized in irrigated and rainfed area and soil conditions (g CH_4 /m^2/day) (2011).

	Conventional system			SRI		
Criteria	Min	Max	Mean	Min	Max	Mean
Irrigated	0.38	0.72	0.55	0.24	0.46	0.35
Rainfed	0.02	0.45	0.24	0.01	0.29	0.15
Clay soil	0.08	1.02	0.55	0.05	0.65	0.35
Sandy loam	0.04	0.59	0.31	0.02	0.38	0.20

Remark: From author's calculation

Appendix T: Level of LD_{50} in each type of pesticides; herbicide, mollussicide, insecticide and fungicide.

Pesticides	Common names	LD_{50} (mg/kg)	Reference
Herbicides	Paraquat Dichloride	283 - 344	EPA, 1997
	Glyphosate	4,900	Fishel, 2006
	Glufosinate Ammonium	1,620	Hock, 2005
	Propanil	2,500	
	Fenoxaprop-P-Ethyl	2,565	
	2, 4-D (acid)	375 - 666	Hock, 2005; Fishel, 2006
	2,4-DB or Butyrac	2,000	Hock, 2005
	Butachlor	3,300	Dikshith and Diwan, 2003
	Pretilachlor	3,100	IUPAC, 2012
	Oxadiazon	5,000	EPA, 2004
Mollussicide	Metaldehyde	630	Pirone, 1978; Hock, 2005
	Niclosamide Ethanolamine Salt	5,000	WHO, 2002
Insecticides	Carbofuran	8 - 11	Siriwat, 2010; Hock, 2005

	Chlorpyrifos	92 – 276	
	Carbaryl	500 – 850	
	Triazophos	64	Siriwat, 2010
	Formetanate hydrochloride or Carzol	21	Hock, 2005
Fungicides	Hexachlorocyclohexane	1,752	Dikshith and Diwan, 2003
	Propiconazole	1,517	Hock, 2005
	Difenoconazole	1,453	Hock, 2005

Remark: From author's calculation

Appendix U: Estimated social and environmental cost of pesticide application in United States

	Social and environmental cost ($ million/year)		
Environment factor	**1980**	**1992**	**2005**
Public health impacts	184	787	1,140
Domestic animals deaths and contaminations	12	30	30
Reduced natural enemies	154	520	520
Increased pesticide resistance	133	1,400	1,500
Honeybee and pollination losses	135	320	334
Crop and tree losses	70	942	1,391
Fishery losses	11	24	100
Bird losses (wildlife)		2,100	2,160
Groundwater contamination		1,800	2,000
Government regulations to prevent damage	140	200	470

Remark: Data in year 1980 is gathered from Pimentel, 1980
Data in year 1992 is gathered from Pimentel, 1992
Data in year 2005 is gathered from Pimentel, 2005

The estimated social and environmental cost of year 1980 represents only a small portion of the actual costs due to time and information constraints. Hence, a more complete accounting would probably be several times higher than the presented one.

Appendix V: Sensitivity analysis of producer's cost and profit under conventional system and clay soil condition ($/ha/cropping year) (2011)

	Seed	Profit		**Labour**	Profit		**Irrigation**		Profit		**Fertilizer**	Profit	
		Irrigated	Rainfed		Irrigated	Rainfed	**Irrigated**	**Rainfed**	Irrigated	Rainfed		Irrigated	Rainfed
Min	38.98	1,123.18	1,139.20	251.24	1,073.08	1,089.11	825.45	183.58	825.45	552.54	125.41	1,007.23	1,023.26
Max	48.71	1,132.90	1,148.93	361.14	1,182.99	1,199.01	1,430.50	1,367.04	1,430.50	1,736.01	366.98	1,248.80	1,264.83
Mean	43.96	1,127.92	1,143.94	306.59	1,127.64	1,143.66	1,125.37	768.54	1,125.37	1,151.04	243.78	1,130.43	1,146.45
Standard Deviation	2.82	2.82	2.82	31.65	31.65	31.65	172.98	349.05	172.98	349.05	68.78	68.78	68.78

(Continued)

	Pesticide	Profit		**Income**	Profit		**All random components**							Profit	
		Irrigated	Rainfed		Irrigated	Rainfed	Income	Seed	Labour	Irrigated	Rainfed	Fertilizer	Pesticide	Irrigated	Rainfed
Min	34.21	867.25	883.27	2,016.66	333.87	349.89	2,016.24	38.97	250.99	489.36	184.39	125.41	34.11	-205.73	-442.08
Max	555.82	1,388.86	1,404.88	3,605.75	1,922.96	1,938.98	3,602.97	48.70	361.11	1,093.23	1,367.19	367.02	554.36	2,371.12	2,598.66
Mean	305.31	1,117.76	1,133.79	2,822.77	1,139.98	1,156.00	2,829.51	43.72	305.49	785.34	790.52	247.49	291.61	1,155.86	1,150.69
Standard Deviation	150.96	150.96	150.96	461.55	461.55	461.55	455.70	2.78	31.44	174.60	348.85	69.85	152.24	520.21	593.00

Remark: From author's calculation

Appendix W: Sensitivity analysis of producer's cost and profit under conventional system and sandy loam condition ($/ha/cropping year) (2011)

	Seed	Profit		**Labour**	Profit		**Irrigation**		Profit		**Fertilizer**	Profit	
		Irrigated	Rainfed		Irrigated	Rainfed	**Irrigated**	**Rainfed**	Irrigated	Rainfed		Irrigated	Rainfed
Min	48.76	238.74	253.23	173.66	191.10	205.59	489.18	183.62	-60.12	-336.07	192.08	49.41	63.89
Max	68.18	258.16	272.65	288.24	305.68	320.17	1,106.28	1,382.23	556.98	862.54	590.38	447.70	462.19
Mean	58.51	248.41	262.90	230.76	248.57	263.06	799.15	775.07	247.00	271.09	394.83	244.95	259.44
Standard Deviation	5.71	5.71	5.71	33.37	33.37	33.37	182.76	345.96	182.76	345.96	112.32	112.32	112.32

(Continued)

	Pesticide	Profit		**Income**	Profit		**All random components**							Profit	
		Irrigated	Rainfed		Irrigated	Rainfed	Income	Seed	Labour	Irrigated	Rainfed	Fertilizer	Pesticide	Irrigated	Rainfed
Min	34.21	-12.48	2.01	1,448.56	-324.82	-310.33	1,448.98	48.73	173.44	489.12	185.13	192.30	34.45	-872.52	-1,189.12
Max	555.98	509.29	523.78	2,595.30	821.92	836.41	2,595.57	68.20	288.29	1,106.29	1,382.66	590.66	555.46	1,272.82	1,665.63
Mean	299.92	243.58	258.07	2,006.39	233.01	247.50	2,015.98	58.62	230.42	804.00	770.73	388.34	297.20	237.40	270.67
Standard Deviation	150.27	150.27	150.27	324.12	324.12	324.12	329.60	5.56	33.87	178.97	337.85	114.62	148.22	417.87	507.57

Remark: From author's calculation

Appendix X: Sensitivity analysis of producer's cost and profit under SRI and clay soil condition ($/ha/cropping year) (2011)

	Seed	Profit		**Labour**	Profit		**Irrigation**		Profit		**Fertilizer**	Profit	
		Irrigated	Rainfed		Irrigated	Rainfed	**Irrigated**	**Rainfed**	Irrigated	Rainfed		Irrigated	Rainfed
Min	2.64	1,673.76	1,668.55	181.17	1,635.21	1,630.00	322.61	120.98	1,412.71	1,200.39	125.34	1,631.48	1,626.26
Max	5.20	1,676.32	1,671.11	260.70	1,714.74	1,709.53	847.71	1,060.03	1,937.81	2,139.44	212.40	1,718.54	1,713.33
Mean	3.93	1,675.03	1,669.81	220.39	1,675.51	1,670.30	590.18	581.05	1,670.24	1,679.37	168.76	1,675.12	1,669.91
Standard Deviation	0.75	0.75	0.75	23.51	23.51	23.51	150.38	273.84	150.38	273.84	24.70	24.70	24.70

(Continued)

	Income	Profit		**All random components**						Profit	
		Irrigated	Rainfed	Income	Seed	Labour	Irrigated	Rainfed	Fertilizer	Irrigated	Rainfed
Min	1,661.95	682.96	677.75	1,662.04	2.63	181.12	323.05	123.61	125.29	490.97	211.66
Max	3,643.69	2,664.70	2,659.49	3,646.02	5.19	260.60	847.42	1,059.51	212.40	2,880.98	3,038.59
Mean	2,705.39	1,726.40	1,721.19	2,667.96	3.91	221.08	588.68	588.47	169.66	1,684.62	1,684.83
Standard Deviation	576.97	576.97	576.97	573.31	0.75	23.05	154.54	277.97	24.87	591.18	647.07

Remark: From author's calculation

Appendix Y: Sensitivity analysis of producer's cost and profit under SRI and sandy loam condition ($/ha/cropping year) (2011)

	Seed	Profit		**Labour**	Profit		**Irrigation**		Profit		**Fertilizer**	Profit	
		Irrigated	Rainfed		Irrigated	Rainfed	**Irrigated**	**Rainfed**	Irrigated	Rainfed		Irrigated	Rainfed
Min	4.68	1,115.40	1,109.56	524.76	943.43	937.59	322.61	121.02	852.82	638.61	125.29	1,073.24	1,067.40
Max	7.48	1,118.20	1,112.36	871.18	1,289.85	1,284.02	851.86	1,066.07	1,382.07	1,583.65	212.40	1,160.35	1,154.51
Mean	6.05	1,116.82	1,110.99	700.32	1,114.30	1,108.46	587.08	592.05	1,117.60	1,112.63	168.87	1,116.76	1,110.93
Standard Deviation	0.81	0.81	0.81	99.91	99.91	99.91	153.88	271.33	153.88	271.33	25.10	25.10	25.10

(Continued)

	Income	Profit		**All random components**						Profit	
		Irrigated	Rainfed	Income	Seed	Labour	Irrigated	Rainfed	Fertilizer	Irrigated	Rainfed
Min	1,162.75	-297.86	-303.69	1,159.09	4.68	524.21	324.01	121.39	125.34	-697.59	-897.98
Max	3,992.31	2,531.70	2,525.87	3,993.70	7.48	871.36	852.34	1,063.46	212.21	2,903.26	3,047.61
Mean	2,579.32	1,118.71	1,112.88	2,577.39	6.06	702.91	590.89	587.81	168.75	1,108.78	1,111.86
Standard Deviation	832.82	832.82	832.82	819.99	0.80	97.60	153.33	277.55	25.12	843.92	867.93

Remark: From author's calculation