Institute of Agricultural Policy and Market Research

Assessing Economic and Environmental Efficiency of Rice Production Systems in Southern Thailand: An Application of Data Envelopment Analysis

Dissertation

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Abstract

Rice farming is a dominant rural economic as well as culturally important activity in southern Thailand. Rice production in this region is constrained by bio-physical and economic factors especially high costs of production and high application rates of chemical fertilizers. In addition, the actual outputs from rice production process are not only paddy rice but also the potential negative environmental effects. The flooded condition generates methane gas emission, while the excessive use of N-fertilizers causes the emission of nitrogen gases and the leaching of nitrate. In this study, therefore, the efficiency of use of all combination inputs and efficiency of use of chemical N-fertilizers as its excessive use causes the negative externalities are focused. The objectives of this study are to investigate the existing rice production systems and to assess the technical efficiency, economic efficiency, and environmental efficiency of rice production systems, then to investigate factors affecting the technical, economic and environmental efficiency of rice production systems in southern Thailand. Two-stage DEA methodology of efficiency analysis was focused. The two-stage DEA procedure began with calculating efficiency scores from input-oriented DEA model. Then these efficiency scores were used as dependent variables in the second stage by using the Tobit regression technique.

The total of 247 rice farm household samples was randomly selected from the main rice farming area, the Songkhla Lake Basin. The empirical results showed that 17, 2, and 2 percent of the sample farms were on the technical, economic, and environmental efficiency frontiers, respectively and the average technical, economic, and environmental inefficiency were 14, 32, and 46 percent, respectively. Moreover, the common significant variables affecting the efficiency were soil type and rice variety. To improve the efficiency of rice farms, therefore, soil quality testing which help to improve soil quality and efficiency use of chemical fertilizers is urgent needed to implement while the research on new technologies: new suitable rice variety and new fertilizer products are considered as long-term policy implementation.

Kurzfassung

Der Reisanbau ist sowohl eine ökonomisch für den ländlichen Raum dominante als auch kulturell bedeutsame Aktivität im südlichen Thailand. Die Reisproduktion in diesem Gebiet wird dabei von biophysischen und ökonomischen Faktoren bestimmt, insbesondere von hohen Produktionskosten und hohem Einsatz an synthetischen Düngemitteln. Neben Reis ergeben sich auch potenzielle negative Umwelteffekte als Ergebnis des Produktionsprozesses. So ergeben sich durch die Flutungen Methangas-Emissionen, während der exzessive Gebrauch von N-Düngern zu Emissionen von Stickstoff-Gasen sowie Nitratauswaschungen führt. Daher untersucht diese Studie die Effizienz des Einsatzes aller Inputkombinationen sowie die Effizienz der Verwendung synthetischer N-Düngemittel, deren exzessiver Gebrauch negative externe Effekte hervorruft. Die Studie zielt auf die Untersuchung der bestehenden Systeme zur Reisproduktion ab sowie auf die Abschätzung der technischen Effizienz, der ökonomischen Effizienz und der Umwelteffizienz. Weiterhin sollen die Faktoren identifiziert werden, die die technische, ökonomische und Umwelteffizienz im südlichen Thailand beeinflussen. Dazu wird eine zweistufige DEA-Methode zur Effizienzanalyse herangezogen. Zunächst werden die efficiency scores eines Input orientierten DEA-Modells berechnet. Diese efficiency scores werden in einer zweiten Stufe als abhängige Variablen einer Tobit Regressionsschätzung verwendet.

Insgesamt wurde eine Stichprobe von 247 Reis anbauenden Haushalten aus dem Songkhla Lake Basin, der Hauptanbauregion für Reis, zufällig ausgewählt. Die empirischen Ergebnisse zeigen, dass von den untersuchten Betrieben 17% auf der technischen, 2% auf der ökonomischen und 2% auf der Umwelt efficiency frontier produzieren, während die durchschnittliche technische Ineffizienz bei 14%, die ökonomische bei 32% und die Umweltineffizienz bei 46 % liegen. Darüber hinaus sind Bodenqualität und Reissorte die signifikanten Variablen, die die Effizienz beeinflussen. Zur Verbesserung der Effizienz des Reisanbaus sind daher die Qualitätsbestimmung des Bodens zu dessen Verbesserung sowie die Verbesserung der Effizienz des Einsatzes von Düngemitteln voranzutreiben. Als langfristige Politikempfehlung ergibt sich die Bereitstellung neuer Reissorten und neuer Düngeprodukte über die verstärkten Forschungs-und Entwicklungsbemühungen.

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Abbreviations

BAAC	Bank of agriculture and agricultural cooperatives
BCC	Banker, Charnes and Cooper
BPFs	Best practice farms
CCR	Charnes, Cooper, and Rhodes
CRS	Constant returns to scale
DAP	Di-ammonium phosphate
DEA	Data envelopment analysis
DIT	Department of internal trade
DMU	Decision making unit
DOAE	Department of agricultural extension
EE	Economic efficiency
ENE	Environmental efficiency
GDP	Gross domestic products
GPP	Gross provincial products
GRP	Gross regional products
ha	Hectare
kg	Kilogram
km	Kilometer
LDD	Land development department
MOAC	Ministry of agriculture and cooperatives
N	Nitrogen
NESDB	National economic and development board
NESDP	National economic and development plan
NTIP	Na-Tom irrigation project
OAE	Office of agricultural economics
PAO	Phatthalung agricultural office
PCD	Pollution control department
PSU	Price of Songkhla university
PWO	Public warehouse organization
RD	Rice department
REO	Regional environmental office
RIP	Ranot irrigation project
SAO	Songkhla agricultural office
SLB	Songkhla lake basin
TE	Technical efficiency
THB	Thai baht, approximately 48 THB = 1 euro
TRPC	Thai rice policy committee
VRS	Variable returns to scale

1 Introduction

1.1 Problem statement

Rice farming is a dominant rural economic as well as culturally important activity in Thailand. Rice farming utilizes half of the agricultural land (10.4 million hectares) of the country (OAE, 2005) and it produces 27 million metric tons of paddy rice. The average actual yield of the major rice crop is 2.6 ton per hectare (ha) in 2004 while the average potential yield is 5.3 ton per ha (PINGALI *et al.*, 1997). In other words, Thailand has a substantial rice yield gap (approximately twice of the current yield) between the potential and actual yield levels which requires production improvement to reduce this gap.

Thailand is divided into four regions, i.e. north, northeast, central plain and south. Rice production systems are divided into two main agro-ecosystems: irrigated and rain-fed. The main irrigated areas are located in the central plain, while the main rain-fed areas are located in the northeast region. For the Kingdom as a whole, the rice planted area has been stable for the past ten years. In contrast, a decreasing trend is observed in the southern region (OAE, 2005). It decreased from 490,000 ha in the crop year 1993/94 to 338,000 ha in the crop year 2004/05 or it has decreased approximately 3 percent per annum.

Even though southern Thailand is not the main rice bowls of the country, rice farming is very important activity since rice is the only food crop of the region. The total production of the region was 869,075 tons of paddy rice in 2004 (OAE, 2005), while its demand is approximately 1.3 million tons a year (150 kg paddy rice per capita). Consequently, a certain deficit quantity of rice has to be imported from other regions. Moreover, rice farming is not only significant in region's food security but also in rural employment, biodiversity, and cultural and tradition conservation.

Rice production in this region is constrained by bio-physical, economic bottlenecks. The bio-physical constraints consist of frequent floods, irregular pattern of rainfall, water shortage, low soil fertility, and pest menace, while the economic constraints are high cost of production, low productivity, instability of paddy price, and agricultural labor shortage and higher wages due to the high opportunity cost of labor in other activities. In addition, technological constraints like low yielding varieties and accelerated conversion of paddy land to shrimp farms are other major threats (ANGVITTHAYATHORN, 2001). These factors caused the paddy farmers in the southern being poorer than other farmers engaged in rubber and fruit tree plantations, fishery as well as vegetable cultivations (OAE, 2000).

Presently, climate change and global warming are crucial issues and widely discussed in the national and international levels. The major contribution of greenhouse gases to global warming are 49 percent from carbon dioxide (CO_2), 18 percent from methane (CH_4), and 6 percent from nitrous oxide (N_2O) (CHANTALAKANA and SKUNNUN, 2002). The release of the latter two is related to agricultural production processes and occurs especially in rice faming. Methane and nitrous oxide are effective greenhouse gases that are 20-60 times and 200-300 times more efficient than carbon dioxide gas, respectively (KYUMA, 2004).

Rice farming is characterized by combination conditions of flooding and the universal application of inorganic fertilizers (PANDEY, 1999; ROY and MISRA, 2003; KYUMA, 2004) especially nitrogen (N) fertilizers. The flooded condition generates methane gas emission, while the excessive use of N-fertilizer causes the emission of nitrous oxide (and other nitrogen gases) and the leaching of nitrate (KYUMA, 2004; CHOUDHURY and KENNEDY, 2005). The magnitude of these environmental effects varies depending on the farm management practices, soil properties, and agro-ecosystem conditions (WASSMANN *et al.*, 2000; LI *et al.*, 2004; CHOUDHURY and KENNEDY, 2005). Hence, the actual outputs from rice production process are not only paddy rice but also the negative environmental effects. In other words, rice farming would be considered as a potential non-point source of pollution.

Due to above constraints and problems, they may lead to be unsustainable rice production systems in southern Thailand (Figure 1.1). Therefore, the efficiency of inputs use of rice production especially chemical N-fertilizers can help to reduce cost of production as well as environmental pollutions, and would result in boosting sustainability of rice farming in southern Thailand.

Considering inputs and outputs of rice production system, inputs of rice production can be categorized into conventional and environmental detrimental inputs. The conventional inputs consist of land, labors, machines, fuel, and seed, while environmental detrimental inputs comprise chemical fertilizers and chemical pesticides. On the other hand, outputs from rice production process are economic desirable and environmental undesirable outputs (Figure 1.2).
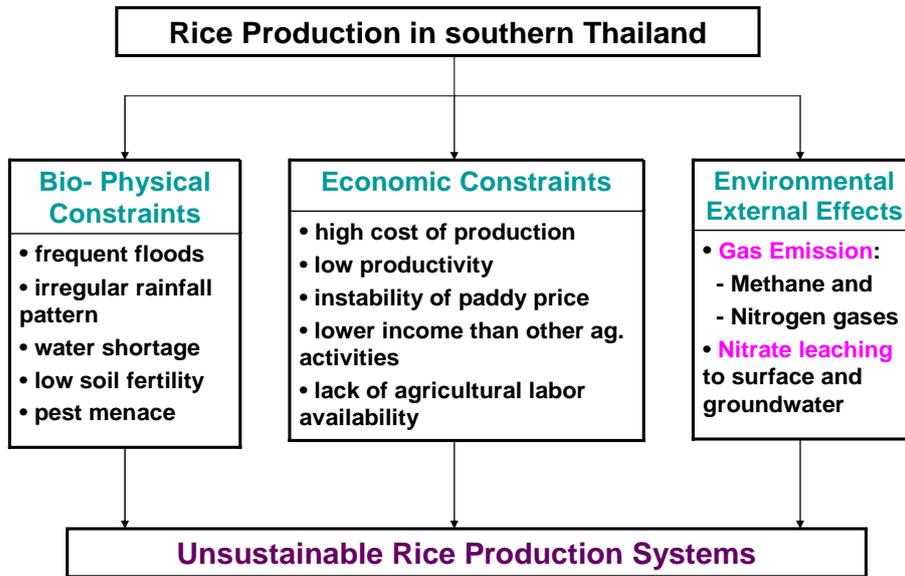
Figure 1.1: Constraints of rice production in southern Thailand
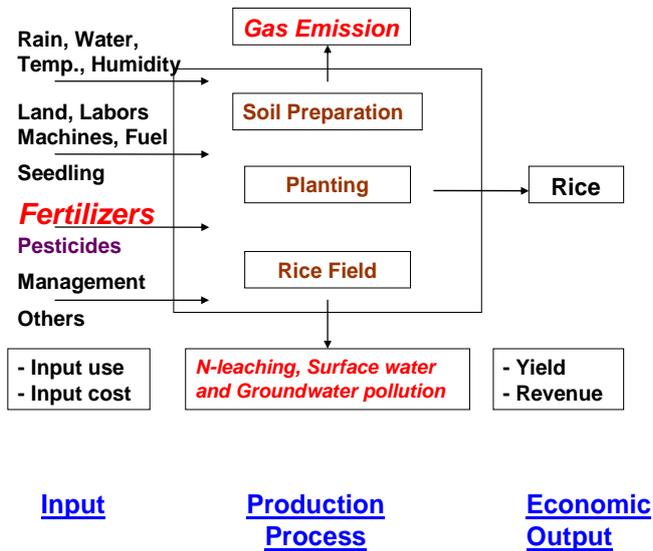
Figure 1.2 Multiple inputs – multiple outputs of rice production system

Recent studies on efficiency of rice farms have been focused only on technical and/or economic efficiency (for example; ABDULAI and HUFFMAN (2000); RAHMAN (2002); KRASACHAT (2003); DHUNGANA *et al.* (2004)). As a step forward, present study focuses on efficiency use of input combinations of rice production at farms level and attempts to quantify technical efficiency, economic efficiency, and environmental efficiency of individual observed farm.

The following research questions have been raised and try to answer by this research:

1) What are the existing farm practices and management situations of rice production in southern Thailand?

2) Do farmers efficiently use the combination of inputs for producing rice?

3) What are the existing technical and economic efficiency levels of rice production in southern Thailand?

4) Are there any differences in efficiency among rice farmers?

5) What is the existing environmental efficiency level of rice production in southern Thailand?

6) What are the determinants of technical, economic and environmental efficiency of rice production in southern Thailand?

1.2   Objectives of the study

This study attempts to understand the existing rice farming systems in Songkhla Lake area of southern Thailand which divided into irrigated area and rain-fed area, and to formulate recommendations for improving farm performances in both economic and environmental views and sustaining rice production systems in the study area.

The specific objectives are:

1) To investigate the existing rice production systems in southern Thailand.

2) To assess the technical efficiency of rice production systems.

3) To assess the economic efficiency of rice production systems.

4) To evaluate the environmental efficiency of rice production systems.

5) To investigate the factors affecting the technical, economic and environmental efficiency of rice production systems in southern Thailand.

1.3   Hypotheses of the study

1) Rice farmers in irrigated areas have higher income than in rain-fed areas.

2) Irrigated rice farms have higher technical and economic efficiency scores than rain-fed farms.

3) Rain-fed rice farms have higher environmental efficiency scores than in irrigated farms.

4) Farmer characteristics, farm practices and management, agro-ecosystems, and rice variety are significant factors affecting the efficiency of rice production.

1.4   Expected outcomes

1) The technical and economic best practice levels or benchmarking of rice production systems in southern Thailand

2) The environmental benchmarking of rice production systems in southern Thailand

3) Policy implications for efficiency improvement on rice production and for sustainable rice production systems in southern Thailand

1.5   Organization of the study

The study contains seven chapters. The next chapter, Chapter 2 starts with brief introduction of the structure of Thai economy and agricultural sector and then follows by the discussion of roles of rice in Thai economy, rice farming and multi-functional aspects, current domestic rice production and consumption situations, and international rice production and trade situations. The last section of this chapter summarizes the existing Thai rice strategic plan and rice policy.

In chapter 3 explores and reviews theoretical background of production and efficiency analysis. It begins with the discussion of production analysis and then follows by efficiency analysis and summary of data envelopment analysis method. The last section of this chapter ends with the literature surveys of empirical study on efficiency measurement of agricultural production.

Chapter 4 begins with data collection section which gives the details of sampling method and sample sizes of primary data collection. Then the data analysis section provides the details of descriptive statistic analysis, cost-revenue and profitability analysis, Data envelopment analysis model, and Tobit regression analysis.

Chapter 5 starts with background information of the south and the study area. Then the existing situation of rice farm households and rice production were analyzed. It presents the information and discussion on farm household characteristics, farmer characteristics, resources and farm management, profitability of rice production, and rice farm household income. The last section of this chapter presents the farmers' opinion and perception on rice production problems and negative environmental effects of rice farming.

In Chapter 6 focuses on presentation of the results of efficiency analysis and analysis of factors affecting efficiency of rice farms. The first section starts with empirical results of technical efficiency analysis then follows by results of economic and environmental efficiency analysis. The results of factors affecting on efficiency of rice production systems are discussed in the last section.

Lastly, in Chapter 7 summarizes the main findings of the study and draws the policy recommendations. The last section of this chapter, limitations of the study and recommendations for further study are discussed.

2 Rice in Thai Economy

In this chapter, the structure of Thai economy and agricultural sector are introduced. Then the following sections provide information about significant roles of rice toward the Thai economy, and multi-functionality of rice farming. Afterward, current rice production, consumption, and trade situations are elaborated. The final section, the Thai rice strategic plan and rice policy are presented.

2.1 Introduction

Thailand is located in Southeast Asia and surrounded by Myanmar, Laos, Cambodia, and Malaysia. Thailand is approximately 513,000 square kilometers or 51 million hectares in areas. It is divided into 4 geographical regions, i.e. north, northeast, central, and south, and that is comprised 76 provinces. Thai populations are nearly 64 millions, while the population density is 125 people per square kilometer. Fifty five percent of the total populations are labor forces of the country and 43 percent of total labor forces are engaged in agricultural activities. The average unemployment rate is 2 percent (NSO, 2006).

The Thai economy can be categorized into three main sectors, i.e. industry, service, and agriculture. In 2005, the first two sectors shared approximately the same proportion, 45 percent, to the Gross Domestic Product (GDP), while agricultural sector contributed nearly 10 percent (0.7 trillion THB[1]) to the GDP (NESDB, 2006). The GDP per capita was 109,440 THB at 2005 current market prices. The GDP growth rate was approximately 4.5 percent per annum.

In addition, the Thai economy is export-dependent which total export value accounts for 60 percent of the GDP. In 2005, the total export value was 4.4 trillion THB and agricultural commodities and products represented nearly 22 percent of the total export value (OAE, 2006). Natural rubber, rice, and fishery products are main agricultural exported items. On the other hand, the total import value was 4.7 trillion THB. Approximately 10 percent of the total import value was shared by agricultural commodities and products. The significant imported agricultural inputs are chemical fertilizers, chemical pesticides and animal feeds. As the results, the world market prices and market situation as well as foreign exchange rates have much influenced on the Thai economy especially on its agriculture sector.

2.2 Agriculture in Thai economy

The Thai agricultural sector can be divided into 5 sub-sectors: crops, trees, livestock, fishery, and forestry. The important crops in terms of land use are rice, maize, sugarcane, cassava,

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[1] Thai Currency, approximately 48 Baht = 1 Euro

mungbean, and soybean. The key tree plantations are para-rubber, oil palm, and fruit trees. Regarding to livestock, the important livestock are broiler and hen-layer, duck, swine, cattle, and dairy-cow. The fishery comprises the ocean, coastal, and inland fishing. Lastly, the forestry includes logging and related service activities (OAE, 2005; NESDB, 2006)

Agricultural sector has played a significant role in the Thai economy though its performance in terms of percentage of GDP has been shown the decreasing trend over the past forty years. In 1960, agricultural sector shared 38 percent of GDP. It decreased to 29 percent in 1970 and followed by 13 percent, 11 percent and 10 percent in 1990, 2000, and 2005, respectively (KIATPATHOMCHAI, 2005). Moreover, crop products (rice mainly) shared 60 percent of agricultural GDP (NESDB, 2006).

In fact, agricultural sector serves a number of populations and creates food supply, food sufficiency, rural employment, and foreign income. Approximately 50 percent of the total population or 5.8 million households are engaged in this sector. Furthermore, 41 percent of the country areas are utilized to agricultural land with the average land holding of 3.7 hectares per household (OAE, 2005). In terms of foreign income, as mentioned in the previous section, agricultural commodities and products contributed 22 percent to the total export value.

At the regional level, Gross Regional Product (GRP) is considered as a key indicator. The central region including Bangkok produce the highest GRP compare to other regions. In terms of contribution of agriculture to the GRP among all regions, southern agricultural sector produces highest proportion to its GRP, i.e. 35 percent. The northern and northeastern agricultural sectors contribute approximately 20 percent of their GRP, whereas agriculture sector in the central region shares only 4 percent of its GRP (see Figure 2.1).

Over the past ten years, the Thai agricultural sector has seriously faced unstable farmer income, unequally income distribution between agricultural and non-agricultural sectors, natural resources and environment degradation which have lead to unsustainable development of this sector. In addition, it has been pressured by the global issues such as international trade agreements and regulations, technological changes, and changes in consumer behaviors that more concern on health and environmental aspects. These pressures lead the farmers and policy makers to adjust and to change strategies for development and the competitiveness of this sector. Therefore, the present agricultural policies are concerned about increasing production efficiency and reducing cost of production, supporting research and development in both production and market sides, transferring of new agricultural technologies, supporting agricultural credits as well as improving the farmers' quality of life.
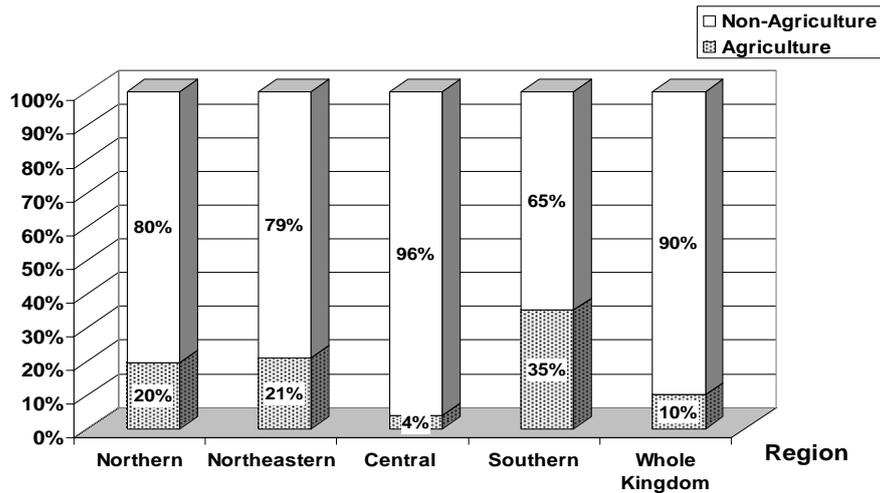
Figure 2.1: Composition of GDP and GRP in 2005
Source: NESDB, 2006

2.3 Significant roles of rice in Thai economy

Thailand is one of the world's biggest rice producers and exporters. Rice is a staple food of the Thai people with its importance role not only in terms of land use but also in terms of labor force and rural development as well as source of foreign currency. Moreover, since rice has been the most important food crop for more than 700 years, it is part of the tradition and cultural heritage.

2.3.1 Significance of land use

Rice is grown in all provinces of Thailand. In terms of land use, rice farming utilizes half (10.4 million hectares) of the agricultural land of the country, while other crops, such as mungbean, soybean, sorghum, sugarcane, maize, share only 22 percent of agricultural land. In addition, fruit trees and trees (para-rubber, oil palm) are grown on 20 percent of the agricultural land (OAE, 2005). Although irrigated area of the country is covered on 24 percent of the agricultural land, rice farming occupies on 80 percent of the total irrigated area.

Considering the country as a whole, more than half (57 percent) of the total rice farming areas are found in the northeast region. The northern and central regions share 22 percent and 17 percent of the total rice farming areas, respectively, whereas in the south rice is grown on only 4 percent of the total rice farming areas.

At the regional level, main agricultural land use is rice farming in all regions with the exception of the south (Figure 2.2). Rice farming area shares 49 percent, 65 percent, 40 percent of agricultural land of the northern, northeastern, and central regions, respectively, whereas only 14 percent in the south (OAE, 2005).
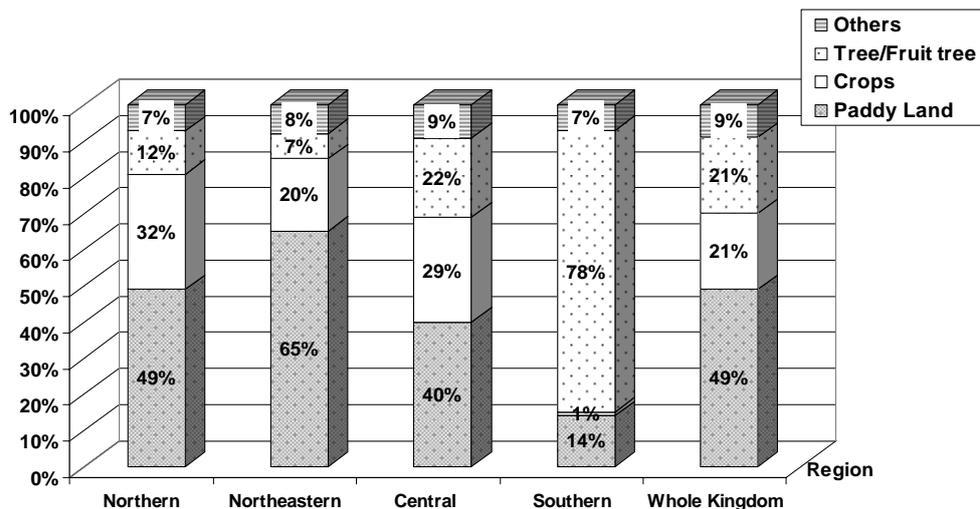
Figure 2.2: Paddy land use by regions in 2005
Source: OAE, 2006

2.3.2   Significance of labor force and rural employment

In terms of labor force, it is inevitable that rice farming households are the main source of labor supply of agricultural sector and of the country. Presently, there are 17.8 million of total households in Thailand and 5.8 millions (33 percent) are agricultural households (NSO, 2004). The agricultural households are mainly in the northeast where accounting for 2.6 millions followed by 1.4 millions in the north and 0.9 millions equally in the central and south.

To be more specific, approximately 65 percent of agricultural households or 3.8 million households are paddy or rice farm households. The average labor force of agricultural households is 3.06 persons per household (OAE, 2002). This implies that 11.6 millions out of 17.5 million of total agricultural labor forces come from rice farm households. In addition, more than 80 percent of these agricultural labor forces are working in the rural area.

2.3.3   Significance of foreign currency

Rice is one of the important agricultural exported commodities of Thailand. It shares approximately 2 percent of the total export value or 10 percent of the total agricultural export value. In other words, rice products can earn 93,547 million THB from export of 7.5 million tons of rice (OAE, 2006). More details of rice trade situation are presented in section 2.6.3.

2.3.4   Significance of culture and tradition conservation

In Thailand, since rice has been growing for more than 700 years, rice and culture cannot be separated. Rice culture plays an important part in the Thai social structure. It has been involved in the local wisdom, beliefs, traditions, ceremonies and religious activities, which help farmers to make decisions during rice production process. There are both differences and similarities

among the different geographical regions. As rice production depends a lot upon the uncontrollable factors especially rainfalls, thus farmers learn and have the local wisdoms relating to the weather forecast (DAMSRI, 2001). For example, if farmers observe that animals surrounding the paddy fields, such as ants, moving their eggs to higher places would know that there will be rain soon, so that they can plan for their farming and household activities. More details of cultural conservation of rice are discussed in the next section (2.4.4.3).

2.4 Rice farming and multi-functional aspects

2.4.1 Introduction of multi-functionality of agriculture

Multi-functionality of agriculture relates to an activity-oriented concept referring to specific characteristics of the production process and its multiple outputs (OECD, 2001). It involves on both commodity and non-commodity outputs from agricultural process. The commodity outputs are desirable outputs from the production process, which can be valued by market prices of commodities. On the other hand, the non-commodity outputs have non-market values and can be positive and/or negative external effects on the environment and society. Multi-functionality aspects may have different effects on developed countries and developing countries because of, for example, the different demand patterns in non-commodity outputs, institutional framework, and capacity of public administrations. Hence the policy implications for this issue may also be different.

2.4.2 Multi-functionality of rice farming

Rice is one of important food crops for the world population and it is a staple food for Thais. The Food and Agriculture Organization of the United Nations (FAO), therefore, declared that "rice is life" as the theme of international year of rice in 2004. The mission statement was "promotes improved production and access to this vital food crop, which feeds more than half the world's population while providing income for millions of rice producers, processors and traders. Development of sustainable rice-based systems will reduce hunger and poverty, and contribute to environmental conservation and a better life for present and future generations." (FAO, 2004).

Multi-functionality of rice farming refers to that rice farming activity could have multiple outputs besides the paddy rice. This means that apart from the paddy rice which is an economic desirable output, rice farming activity creates non-commodity outputs which have non-market values (MATSUNO *et al.*, 2006). As summarized in Table 2.1, the non-commodity outputs from rice farming can be grouped into social outputs and externality outputs. The social outputs consist of rural employment, food security as well as culture and tradition conservation, whereas the externality from rice farming can be both negative and positive externalities.

Table 2.1: Summary of multiple outputs of rice farming

Commodity outputs	Non-commodity outputs
Economic outputs	**Social outputs**
- paddy rice	- rural employment
- by products: husk, straw	- food security
	- culture and tradition conservation
	Externality from rice production
	Negative externality
	- methane gas emission
	- nitrous oxide gas emission
	- nitrogen leaching
	- water contamination from excessive use of chemical fertilizers and pesticides
	Positive externality
	- flood control
	- soil erosion prevention
	- conservation of biodiversity
	- landscape amenities
	- rural tourism

Source: own presentation

2.4.3 Rice farming and commodity outputs

A main product from rice farming is paddy rice. Most of the Thai farmers sell their excess products to local millers or middlemen at farm gate price. Rice farming also produces husk and straw residues, which farmers can use them for other agricultural activities. For example, straw can be used either as roughage feed for the cattle or as material for producing straw mushroom. The current paddy rice production situations are discussed in section 2.5.

2.4.4 Rice farming and social outputs

2.4.4.1 Rural employment

Rice production activities provide employment and generate incomes which are from work directly either in rice production or in related support services (post-harvest activities), i.e. harvesting, threshing, drying, milling, storing, processing, and trading. Moreover, the use of by products: straw and husk can also offer the employment in the rural area. This implies that sustainable rice-based production is the key to livelihood improvement.

2.4.4.2 Food security

According to the Thai context, rice is very important for food security of households. They usually stock amounts of rice in their kitchens for daily consumption of family members. Especially rice farm households, they primarily produce rice to satisfy and meet family needs or to achieve self-sufficiency of household. These households usually store their paddy rice for consumption of family members on the year to year basis.

2.4.4.3 Culture and tradition conservation

Rice cultural heritage is one of the public goods and multifunctional attributes of agriculture. Thai rice farmers are admired as the country's backbone because they produce rice to feed all of us. Moreover, rice farmers and rural communities are perceived as preservers of Thai cultural values. The rice culture has been involved in the local wisdom, beliefs, traditions, ceremonies and religious activities. In this section, some examples of rice culture are discussed.

Royal Ploughing Ceremony is one of the important ceremonies, and has been held an annual occasion in May at the Royal Field in front of the Grand Palace in Bangkok. It is a Brahman ceremony foretells the amount of foods and water expected in the agricultural land each year (TRFRP, 2006). This ceremony gives opportunity to people especially the rice farmers to collect the rice seeds sowed by 'Phaya Raek Na'. 'Phaya Raek Na' is the person who performs the ceremony on behalf of the King. The rice seeds, then, are taken back to the farms as a good luck charm. In addition, farmers prefer doing the first ploughing day on Sunday because they believe that Sunday is sunny and hot enough killing weeds in the field (DAMSRI, 2001).

During rice production, rice farmers may pray to the spirits or gods for watching over the rice in order to ensure that it gives a good harvest, free of birds, rats or insects. The farmers would ask for forgiveness from the rice goddess or 'Mae Phosop' before pulling the rice seedlings for transplanting, and asking her to go to where the rice seedlings are transplanted (TRFRP, 2006). The rice farmers believe that the rice goddess would protect the rice in the field and attain the high yields.

In the south of Thailand, *Lak Pra* festival is a tradition that people put the Buddha on boat and row along the river. The southern farmers believe that if the boat passes whose paddy fields, rice production will be more successful. Especially, for those who can join this festival every year will have the prosperous life (DAMSRI, 2001). In addition, they believe that this festival can make the regular seasonal rainfalls.

2.4.5 Rice farming and negative environmental externality

Currently, climate change and global warming are crucial issues and widely discussed. Rice production is one of the agricultural activities concerned about producing the greenhouse gases during the production process. However, rice production is seldom recognized as a potential non-point source of pollution. The major contribution of greenhouse gases to global warming are 49 percent from carbon dioxide (CO_2), 18 percent from methane (CH_4), and 6 percent from nitrous oxide (N_2O) (CHANTALAKANA and SKUNNUN, 2002). The release of the latter two is related to agricultural production process especially rice faming activity. Main negative effects of rice farming on the environment comprise emissions of methane and nitrous oxide, and excessive pesticide and nutrient discharged through drainage.

2.4.5.1 Methane gas emission

Due to flooded condition of rice production systems, it causes methane greenhouse gas emission by microbiological processes. Methane is an effective greenhouse gas that is 20-60 times more efficient than carbon dioxide gas (KYUMA, 2004). The methane emission from rice fields contributes 20 percent of the world methane emission (MATSUNO *et al.*, 2006) which has been increasing 1 percent annually (KYUMA, 2004). Most factors influencing methane emission are related to the soil chemical, temperature, and biological processes. In addition, irrigated rice creates higher methane emission than rain-fed rice and deepwater rice (WASSMANN *et al.*, 2000). However, farm management practices, such as water drainage during the farming season, can reduce some of this gas emission.

2.4.5.2 Nitrous oxide gas emission and nitrogen leaching

The rice farmers universally apply inorganic or chemical fertilizers to the fields (PANDEY, 1999; ROY and MISRA, 2003; KYUMA, 2004). The excessive use of inorganic fertilizers, especially nitrogen (N) fertilizer is harmful the environment. The N-fertilizer is transformed by the processes of ammonia volatilization and denitrification, which lead to emission of nitrous oxide and other forms of nitrogen gas and the leaching of nitrate to surface water and groundwater (KYUMA, 2004; CHOUDHURY and KENNEDY, 2005). Nitrous oxide is an effective greenhouse gas that is 200-300 times more efficient than carbon dioxide gas (KYUMA, 2004).

2.4.5.3 Water contamination from excessive use of chemical fertilizers and pesticides

Two important variable inputs applied during the rice production process are chemical fertilizers and pesticides. Besides the greenhouse gas emission from the use of N-fertilizer, the excessive use of chemical fertilizers and pesticides leads to nitrate and toxic substance contaminations in water body nearby the rice fields.

2.4.6   Rice farming and positive environmental externality

Apart from the negative external effects, rice farming also produces the positive external effects to the environment. The positive environmental externalities from the rice farming are discussed as follows:

2.4.6.1 Flood control

As mentioned earlier, rice fields need flooded or pond-liked condition. Since the flooding occurs during the growing season, the rice fields have a function like several small reservoirs which can help to control or prevent the flood (KIM *et al.*, 2006). In other words, rice fields have a function as a buffer which increases the water storage capacity. The decrease in flood control function is affected by abandonment of cultivation (MATSUNO *et al.*, 2006).

2.4.6.2 Soil erosion prevention

During the monsoon season, Thailand is affected by high intensity storm and heavy rain. As rice production systems are under flooded condition therefore it has ability to minimize soil erosion because the raindrops do not directly contact to the soil (KIM *et al.*, 2006; MATSUNO *et al.*, 2006). This is an advantage function of paddy fields to prevent soil erosion. The decrease in soil erosion prevention is affected by abandonment of cultivation or conversion of the paddy fields to other crops especially in the highland areas.

2.4.6.3 Conservation of biodiversity

Rice fields provide the habitats to many living organisms, which vary from visible to small living organisms. For instance, fish, crap, snails, insect pest and natural enemies, mosquitoes, water weevils, bacteria, and phytoplankton (TRAN, 2004). This implies that rice production systems enhance and conserve biodiversity both surrounding and in the rice fields.

2.4.6.4 Landscape amenities and rural tourism

Rice fields, which attach to the nature, create not only a very beautiful landscape but also present the unique cultural and social environment. These may attract people in the city or urban area to find the place for fresh air and relaxation in rural area (HUANG *et al.*, 2006).

2.5   Current domestic rice production and consumption situations

2.5.1   Rice production situation

Thailand mainly produces a long grain type of rice, the so-called *Indica* sub species (*Orysa sativa indica*). Rice production systems are divided into two main agro-ecosystems: irrigated and rain-fed. The irrigated rice production system, rice can be cultivated (at least) two crops in

a year: the major (wet season) crop and the second (dry season) crop. In contrast, under the rain-fed rice production system, rice can be grown only one (the major) crop in a year.

Most of rice of the country is grown under the rain-fed farming system, while only 20 percent of rice area is under irrigated environment (OAE, 2005). In this sub-section, therefore, the rice production situations of the major crop are mainly discussed. It starts with the situation of planted area, inputs use, and then follows by paddy prices at farm-gate, costs of production and profitability, and constraints of rice production.

2.5.1.1 Rice planted area

Rice planted area of the country has shown stable trend over the past ten years (Figure 2.3). In the crop year 2004/05, for example, rice was grown covering 9.2 million hectares. Approximately 55 percent, 20 percent, 17 percent, and 8 percent of the total planted areas were cultivated in northeastern, central, northern, and southern regions, respectively. The main rain-fed paddy areas located in northeastern region, while the main irrigated areas located in the central plain.

According to the definition of OAE, the major rice planting season in each region is in similar period that begin from May to October, except in the south where the major rice planting season starts from June to February of the following year (OAE, 2005).
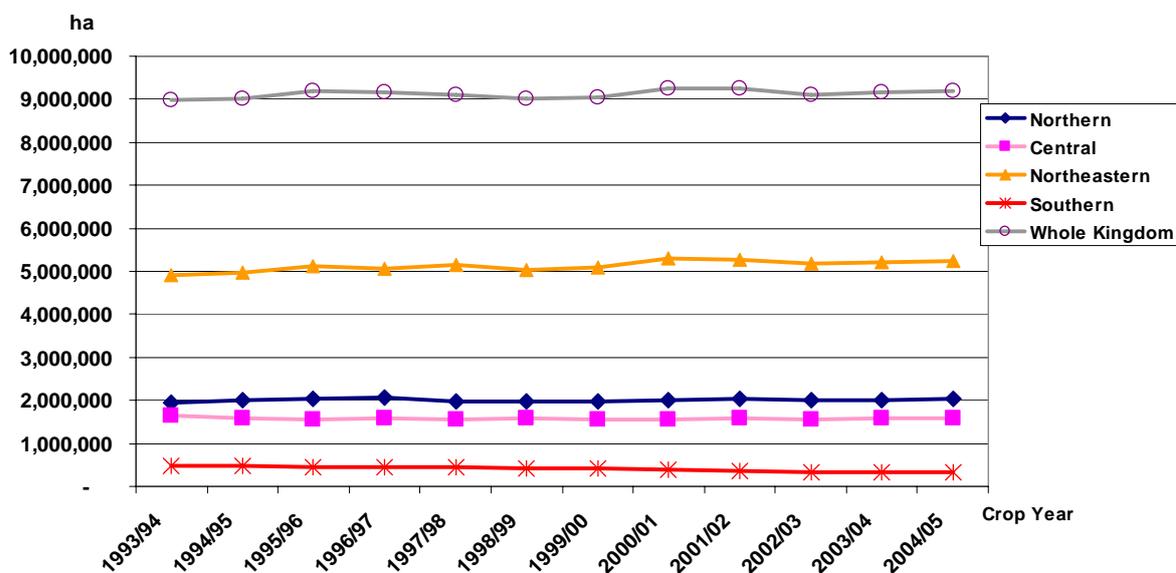
Figure 2.3: Rice planted area by regions in the crop year 1993 - 2004

Source: OAE various issues

2.5.1.2 Total seeds use and average seed rate

As mentioned earlier, Thailand produces the long grain rice therefore long grain seeds are used for rice production. The rice seeds or varieties can be classified by chemical qualifications in grain, or by photoperiod sensitive characteristics. The chemical qualifications in grain can be divided into Non-glutinous rice (amylopectin 60-90% and amylose 10-30%), and Glutinous rice (amylopectin 95% and low amylose). The latter is mainly grown in northeast region. The photoperiod sensitive characteristics can be divided into Non-photoperiod sensitive and Photoperiod sensitive (flowering during long day length). The Non-photoperiod sensitive is mostly the modern or high yield variety, and mainly grown in irrigated areas. The Photoperiod sensitive is mostly the traditional variety, and mainly grown in rain-fed areas.

According to record of the crop year 2002/03, approximately 0.87 million tons of rice seed were used for 9.1 million hectares of rice production areas. In other words, the average seed rate of the country was 95.50 kilograms (kg) per hectare (ha) or 44.29 kg per ton of paddy. At the regional level, the central region showed the highest average seed rate per ha and the highest average seed rate per ton of paddy (167 kg per ha and 53 kg per ton of paddy), followed by the northern, southern, and northeastern, respectively. See the details in Table 2.2.

Table 2.2: Total seeds use and average seed rate in the crop year 2002/03 by regions

Item	North	Northeast	Central	South	Whole Kingdom
Planted area (ha)	2,015,808	5,185,753	1,565,126	338,525	9,105,212
Total seeds use (ton)	250,005	330,141	261,895	27,570	869,612
Average seed rate (kg/ha)	124.00	63.69	167.31	81.44	95.50
Average yield (kg/ha)	2,419	1,756	3,138	2,238	2,156
Average seed rate (kg/ ton of paddy)	51.26	36.27	53.32	36.39	44.29

Source: OAE, 2005

2.5.1.3 Environmental detrimental inputs use

The Thai agricultural sector has been adapted to the green revolution technology, involving the use of chemical fertilizers and pesticides. Since the 1990s, Thailand has become a significant importer of chemical fertilizers and pesticides, with a small local production capacity (FALVEY, 2000). As discussed in the previous section, the excessive application of these chemical inputs can cause negative external effect on the environment, i.e. water and air pollution.

Chemical fertilizers use

Generally, there are two formulas of chemical fertilizers used in rice farming in Thailand; diammonium phosphate (N-P-K ratio: 16-20-0), and urea (46-0-0). Diammonium phosphate is applied for basal purpose whereas urea is applied for dressing purpose.

According to record of the crop year 2002/03, approximately 1.6 million tons of chemical fertilizers were used for rice production. In other words, the average fertilizer rate of the country is 173.94 kg per ha or 80.68 kg per ton of paddy (Table 2.3). At the regional level, the average chemical fertilizer rate per ha is highest in the central region (273 kg per ha), followed by the southern, northern, and northeastern regions, respectively. On the other hand, the southern region showed the highest average chemical fertilizer rate per ton of paddy (88 kg per ton of paddy), followed by the central, northeastern, and north regions, respectively.

Table 2.3: Total chemical fertilizer application and average chemical fertilizer rate for rice production in the crop year 2002/03 by regions

Item	North	Northeast	Central	South	Whole Kingdom
Planted area (ha)	2,015,808	5,185,753	1,565,126	338,525	9,105,212
Total chemical fertilizer Application (ton)	328,095	761,367	427,538	66,813	1,583,813
Average chemical fertilizer rate (kg/ha)	162.75	146.81	273.19	197.38	173.94
Average yield (kg/ha)	2,419	1,756	3,138	2,238	2,156
Average chemical fertilizer rate (kg/ton of paddy)	67.28	83.60	87.06	88.19	80.68

Source: OAE, 2005

As mentioned earlier, chemical fertilizer is one of the important imported agricultural inputs. Thailand imported 3.40 million tons of chemical fertilizers in 2001, and drastically increased to 3.94 million tons in 2004. In other words, the total import quantity has grown at an annual rate of 5 percent from 2001 to 2004. Various formulas of fertilizers are imported (Table 2.4). The import quantity of urea (46-0-0) accounted for the highest proportion (40 percent) of total imported quantity, followed by (0-0-60), (15-15-15), (18-46-0), and (16-20-0) which accounted for 14, 10, 9, and 8 percent of total imported quantity, respectively. The import value was 21 billion THB in 2001, and considerably increased to 34 billion THB in 2004 (OAE, 2005). The increased import value was due to the increased prices per unit of fertilizer. For example, the price per unit of urea (46-0-0) increased by 25 percent from 6,650 THB per ton in 2003 to approximately 8,400 THB per ton in 2004.

If it is assumed that all imported fertilizers are applied for agricultural production and that the proportion of chemical fertilizers used in rice production is 50 percent of the total use in agricultural production, then approximately 1.9 million tons of fertilizers are used in rice farming. Therefore, the value of imported chemical fertilizer for rice production is approximately 17,000 million THB or 355 million euros per annum.

Table 2.4: Import quantity and value of chemical fertilizers by types of fertilizer in 2000-2004

Unit: Quantity (million tons)

Value (million THB)

Fertilizer formula	2001		2002		2003		2004	
	Quant.	Value	Quant.	Value	Quant.	Value	Quant.	Value
46-0-0	1.26	6,899	1.38	7,374	1.62	10,771	1.60	13,493
21-0-0	0.45	1,399	0.29	928	0.31	1,044	0.12	568
18-46-0	0.35	2,721	0.27	2,083	0.31	2,770	0.37	3,983
16-20-0	0.33	1,999	0.32	1,676	0.36	2,051	0.33	2,249
0-0-60	0.31	1,834	0.26	1,525	0.34	1,970	0.54	3,860
15-15-15	0.25	1,891	0.29	2,106	0.35	2,567	0.39	3,428
13-13-21	0.07	649	0.06	468	0.05	433	0.08	762
16-16-8	0.04	229	0.09	519	0.04	248	0.02	138
Others	0.35	3,264	0.49	4,252	0.45	3,893	0.50	5,525
Total	3.40	20,885	3.46	20,931	3.84	25,747	3.94	34,006

Source: OAE, 2005

Chemical pesticide use

Chemical pesticide is also one of the main imported agricultural inputs. In 2001, Thailand imported 37,039 tons of active ingredients of pesticide which increased drastically to 86,905 tons in 2004. It shows that the total import quantity of pesticide have been increased more than two times during the past four years (2001-2004). In addition, herbicide, insecticide, and fungicide account for 64, 14, and 12 percent of total import quantity, respectively. The total import value has increased from 8,761 million THB in 2001 to 11,135 millions in 2004 (Table 2.5).

In rice production process, various types of chemical pesticide are applied but their application rates are not that high compare to other crops production. If it is assumed that all imported pesticides are applied for agricultural production, and that the proportion of chemical pesticide used in rice production is approximately 30 percent of the total import value of pesticide. Therefore, the value of imported chemical pesticide for rice production is approximately 3,300 million THB or 70 million euros per annum.

Table 2.5: Import quantity and value of chemical pesticide in 2000-2004

Unit: Quantity (tons of active ingredient)

Value (million THB)

Pesticide	2001		2002		2003		2004	
	Quant.	Value	Quant.	Value	Quant.	Value	Quant.	Value
Insecticide	8,356	2,553	9,046	2,931	9,790	3,136	16,731	2,835
Fungicide	5,384	1,265	5,681	1,444	6,732	1,678	10,108	1,719
Herbicide	20,957	4,502	22,670	4,349	31,879	6,101	55,649	6,080
others	2,342	441	2,237	392	1,930	426	4,417	502
Total	37,039	8,761	39,634	9,116	50,331	11,341	86,905	11,135

Source: OAE, 2005

2.5.1.4 Total rice production and average yield

In terms of total rice production, Thailand produced 27 million metric tons of paddy rice in 2004 (OAE, 2005) or 18 million metric tons of milled rice[2]. In the crop year 2004/05, the average yield of the country was 2.4 tons per ha and approximately equal to the average yield of southern region. The central region attained the highest average yield at 3.3 tons per ha, while the lowest average yield was in the northeast, i.e., 1.8 tons per ha. The comparison of the average yield by regions in the crop year 1993-2004 is shown in Figure 2.4.
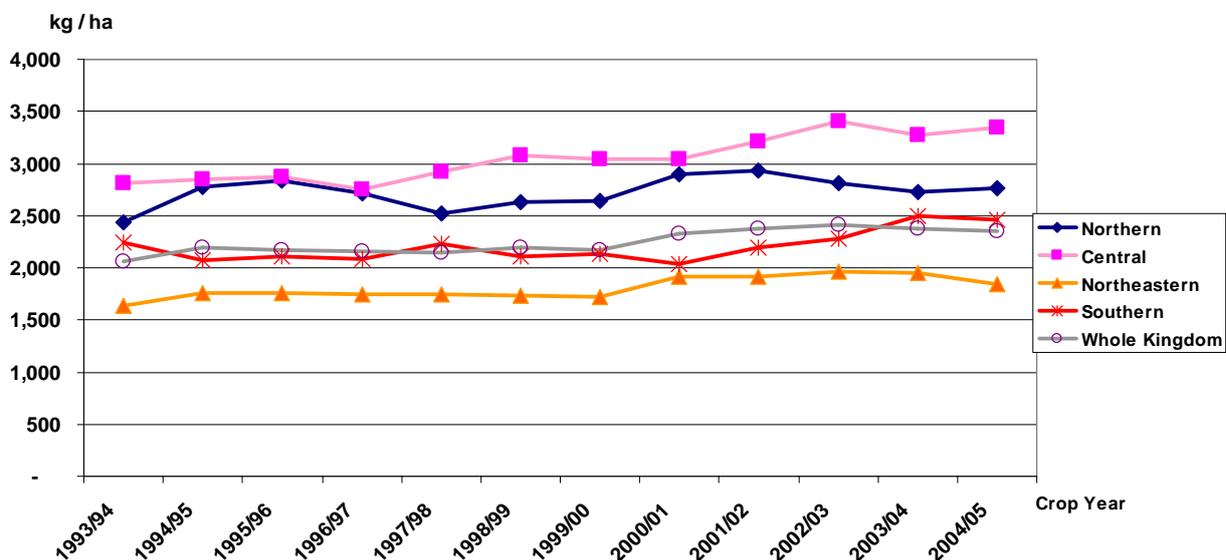
Figure 2.4: Average rice yield by regions in the crop year 1993-2004
Source: OAE various issues

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[2] the conversion rate is approximately 0.66; one ton of paddy rice = 0.66 ton of milled rice

2.5.1.5 *Paddy farm-gate price*

Generally after harvesting paddy rice, the surplus of paddy rice is sold at farm gate to the millers or middlemen. The actual farm-gate price depends upon various factors such as the variety of rice, grain moisture content, location of the rice field. In the crop year 2004/05, the average paddy price at farm-gate of the country was 6,343 THB per ton. Over the past 12 years, the average of paddy farm-gate prices have fluctuated in range of 3,163 THB per ton: the maximum price was 6,973 THB per ton in the crop year 1997/98 and the minimum price was 3,810 THB per ton in the crop year 1994/95 (Figure 2.5).
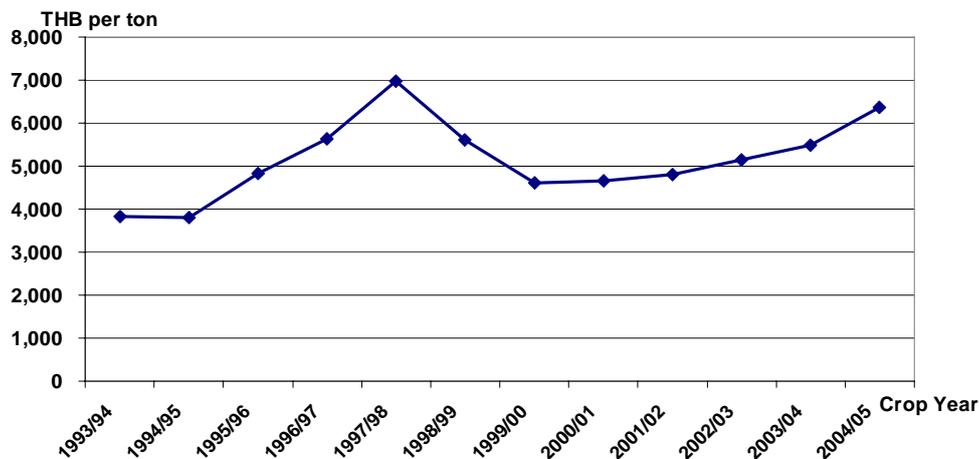
Figure 2.5: Average paddy price at farm-gate in the crop year 1993-2004
Source: OAE various issues

2.5.1.6 *Cost-revenue and profitability of rice production*

According to record of the production of crop year 2003/04, the average total production cost of the country was 11,132 THB per ha which 80 percent was variable costs. The important variable cost items were labor and materials costs which shared 95 percent of total variable costs. At the regional level, the highest cost production of one kilogram paddy was in the northeastern (5.76 THB per kg), whereas the lowest was in the central region (3.93 THB per kg).

The average revenue of rice production of the country was 12,183 THB per ha. At the regional level, the highest revenue of rice production was in the central (17,345 THB per ha), whereas the lowest was in the northeastern region (11,201 THB per ha). Therefore, the average profit of producing one hectare of paddy rice of the country equaled to 1,051 THB which was very low profit. In other words, the rice farmers earned 200 THB per month because they had to work on the fields at least 5 months till harvesting.

At the regional view, moreover, the rice farmers in southern and northeastern regions got lower profit than the average of the country. Particularly in the south, the figures showed that the rice farmers got minus profit (loss) in this crop year. See the details of cost-revenue and profit of each region in Table 2.6.

Table 2.6: Cost-revenue and profitability of major rice production by regions in the crop year 2003/04

unit: THB per ha

Item	Northern	Northeastern	Central	Southern	Whole Kingdom
1. Variable cost	9,919.13	9,257.50	10,988.94	10,933.94	9,760.69
- Labor	7,131.94	7,158.06	7,359.25	8,457.56	7,235.38
- Materials	2,292.44	1,637.69	3,081.56	1,930.94	2,038.44
-Others	494.75	461.75	548.13	545.44	486.88
2. Fixed cost	1,616.63	1,185.19	1,606.56	1,499.06	1,371.44
3. Total cost	11,535.75	10,442.69	12,595.50	12,433.00	11,132.13
Yield (kg per ha)	2,693.75	1,812.50	3,206.25	2,287.50	2,268.75
Paddy cost (THB/kg)	4.28	5.76	3.93	5.44	4.91
Paddy price (THB/kg)	5.63	6.18	5.41	5.42	5.37
Revenue	15,165.81	11,201.25	17,345.81	12,398.25	12,183.19
Net revenue	5,246.69	1,943.75	6,356.88	1,464.31	2,422.50
Profit	3,630.06	758.56	4,750.31	(34.75)	1,051.06

Source: Adapted from PETCHPRASERT, 2005

2.5.1.7 Constraints of rice production

The actual average rice yield of Thailand is 2.6 tons per ha, while the potential yield is 5.3 tons per ha (ROY and MISRA, 2003). This means that the yield gap is approximately twice of the current yield. The deviation of the actual yield from the potential yield may cause by the different of physical, biological and socio-economic factors (CHAUDHARY *et al.*, 2002). The physical constraints are high temperature, drought, flooding, low soil fertility, soil salinity, and acid soil especially in rain-fed rice. The biological factors are rice variety, insect pests, diseases, and weeds. Lastly, the socio-economic factors are related to the farmers' knowledge and management, amounts of input use, cost of production, institutional involves. The concept of yield gap is shown in Figure 2.6.

Yield Gap "0"   For scientists to conceive
and breed potential varieties

Yield Gap "I"   **Non-transferable technology**
Environmental difference

Yield Gap "II"   **BIOLOGICAL**
- **variety**
- **weeds**
- **pests**
- **problem soils**
- **water**
- **soil fertility**

SOCIO-ECONOMIC
- **costs**
- **credit**
- **tradition**
- **knowledge**
- **input**
- **institutions**

| **Theoretical potential** | **Experimental station yield** | **Potential farm yield** | **Actual farm yield** |

Figure 2.6: Concept of rice yield gap
Source: CHAUDHARY *et al.*, 2002

2.5.2   Consumption situation

In this section, rice consumption or demand for rice is considered in terms of paddy rice. The paddy output is mainly used as food grain and some used as seed for the next growing season. Based on the yearly rice supply, Thailand produces rice with excess supply. The total domestic rice consumption of the Thais is approximately 10 million tons per annum or 55 percent of total production: 40 percent as rice and 15 percent for other purposes (PETCHPRASERT, 2005).

In other words, the Thai people consume 150 kg of paddy per capita per year. The consumption amounts have not been drastically changed though rice is a staple food and the population has annually increased. It is probably because rice becomes an inferior good which income elasticity (percentage change in consumption due to one percent change in income) has the negative sign. According to ITO *et al.* (1989), they employed time series data of 1961-1985 to calculate income elasticity of rice consumption in Asian countries. The results of Thailand show that rice is an inferior good which reveal the negative and decreasing income elasticity since 1966. Moreover, the combining effects of income increase, the westernization diets,

urbanization, health concern, people diversify their diet toward more vegetables and fruits as well as more protein-based food (HOSSAIN, 1998). This may reflect in declining trends in per capita rice consumption of the country.

At the regional level, only the southern region shows a deficit in paddy supply. The deficit amounts were approximately 0.4 million tons in 2004 (Table 2.7). This implies that it cannot produce rice to meet the level of food self-sufficiency of the region hence it needs to import rice from other regions.

Table 2.7: Domestic rice consumption and its excess supply in 2004

Region	Population[1]	Paddy rice supply[2]	Per capita paddy production	Rice consumption[3]	Excess paddy supply[4]
	(1,000)	(ton)	(kg)	(ton)	(ton)
North	11,654	7,422,446	637	1,748,100	5,674,346
Northeast	21,629	10,103,979	467	3,244,350	6,859,629
Central	21,810	8,736,295	400	3,271,500	5,464,795
South	8,562	869,075	101	1,284,300	- 415,225
Whole Kingdom	63,655	27,131,795	426	9,548,250	17,583,545

Source: [1]NESDB, 2004 and [2]OAE, 2005
Remark: [3]calculation by assumed average consumption 150 kg paddy per capita per year
[4] calculation based on paddy supply of 2004

2.6 International rice production and trade situations

2.6.1 Production situation

The world rice harvested areas were approximately 150 million hectares and attained 606 million tons of paddy rice in 2004 (FAO, 2006). China is the world's biggest producer who produces nearly 30 percent of the world production. While Thailand ranks in the sixth biggest producer, it produces approximately 4 percent of the world production. The other key producers are India, Indonesia, Bangladesh, Vietnam, and Myanmar. See the production contribution of these key producers in Figure 2.7.

In addition, the world average yield is 4 tons of paddy per ha. China, again, can produce the highest average rice yield which is 6 tons per ha. While Thailand produces the lowest yield among the key producers, its average yield is 2.6 tons of paddy per ha. This is likely because of the different among each country in rice varieties, proportion of irrigated area, and soil quality. For example, hybrid rice varieties, which attain 15-20 percent higher yield than inbred varieties, have been grown in China, Vietnam, and India (HOSSAIN, 1998). Moreover, Thailand has lower

proportion of irrigated area than China and Vietnam. The comparison of the average yield of key producers is presented in Figure 2.8.
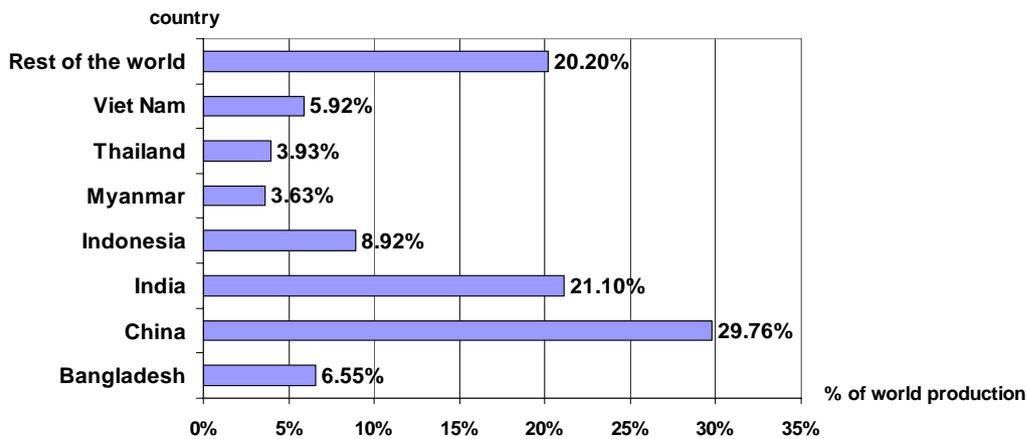
Figure 2.7 The world's key rice producers in 2004
Source: FAO, 2006
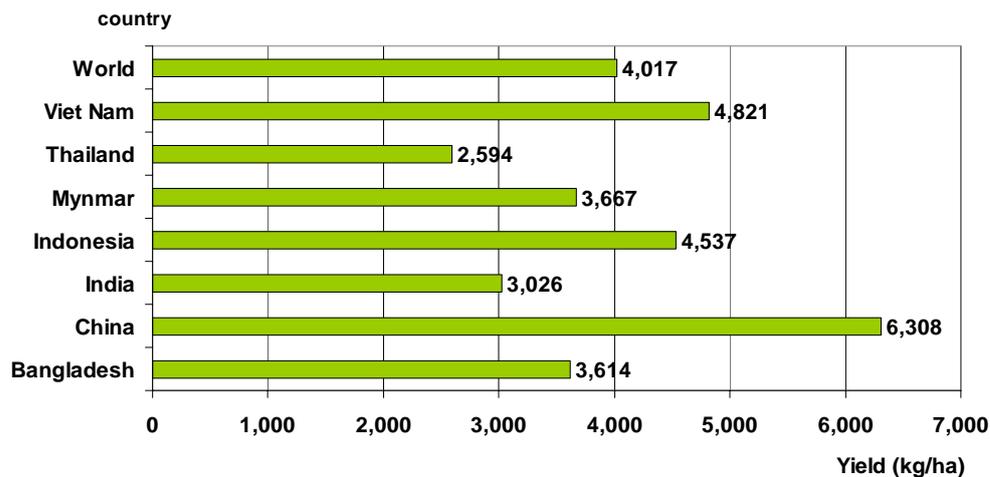
Figure 2.8: Average rice yield of key producers in 2004
Source: FAO, 2006

2.6.2   Consumption situation

According to FAPRI (2007), the world average rice consumption per capita is 63.8 kg in 2006/07. It has slightly declined trend in the prediction of 2007/08 and 2008/09 to 63.4 and 63.0 kg, respectively. However, total world rice consumption in 2006/07 increases by 1.1 percent as world population increases by 1.2 percent.

Focusing on key producing countries, Myanmar's per capita consumption is highest among the world key producers while the lowest is India. See the comparison of per capita consumption of the key producers in Table 2.8.

Table 2.8: Projection of per capita consumption of selected key producing countries

Unit: kilogram

Key Producers	2006/07	2007/08	2008/09
China	89.0	87.7	86.6
India	79.1	78.5	78.5
Indonesia	153.2	152.7	152.4
Bangladesh	203.3	203.3	200.4
Vietnam	217.4	217.6	218.2
Thailand	147.8	148.7	147.9
Myanmar	221.7	224.0	226.1

Source: FAPRI, 2007

2.6.3   Trade situation

The world rice trade quantity accounts for approximately 5 percent of the world production. As mentioned in section 2.5.2, Thailand produces 45 percent excess supply therefore it is the commercially oriented rice exporters. Thailand has been the world's biggest rice exporter for 20 years (DAWE, 2002). In 2004, it exported 42 percent of its production or approximately 10 million tons with $ 2.7 billion export value, and shared approximately 35 percent of the world market quantity (FAO, 2006). While the biggest producer, China, shared only 3 percent of the world export quantity. The other key exporters were India and Vietnam who shared 16 and 14 percent of the world export quantity, respectively (Figure 2.9).

Thailand's main export markets are China, Malaysia, Hong Kong, Singapore, Iran, United States, and African countries such as Nigeria, South Africa, Senegal, Ghana (PETCHPRASERT, 2005). Thailand exports rice to two channels; 1) Business to Business (B to B) and 2) Government to Government (G to G). More than 95 percent of the total export quantity is exported through B to B channel.
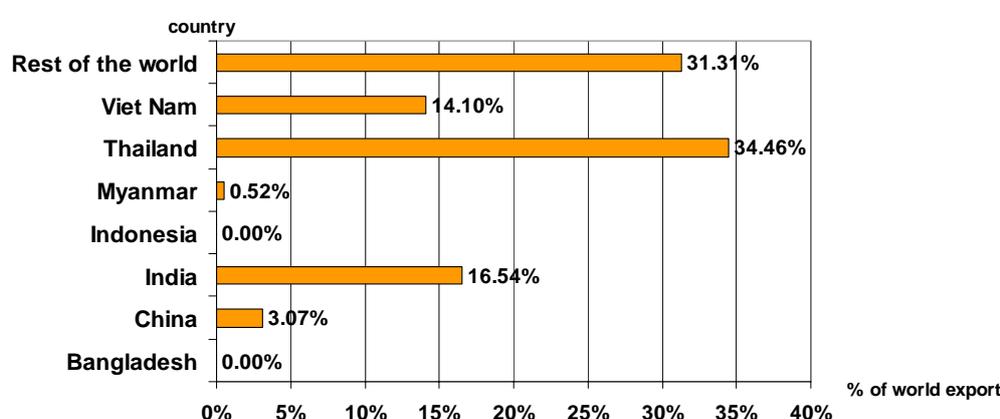
Figure 2.9: The world's key rice exporters in 2004
Source: FAO, 2006

Non-glutinous rice is main type of exported rice of Thailand. It can be categorized into five groups: white rice, Thai Hom Mali (Jasmine) rice, Thai fragrant rice, Parboiled rice, and others. The strengths of Thai rice are its high quality, uniform long-grain white rice, which has a substantial price advantage over the lower quality from other exporting countries. Thai Hom Mali, particularly, is significant in price advantage and high quality.

In 2006, for example, Thailand earned 97.54 billion THB from exporting 7.43 million tons of rice (OAE, 2007). In terms of export value, Thai Hom Mali rice contributed 41 percent of the total rice export value, followed by white rice, parboiled rice, Thai fragrant rice, and others which shared 29, 19, 5, and 6 percent of the total rice export value, respectively (Table 2.9). In terms of export quantity, again, Thai Hom Mali rice contributed 35 percent of the total rice export quantity, followed by white rice, parboiled rice, Thai fragrant rice, and others which shared 33, 22, 5, and 5 percent of the total rice export quantity, respectively.

The popular exported grades of Thai Hom Mali rice are Thai Hom Mali rice 100% grade B (51 percent of Thai Hom Mali rice) and Broken Thai Hom Mali rice A1 (29 percent of Thai Hom Mali rice). While the well-known exported grades of white rice are white rice 100 % grade B (43 percent of white rice) and white rice 5% (31 percent of white rice). More details of rice standards are summarized in Appendix.

Table 2.9: Thai rice export by types of rice in 2006

Types of rice	Percent of total rice export quantity	Percent of total rice export value
White rice	33.40	28.70
Thai Hom Mali rice	34.98	41.38
Thai fragrant rice	4.69	5.23
Parboiled rice	21.69	18.71
Others	5.24	5.99

Source OAE, 2007

In summary, Thailand, India, and Vietnam are the world's largest rice producers and net exporters while Indonesia is the world's largest rice producers as well as net importers. See list of the world's key rice producers, net exporters and net importers in Table 2.10.

Table 2.10: List of the World's key rice producers, net exporters and net importers

Main rice producers[1]	Main net exporters[2]	Main net importers[2]
China	Thailand	Indonesia
India	Vietnam	Nigeria
Indonesia	India	Philippines
Bangladesh	Pakistan	Saudi Arabia
Vietnam	USA	Iraq
Thailand	Egypt	Brazil
Myanmar	Uruguay	Ivory Coast

Source: [1] FAO, 2006 and [2] FAPRI, 2007

2.7 Thai rice strategic plan and rice policy

Thai rice development plan is a part of agricultural development plan. The Thai agricultural development has complied with the national economic and social development plan (NESDP). The NESDP is a five year plan and nowadays it is under the tenth NESDP which is implemented during 2007-2011. In this section, the current Thai rice strategic plan and rice policy are summarized.

2.7.1 Rice strategic plan

Thailand Rice Strategic Plan 2004-2008 has been prepared by Ministry of Agriculture and Cooperatives. The plan can be divided into 5 strategies; 1) Increasing productivity strategy, 2) Value added strategy, 3) Rice and its products marketing strategy, 4) Rice farmers' well being strategy, and 5) Increasing efficiency of management system strategy (MOAC, 2004).

The increasing productivity strategy comprises geographical rice zoning by variety, development of infrastructure and production machinery, research and development of rice variety, distribution of good seed quality, and enhancement of rice farmers' knowledge.

The value added strategy includes research and development of rice products in both food products and non-food products, development of packaging, and implementation of paddy quality standard.

The rice and its products marketing strategy entail domestic and international markets. They include development of marketing network among farmer groups, agricultural cooperatives, government agencies and private sector as well as promoting rice consumption, and research on consumer's behavior of rice consumption.

The rice farmers' well being strategy, which is related to risk management and health concerns, comprises promoting crop insurance, promoting farm record systems, paddy price stabilization, and promoting use of organic or bio pesticides and substances.

Lastly, the increasing efficiency of management system strategy, this strategy is related to institutional structure of government agency and private sector as well as rice farmers. It needs skillful staffs to manage the whole rice aspects.

2.7.2   Rice policy and related institutions

Presently, Thai rice policy allows free trade. The rice export tax and export subsidy have been abolished since 1993 (PETCHPRASERT, 2005). The Thai government concerns very much on rice production and trade, therefore, the restructure of the government agencies in 2006 has been grouping the related-rice production agencies together and establishing as Rice Department under the Ministry of Agriculture and Cooperatives (MOAC). The responsibility of Rice Department (RD) focuses on rice policy and strategy planning, rice research and development, rice seed production, rice production extension services, and rice product development (RD, 2007).

Moreover, recently on July 16, 2007 (DIT, 2007), the Thai rice policy committee (TRPC) composition has been improved. The chairman of the committee has been changed from Deputy-Prime Minister to Prime Minister. The authorities of this committee are to suggest the rice policies and strategies to the Thai Government, to approve rice production and rice trade and marketing plans or projects or measures which are related to the rice farmers, millers, traders, and exporters, as well as to promote and support research on rice production and rice marketing.

The composition of the new structure of TRPC is

Prime Minister	Chairman
Minister of Commerce	Vice-Chairman
Minister of Agriculture and Cooperatives	Vice-Chairman
Minister of Finance	Vice-Chairman
Permanent Secretary of Ministry of Agriculture and Cooperatives	Member
Permanent Secretary of Ministry of Interior	Member
Permanent Secretary of Ministry of Finance	Member
Permanent Secretary of Ministry of Industry	Member
Permanent Secretary of Prime Minister Office	Member
Secretary General of Office of NESDB	Member
Director General of Bureau of Budget	Member
Director General of Department of Comptroller General	Member
Representative of National Economic and Social Advisory Council	Member

Representative of Thailand Research Fund	Member
Mr. Pramote Vanichanoon	Member
Mr. Somporn Isvilanonda	Member
Mr. Apichart Pongsrihadulchai	Member
Permanent Secretary of Ministry of Commerce	Member and Secretary
Director General of Department of Internal Trade	Member and Assistant Secretary
Director General of Rice Department	Member and Assistant Secretary

Paddy mortgage project

Currently, paddy mortgage project is one of the important rice policies and approved by the TRPC. The paddy mortgage project is a domestic paddy price support project which implemented in order to stabilize paddy market prices during harvesting period. The project is operated by the Bank for Agriculture and Agricultural Co-operatives (BAAC), in collaboration with the Public Warehouse Organization (PWO). The project participants include rice farmers, farmer groups, rice millers of agricultural cooperatives, and private rice millers. The rice farmers, who participate in this project, have to be the BAAC's customers, have the approved document from MOAC, have their own barns or storage spaces, and join the project in their province. The millers, who participate in this project, have to have potential to mill the mortgaged paddy, have spaces and machine capacities for drying paddy, and have enough spaces for paddy storage (DIT, 2006).

There are two alternatives of mortgage: 1) BAAC as a mortgagee who deal with mortgaged paddy contract from the farmers and farmer organizations by keeping mortgaged paddy at their barns and 2) PWO as a mortgagee who deal with warranty of mortgaged paddy and/or mortgaged milled rice from farmer groups, cooperatives rice millers, private rice millers by keeping mortgaged paddy at their places before handing to the public warehouse.

The BAAC is in charge of issuing trade credits for farmers, according to each rice mortgage program. The participating farmers can receive loan at preferential credit rates for up to 90 percent of the value of the mortgaged paddy at the official support price. In addition, barn rental fees of 20 THB per ton paddy are paid for the farmers.

The official support or mortgaged prices are varied by types of paddy, grain moisture content, and grain quality and approved by TRPC crop by crop basis. The purchase back period for farmer mortgage contract is 4 months, while the mortgage warranty for the millers is 3 months. The types of paddy and responsible institutions under paddy mortgage project of the major crop year 2005/06 are summarized in Table 2.11.

In summary, the main institutions which related to the Thai rice policy are presented in Table 2.12.

Table 2.11: Types of paddy and responsible institution under paddy mortgage project of the major crop 2005/06

Types of paddy	Responsible institutes	Participants	Purchase back period
Glutinous	BAAC	farmers and farmer organizations by keeping mortgaged paddy at their barns	4 months
Non-Glutinous	BAAC	farmers and farmer organizations by keeping mortgaged paddy at their barns	4 months
	PWO	farmer groups, cooperatives rice millers, private rice millers by keeping mortgaged paddy and/or mortgaged milled rice at their places before handing to the public warehouses	3 months

Source: DIT, 2006

Table 2.12: The main institutions related to the Thai rice policy

Main institutions	Responsible functions
- The National Rice Policy Committee	Production and marketing
- Rice Department, Ministry of Agriculture and Cooperatives	Rice production, research and extension
- Department of Internal Trade Ministry of Commerce	Domestic marketing and standards
- Department of Foreign Trade	International marketing and standards
- Department of Export Promotion	
- Department of Trade Negotiation Ministry of Commerce	
- The Agricultural Futures Exchange of Thailand (AFET)	Marketing
- Bank of Agriculture and Agricultural Cooperatives (BAAC)	Finance and credit
- Ministry of Industry	Rice processing

Source: own summarized

2.8   Concluding Remarks

Rice farming and rice farmers play an important role in the Thai economy. Thailand is one of the world's largest producers and exporters of rice. Nevertheless, Thailand has to import chemical inputs for using in rice farming. The value of exported rice is approximately 100 billion THB per annum, while the value of imported chemical fertilizers and pesticides is approximately 20 billion THB per annum.

3   Literature Review on Production and Efficiency Analysis

In this chapter, the literature on agricultural production and efficiency are surveyed. The following sections give information on agricultural production systems and its outputs, and then followed by the literature surveys of empirical study on efficiency measurement of agricultural production, environmental efficiency measurement, and efficiency use of nitrogen fertilizer in rice farming systems. The last section ends with review of policy instruments for internalizing the negative externality from agriculture.

3.1.   Agricultural production system and its outputs

The agricultural production is commonly related to two types of production technology: multiple inputs-single output, and/or multiple inputs-multiple outputs. As mentioned in multi-functionality of agriculture, agricultural production process can create economic desirable output(s) and undesirable output(s) or negative environmental effects, i.e. waste and/or pollution. The agricultural pollution is known as non-point source pollution which is difficult to measure the effects on environment. However, these undesirable outputs become part of the environmental problems and relate to the climate change and global warming issues. In this section presents brief of agricultural production concept and some case studies of livestock production and crop production and their outputs.

3.1.1   Production technology sets of agricultural production

In standard microeconomic theory, concept of production function is used to describe the technology or technical relationship between the input(s) and output(s) of production process of the firms or decision making units (DMUs). The production technology, therefore, is important and focused for production analysis.

Let assume that the producers or farmers use a nonnegative vector of inputs, denoted $x = (x_1,..., x_N) \in R_+^N$, to produce a nonnegative vector of outputs, denoted $y = (y_1,..., y_M) \in R_+^M$ then the technology set (T) can be defined as (1).

$$T = \left\{ (x, y) : x \ can \ produce \ y \right\} \qquad (1)$$

In words, the technology set composes of pairs, (x,y), such that x can produce y or y can be producible from x. In addition, the technology set is also known as production possibility set which explains technical input-output relationship. In agricultural production is commonly related to two types of production technology; multiple inputs - single output, and/or multiple inputs - multiple outputs.

The input space or input requirement set, L(y), represents the set of all input vectors that can produce the given output vector *y* (at least scalar output). The input requirement set which explains technical input-input relationship can be defined as (2).

$$L(y) = \left\{ x : x \ can \ produce \ y \right\} \quad = \left\{ x : (x, y) \in T \right\} \tag{2}$$

On the other hand, the output space or output set, P(x), represents the set of all output vectors that can be produced by using the given input vector *x*. The output set which describes technical output-output relationship can be defined as (3).

$$P(x) = \left\{ y : x \ can \ produce \ y \right\} \quad = \left\{ y : (x, y) \in T \right\} \tag{3}$$

In (1) the technology set (T) describes the relationship between economic outputs (desirable outputs) and conventional inputs without concerning the external effect from the production processes. In agricultural production, inputs and outputs can specifically define. Inputs can be separated as conventional inputs and environmental detrimental inputs or polluting inputs. The environmental detrimental inputs are the inputs that excessive usages create the negative external effects on the environment. While on the output side, outputs can be defined as desirable outputs and pollutions.

Let consider that the conventional inputs (x) can produce desirable outputs (y) and undesirable outputs (u) then the technology sets of (1) can be rewritten as (4)

$$T = \left\{ (x, y, u) : x \ can \ produce \ y \ and \ u \right\} \tag{4}$$

Alternatively, let consider that the desirable outputs (y) can be produced by conventional inputs (x) and polluting inputs (s), the technology sets of (1) can be rewritten as (5)

$$T = \left\{ (x, s, y) : x \ and \ s \ can \ produce \ y \right\} \tag{5}$$

Then let consider that the conventional inputs (x) and polluting inputs (s) can produce desirable outputs (y) and undesirable outputs (u), the technology sets of (1) can be rewritten as (6)

$$T = \left\{ (x, s, y, u) : x \ and \ s \ can \ produce \ y \ and \ u \right\} \tag{6}$$

Production technology sets properties

The production technology sets are assumed to satisfy the following properties:

- Closed and nonempty

The production technology set is closed and nonempty for all *y*>0. The closed set assumption assures the technically efficient input and output vectors, and guarantees no holes in the

production boundary. The nonempty implies that it is always possible to produce any positive output (CHAMBERS, 1988; KUMBHAKAR and LOVELL, 2003).

- No free lunch

This property means that any nonnegative input vector can produce at least zero output. In other words, it is possible using inputs to produce nothing, but it is not possible to produce something from nothing. Then the technology set is as (7):

$$T : (x,0) \in T \ and \ (0, y) \in T \ then \ y = 0 \tag{7}$$

- Monotonicity

The monotonicity assumption is $if \ x' \geq x, then \ f(x') \geq f(x) \ or \ if \ x' > x, then \ f(x') > f(x)$. This implies that the additional units of any inputs cannot decrease the level of output. In the case of a differentiable production function, this is equivalent to explain that all marginal products are positive (CHAMBERS, 1988). In addition, the monotonicity property can guarantee the feasibility of radial expansions of feasible inputs and radial contractions of feasible outputs (KUMBHAKAR and LOVELL, 2003).

- Free disposal

The free disposability property holds if the absorption of any additional amounts of inputs without any reduction in output is always possible. The interpretation is that the additional amounts of inputs (or outputs) can be disposed of or eliminate at no cost (MAS-COLELL *et al.*, 1995).

The free disposability means that $if (x, y) \in T \ and \ x' \geq x, y' \leq y \ then \ also \ (x', y') \in T$. In words, given inputs *x*, it is possible to decrease the production of any output by any desired quantity, i.e. eliminate any excess output free of charge. In contrast, it is possible to produce a given output *y* with more input resources than is totally required (KUOSMANEN and KORTELAINEN, 2004). Moreover, free disposability can be seen as a first-order curvature condition for the efficient frontier: the maximum output does not decrease if input usage increases (i.e. the marginal product of every input is non-negative).

- Convexity

The convexity means that $if \ y, y' \in T \ and \ \alpha \in [0,1] \ then \ \alpha y + (1 - \alpha) y' \in T$ (MAS-COLELL *et al.*, 1995). Alternatively, the convexity can be seen as the second-order condition: the maximum output increases at non-increasing rate as the inputs increases (i.e., the marginal product of every input is non-increasing) (KUOSMANEN and KORTELAINEN, 2004).

3.1.2   A case study of livestock production

The case studies of dairy and pig production are discussed. The undesirable outputs from livestock production systems are induced by inputs use especially the surplus or excessive use of nutrients. REINHARD *et al.* (2000) discussed that the environmental effects from dairy production caused by nitrogen and phosphorus surplus and fossil energy use. The excessive use of nitrogen and phosphorus, in form of manure and chemical fertilizer applications, create nitrogen and phosphorus pollutions. The nitrogen pollution spreads as nitrate contamination of groundwater and drinking water, ammonia gas emission which causes acid rain. The phosphorus pollution induces eutrophication or surface water which endangers fish life and plant. Lastly, the fossil energy use crates the carbon dioxide gas emission which is also part of global warming problem.

In addition, ASMILD and HOUGAARD (2006) presented that the main environmental problem from pig production farms create undesirable outputs from the surplus use of nutrients as well. These surpluses are nitrate leaching, nitrogen gas emission which caused by the by product of pig production (manure) and chemical fertilizer applications.

However, these two papers do not state on air pollution problems from the livestock production process. Due to the production process, odor and noise which are air pollution may be counted as other undesirable outputs.

3.1.3   A case study of crop production

The case studies of rice and sugar beet production are discussed. The undesirable outputs from crop production systems are also induced by inputs use especially pesticide application and the excessive use of nutrients from chemical fertilizer. As mentioned earlier in section 2.4.3, rice production, for example, is one of the agricultural activities which concerning to produce the greenhouse gases during the production process. In addition, the excessive use of inorganic fertilizers creates substantial negative externalities especially the excessive nitrogen (N) fertilizer transforms into nitrogen gases which loss to the atmosphere and nitrate form which leaches to ground and surface water.

In sugar beet production, DE KOEIJER *et al.* (2002) presented that pesticide application and nitrogen surplus lead to the effects on soil microorganism, aquatic organism, and leaching to groundwater which are undesirable outputs from sugar beet production.

The summary of desirable and undesirable outputs from livestock production and crop production are presented in Table 3.1. It shows that nitrate leaching and greenhouse gases emission are the common undesirable outputs from the agricultural production process.

Table 3.1: Desirable and undesirable outputs from livestock and crop productions

Agricultural production	Economic desirable output	Undesirable output
Dairy production[1]	Raw milk	- Nitrate contamination
		- Ammonia emission
		- Eutrophication of surface water
		- Carbon dioxide emission
Pig/Swine production[2]	Live pigs	- Nitrate leaching
		- Nitrogen gas emission
		- Phosphorus surplus
Rice production[3]	Paddy rice	- Greenhouse gases emission: methane, nitrogen
		- Nitrate leaching
Sugar beet production[4]	Sugar beet	- Pesticide effects on soil microorganism and aquatic organism
		- Nitrate leaching

Source: [1] REINHARD *et al.*, 2000 [2] ASMILD and HOUGAARD, 2006
[3] KYUMA, 2004   [4] DE KOEIJER *et al.*, 2002

3.2 Empirical studies on efficiency measurement of agricultural production

In this section, the literature on efficiency measurement of agricultural production are surveyed and reviewed. They are grouped into three categories: livestock production, crop production, and rice production.

3.2.1 Livestock production

The literature review of empirical studies on assessing efficiency of livestock production over the past ten years has been done. It includes pig and dairy farms as well as ratite production. However, environmental efficiency measurement of livestock production was found in pig and dairy farms. The summarized of the empirical studies on livestock production are shown in Table 3.2.

Table 3.2: Empirical studies on efficiency measurement of livestock production

Author(s)	Country: production	Efficiency approach	Data set	Main results
ASMILD and HOUGAARD (2006)	Denmark: swine	DEA: EE, ENE	Cross-section in 1998, 290 farms	$EE_{slaughter}= 0.81$ $EE_{piglet}= 0.82$ $EE_{both}= 0.87$ $ENE_{slaughter}= 0.44$ $ENE_{piglet}= 0.51$ $ENE_{both}= 0.66$
REINHARD *et al.* (2000)	The Netherlands: dairy	Comparison of SFA and DEA: TE, ENE	Panel data in 1991-94, 613 farms	$TE_{SFA}= 0.89$ $TE_{O(VRS)}= 0.78$ $TE_{I(VRS)}= 0.81$ $ENE_{SFA}= 0.80$ $ENE_{I(VRS)} = 0.52$
REINHARD *et al.* (1999)	The Netherlands: dairy	SFA: TE, ENE	Panel data in 1991-94, 613 farms	$TE = 0.89$ $ENE = 0.44$
SHARMA *et al.* (1999)	USA: swine	Comparison of SFA and two stage DEA: TE	Cross-section in 1994, 53 farms	$TE_{SFA}= 0.76$ $TE_{(CRS)}= 0.64$ $TE_{I(VRS)}= 0.76$ $EE_{SFA}= 0.57$ $EE_{(CRS)}= 0.46$ $EE_{I(VRS)}= 0.60$
GILLESPIE *et al.* (1997)	USA: ratite	two stage DEA: TE	Cross-section in 1996, 57 farms	$TE_{ostrich}= 0.52$ $TE_{emu}= 0.82$

Remark: DEA = data envelopment analysis   SFA = Stochastic frontier analysis
          TE = technical efficiency, I = input oriented, O = output oriented
          EE = economic efficiency   ENE = environmental efficiency
          VRS = variable returns to scale   CRS = constant returns to scale

ASMILD and HOUGAARD (2006) assessed the efficiency of pig farms in Denmark using output-oriented data envelopment analysis (DEA) approach under variable returns to scale (VRS) assumption. The economic and environmental efficiency were analyzed in order to improve potentials of individual farm and society. Cross-section data of 290 pig farms divided into slaughter pig farms, piglet farms, and both pig and piglet farms were used for analysis. The analysis based on per farm data of outputs: gross return, nutrients removal with crops, and

combination of inputs: labor, nutrients from manure, chemical fertilizer costs, energy costs, contract operation costs, capital, and other variable costs. Five different models were estimated. The main results reveal that the average levels of direct economic efficiency of three types of farm are 0.81, 0.82, and 0.87, respectively. Moreover, the average levels of direct environmental efficiency of three types of farm are 0.44, 0.51, and 0.66, respectively.

REINHARD *et al.* (2000) measured the technical and environmental efficiency of dairy farms in the Netherlands using stochastic frontier analysis (SFA) and DEA approaches. Four years panel data of 613 farms were used and translog stochastic production function was assumed for SFA. The analysis based on per farm data of output: gross income, and combination of inputs: conventional inputs (labor, capital, and variable costs), and environmental detrimental inputs (nitrogen surplus, phosphorus surplus, and energy). The main results show that the average levels of technical (SFA), output-oriented technical (DEA/VRS), input-oriented technical (DEA/VRS) efficiency are 0.89, 0.78, and 0.81, respectively. In addition, the average levels of environmental (SFA) and input-oriented environmental (DEA/VRS) efficiency are 0.80, and 0.52, respectively.

REINHARD *et al.* (1999) measured the technical and environmental efficiency of dairy farms in the Netherlands using SFA approach. The same data set as REINHARD *et al.* (2000) (four years panel data of 613 farms) were used and translog stochastic production function was assumed. The analysis based on per farm data of output: gross income, and combination of inputs: conventional inputs (labor, capital, and variable costs), and one environmental detrimental input (nitrogen surplus). The main results show that average levels of technical and environmental efficiency are 0.89, and 0.44, respectively.

SHARMA *et al.* (1999) investigated the technical and economic efficiency of swine production in USA using SFA and input-oriented DEA approach. Cross-section data of 53 pig farms were used. Cobb-Douglas stochastic production function and dual cost function were assumed for SFA technical and economic efficiency analysis. The analysis based on per farm data of live pigs produced, and combination of inputs: feed, labor, fixed costs, others as well as input prices. The hypothesized farm-specific variables which affecting on efficiency were farm size, education (dummy), experience, market hogs (dummy), garbage feeder (dummy), and location (dummy). The main results show that the average levels of technical (SFA), technical (constant returns to scale, CRS), technical (VRS) efficiency are 0.76, 0.64, and 0.76, respectively. In addition, the average levels of economic (SFA), economic (CRS), and economic (VRS) efficiency are 0.57, 0.46, and 0.60, respectively. The significant positive determinants of technical and economic efficiency are farm size, market hogs, and experience, while significant negative determinant of technical and economic efficiency are education.

GILLESPIE *et al.* (1997) examined the technical efficiency of ratite industry in the USA using two stage DEA approach. Cross-section data of 57 farms which divided into ostrich and emu farms were used for analysis. The analysis based on per farm data of outputs: incubated emu and ostrich eggs as well as three-month old of emus and ostriches, and combination of inputs: labor, capital, land and breeding stocks. The hypothesized farm-specific variables which affecting on efficiency were years in business, labor used per breeder, ostrich production (dummy), number of ratite breeder hens, use of colony breeding, number of other livestock, percentage of ratite income, utilization of incubation facilities. The results show that average levels of technical efficiency of ostrich and emu are 0.52, and 0.82, respectively. The significant positive determinants of technical efficiency are number of other livestock, and utilization of incubation facilities, whereas the significant negative determinant of technical efficiency is ostrich production.

3.2.2 Crop production

The literature review of empirical studies on assessing efficiency of crop production over the past ten years has been done. They comprise annual, biannual, and perennial crop productions. The environmental efficiency measurement was found in sugar beet and cotton production. The summarized of the empirical studies on crop production are shown in Table 3.3.

BOZOGLU and CEYHAN (2007) assessed the technical efficiency of vegetable production in Turkey using SFA approach. Cross-section data of 275 vegetable farms were used and Cobb-Douglas stochastic production function was assumed for the analysis. The analysis based on per farm data of vegetable output value and combination of inputs: land, labor, capital (aggregate cash expenditures of fertilizer, pesticide, plowing, and harvesting). The hypothesized determinants of technical efficiency included age of farmer, experience, schooling, family size, off-farm income (dummy), credit use (dummy), farm size (dummy), women's participation, information score. The results show that the average level of technical efficiency of vegetable farm is 0.82. The significant positive determinant of technical inefficiency (negative impact on technical inefficiency) is age of farmer, while experience, schooling, credit use, women's participation, and information score explain the significant negative determinant of technical inefficiency.

Table 3.3: Empirical studies on efficiency measurement of crop production

Author(s)	Country: production	Efficiency approach	Data set	Main results
BOZOGLU and CEYHAN (2007)	Turkey: vegetable	SFA: TE	Cross-section in 2002, 75 farms	TE = 0.82
ALENE *et al.* (2006)	Ethiopia: maize-coffee	Comparison of two stage SFA and DEA: TE	Cross-section in 1999, 124 farms	$TE_{SFA}= 0.72$ $TE_{O(VRS)}= 0.93$ $TE_{PDF}= 0.91$
WOSSINK and DENAUX (2006)	USA: cotton	Two stage DEA: TE, ENE, CE	Cross-section in 2000, 275 farms	All farms $TE_{I(VRS)}= 0.30$ $ENE_{I(VRS)}= 0.26$ CE = 0.34
BINAM *et al.* (2003)	Cote d'Ivorie: coffee	Two stage DEA: TE	Cross-section in 1998, 81 farms	$TE_{I(CRS)}= 0.36$ $TE_{I(VRS)}= 0.47$
IRAIZOZ *et al.* (2003)	Spain: tomato and asparagus	Comparison of two stage SFA and DEA: TE	Cross-section in 1994, 46 farms	Tomato $TE_{SFA}= 0.89$ $TE_{(CRS)}= 0.81$ $TE_{I(VRS)}= 0.89$ Asparagus $TE_{SFA}= 0.80$ $TE_{(CRS)}= 0.75$ $TE_{I(VRS)}= 0.80$
DE KOEIJER *et al.* (2002)	Netherlands: sugar beet	DEA: TE, ENE	Panel data in 1994-97, 121 farms	$TE_{(CRS)}= 0.50$ $TE_{I(VRS)}= 0.54$ $TE_{O(VRS)}= 0.85$ $ENE_{(CRS)}= 0.40$
SHAFIG and REHMAN (2000)	Pakistan: cotton	DEA: TE	Cross-section, 120 farms	10 farms on $TE_{(CRS)}$ frontier 30 farms on $TE_{(VRS)}$ frontier
PIOT-LEPETIT and VERMERSCH (1997)	France: cereal	DEA	Cross-section in 1990, 188 farms	$TE_{I(radial)}= 0.88$ $TE_{I(non-radial)}= 0.82$

Remark: DEA = data envelopment analysis   SFA = Stochastic frontier analysis
      TE = technical efficiency, I = input oriented, O = output oriented
      EE = economic efficiency   ENE = environmental efficiency   CE = cost efficiency
      VRS = variable returns to scale   CRS = constant returns to scale

ALENE *et al.* (2006) investigated the technical efficiency of maize-coffee intercropping system in Ethiopia using the SFA, DEA, and PDF (parametric multi-output distance function) approaches. Cross-section data of 124 farms were used and translog stochastic production function was assumed for SFA analysis. The analysis based on per farm data of maize-coffee output (revenue) and combination of inputs: land, labor, fertilizer, and materials. The main results show that the average levels of technical (SFA), output-oriented technical (VRS), and output distance efficiency are 0.72, 0.93, and 0.91, respectively. They conclude that DEA and PDF approaches reveal the similar results. However, in this study does not consider age of coffee tree in the model.

WOSSINK and DENAUX (2006) examined the efficiency of pesticide use in cotton production using the two stage input-oriented DEA approach. Cross-section data of 275 cotton farms were divided into transgenic and conventional cotton production and used for technical, environmental and cost efficiency analysis. The analysis based on per hectare data of cotton output and combination of inputs (cost unit): insecticide, herbicide, fungicide, growth regulators, and defoliants. The hypothesized determinants of efficiency included farmer characteristics (cotton farming experience, experience in growing transgenic cotton, schooling (dummy), business structure (dummy), farm characteristics (field size, rotation intensity), field characteristics (management plan, previous crop, harvesting timing), production environment (yield expectation, rainfall), and seed types (dummy). The results show that the average levels of all farms' technical (VRS), environmental and cost efficiency are 0.30, 0.26, and 0.34, respectively. The significant positive determinant of technical and cost efficiency is schooling, and of environmental efficiency is seed types. The significant negative determinant of technical efficiency is rainfall.

BINAM *et al.* (2003) examined the technical efficiency of coffee farms in Cote d'Ivoire using two stage input-oriented DEA approach. Cross-section data of 81 farms were used for data analysis. The analysis based on per farm data of coffee output and combination of inputs: land, age of coffee tree, labor, tools (cost), fertilizer (cost). The hypothesized determinants of efficiency included age of farmer (dummy), land tenure (dummy), education (dummy), family size, farming practice (dummy), farm contract (dummy), residence status of farmer (dummy), accessibility to credit (dummy), membership to farmers' club (dummy), and distance from house to farm. The main results show that the average levels of technical (CRS) and technical (VRS) efficiency are 0.36, and 0.47, respectively. The significant positive determinants of technical efficiency are age of farmer and residence status of farmer, while the significant negative determinants of technical efficiency are membership to farmers' club and family size.

IRAIZOZ *et al.* (2003) investigated the technical efficiency of tomato and asparagus production in Spain using SFA and input-oriented DEA approaches. Cross-section data of 46 farms were used and Cobb-Douglas stochastic production function was assumed for SFA analysis. The analysis based on per farm data of tomato and asparagus outputs and combination of inputs: land, labor, capital, and cultivation expenses (sum of seed, fertilizer, others expenses). The main results show that the average levels of technical (SFA), technical (CRS), and technical (VRS) efficiency of tomato production are 0.89, 0.81, and 0.89, respectively. In addition, the average levels of technical (SFA), technical (CRS), and technical (VRS) efficiency of asparagus production are 0.80, 0.75, and 0.80, respectively. They conclude that technical (SFA), technical (VRS) calculation reveal the similar results.

DE KOEIJER *et al.* (2002) measured the efficiency of sugar beet farms in the Netherlands using DEA approach. Four years panel data of 121 farms were used to assess technical and environmental efficiency. The technical efficiency analysis based on per farm data, while environmental efficiency analysis based on per hectare data of sugar beet output and combination of inputs: nitrogen fertilizer and herbicide. The main results show that the average levels of technical (CRS), input-oriented technical (VRS), output-oriented technical (VRS), and environmental efficiency are 0.50, 0.54, 0.85 and 0.40, respectively.

SHAFIG and REHMAN (2000) assessed the technical efficiency of cotton under cotton-wheat production system in Pakistan using the input-oriented DEA approach. Cross-section data of 120 farms were used for analysis. The analysis based on per hectare data of cotton output and combination of inputs: irrigation, nitrogen fertilizer, phosphorus fertilizer, labor, tractor, and pesticide costs. The main results show that number of farms which lie on the technical frontier under CRS and VRS assumptions are 10 and 30 farms, respectively.

PIOT-LEPETIT and VERMERSCH (1997) investigated the technical efficiency of cereal production in France using input-oriented DEA approach. This technical efficiency analysis aimed to the reduction of use of pesticide and fertilizer inputs, which are associated with the environmental effects. Cross-section data of 188 farms were used for analysis. The analysis based on per farm data of cereal (wheat and corn) and other output values, and combination of inputs: quasi-fixed input (land, labor) and variable input costs (equipment, fertilizers, pesticides, seeds, others). Radial and non-radial technical efficiency were estimated. The main results of all variable inputs show that the average levels of radial and non-radial technical efficiency are 0.88 and 0.82, respectively.

3.2.3 Rice production

The literature review of empirical studies on assessing efficiency of rice production over the past ten years has been done. Most of the studies were done in Asian countries where are the main rice planted area of the world, and some in African countries.

The summarized of the empirical studies on rice production are shown in Table 3.4. These studies were focusing only on technical and/or economic efficiency, which did not concern the undesirable outputs.

DHUNGANA *et al.* (2004) investigated the efficiency of rice farms in Nepal. Cross-section data of 76 rice farms in irrigated area were used and applied two stage input-oriented DEA approach to assess the technical and economic (cost) efficiency. The technical efficiency analysis based on per farm data of rice output and combination of inputs: land, seed, fertilizer (cost unit), human labor, machine labor (cost unit), others (cost unit). The hypothesized farm-specific variables which affecting on efficiency were age, age^2, education, risk attitude, share of labor from family sources, gender. The results show that the average levels of technical efficiency (CRS), technical efficiency (VRS), and cost efficiency are 0.76, 0.82 and 0.66, respectively. Moreover, Tobit regression results show that age of the household head has a significant negative impact, while education of the household head has a significant positive impact on technical and economic (cost) efficiency.

KRASACHAT (2003) assessed the technical efficiency of rice farms in the northeast provinces of Thailand. Cross-section data of 74 rice farms were used and applied two stage input-oriented DEA approach to analyze the efficiency. The analysis based on per farm data of rice output and combination of inputs: land, fertilizer, human labor, machine labor, others (cost unit). The hypothesized farm-specific variables which affecting on efficiency were farm sizes, agro-ecosystem (dummy), and province (dummy). The results show that the average levels of technical efficiency (CRS) and technical efficiency (VRS) are 0.71 and 0.74, respectively. Moreover, Tobit regression results show that all hypothesized farm-specific variables have no statistically significant effect on technical efficiency.

Table 3.4: Empirical studies on efficiency measurement of rice production

Author(s)	Country	Efficiency approach	Data set	Main results
DHUNGANA *et al.* (2004)	Nepal	two stage DEA: TE, EE (CE)	Cross-section in 1999, 76 farms	$TE_I(CRS) = 0.76$ $TE_I(VRS) = 0.82$ $CE (CRS) = 0.66$
KRASACHAT (2003)	Thailand	two stage DEA: TE	Cross-section in 1999, 74 farms	$TE_I(CRS) = 0.71$ $TE_I(VRS) = 0.74$
HUANG *et al.* (2002)	Taiwan	SFA: EE (CE)	Cross-section in 1998, 400 farms	$CE_{Hired\text{-}Plowing} = 0.90$ $CE_{Self\text{-}Plowing} = 0.81$
RAHMAN, 2002	Bangladesh	Two stage SFA: TE, EE (CE)	Cross-section in 1998, 530 farms	$TE = 0.84$ $CE = 0.75$
WADUD and WHITE (2000)	Bangladesh	Comparison of two stage SFA and DEA: TE	Cross-section in 1997, 150 farms	$TE (SFA) = 0.79$ $TE_O (DEA/CRS) = 0.79$ $TE_O (DEA/VRS) = 0.86$
ABDULAI and HUFFMAN (2000)	Ghana	two stage SFA: EE (PE)	Cross-section in 1992, 256 farms	$PE = 0.73$
AUDIBERT (1997)	Mali	SFA: TE	Panel data in 1989-90, 844 farms	$TE\ 1989 = 0.68$ $TE\ 1990 = 0.71$
ALI and FLINN (1989)	Pakistan	SFA: EE (PE)	Cross-section in 1982, 120 farms	$PE = 0.72$

Remark: DEA = data envelopment analysis   SFA = Stochastic frontier analysis
      TE = technical efficiency, I = input oriented, O = output oriented
      EE = economic efficiency   PE = profit efficiency   CE = cost efficiency
      VRS = variable returns to scale   CRS = constant returns to scale

HUANG *et al.* (2002) examined the cost efficiency of rice farms in Taiwan using the Cobb-Douglas stochastic cost function assumption. Cross-section data of 400 rice farms which divided into hired-plowing and self-plowing farms were used for the analysis. The results imply that the average levels of cost efficiency of hired-plowing farms and cost efficiency of self-plowing farms are 0.90 and 0.81, respectively.

RAHMAN (2002) assessed the efficiency of rice farms in Bangladesh using two stage SFA approach. Technical efficiency and cost efficiency were examined under Cobb-Douglas stochastic production and cost function assumptions. Cross-section data of 530 rice farms were used for the analysis. The analysis based on per farm data of rice output value and combination of inputs: land, human labor, seed, fertilizer, manure, bullock power, irrigation cost. The hypothesized farm-specific variables which affecting on inefficiency were age of farmer, education, experience, extension contact (dummy), farm size. The main results show that the average levels of all farms technical and cost efficiency are 0.84 and 0.75, respectively. Moreover, the significant negative determinants of technical inefficiency (positive impact on technical efficiency) are age of farmer, experience, extension contact, and farm size. The significant positive determinants of economic inefficiency (negative impact on economic efficiency) are age of farmer, education, farm size, while the significant negative determinants of economic inefficiency are experience and extension contact.

WADUD and WHITE (2000) investigated the technical efficiency of rice farms in Bangladesh using SFA and DEA approaches. Cross-section data of 150 rice farms in irrigated area were used as well as translog stochastic production function and output-oriented DEA were assumed to analyze the technical efficiency. The analysis based on per farm data of rice output value and combination of inputs (cost unit): land, labor, irrigation, fertilizer, and pesticide. The hypothesized farm-specific variables which affecting on inefficiency were age of farmer, land fragmentation (plot size), year of schooling, irrigation infrastructure (dummy), and environmental degradation (dummy). The results show that the average levels of technical efficiency (SFA), technical efficiency (CRS) and technical efficiency (VRS) are 0.79, 0.79 and 0.86, respectively. Furthermore, the regression results show that the significant positive determinants of technical inefficiency (negative impact on technical efficiency) of both approaches are irrigation infrastructure (diesel pump) and environmental degradation.

ABDULAI and HUFFMAN (2000) examined the economic efficiency of rice farms in northern Ghana using the SFA approach. Cross-section data of 256 rice farms were used and translog stochastic profit function was assumed for the analysis. The analysis based on per farm data of rice output and combination of inputs: land, fertilizer, human labor, and capital as well as price information of each variable. The hypothesized determinants of profit inefficiency included hours of non-farm employment, access to credit, level of rice specialization (rice share to total area), household head age, household head education, distance to market, and district (dummy). The results show that the average level of economic (profit) efficiency is 0.73. The significant positive determinants of profit inefficiency (negative impact on profit efficiency) are hours of non-farm employment, age, distance to market while the significant

negative determinants of profit inefficiency (positive impact on profit efficiency) are education, access to credit, and level of rice specialization.

AUDIBERT (1997) assessed the technical efficiency of rice farms in Mali using the SFA approach. Two year panel data of 844 farms were used and Cobb-Douglas stochastic production function was assumed for the analysis. The analysis based on per farm data of rice output and combination of inputs: land, fertilizer (cost unit), human labor, and machinery. The results show that the average levels of technical efficiency of all farms in 1989 and 1990 are 0.68 and 0.71, respectively. In addition, the significant factors affecting the technical efficiency are ethnic group and dependence ratio.

ALI and FLINN (1989) examined the economic efficiency of rice farms in Pakistan using the SFA approach. Cross-section data of 256 rice farms were used and translog stochastic profit function was assumed for the analysis. The analysis based on per plot data of rice output and combination of inputs: fertilizer, human labor, and soil condition (dummy) as well as price information of each variable. The hypothesized determinants of profit inefficiency included socioeconomic (education, tenancy, off-farm employment, credit non-availability), resource base (farm size, tubewell ownership, tractor use), institutional factors (water constraint, late crop establishment, late fertilizer application), and village (dummy). The results show that the average level of economic (profit) efficiency is 0.72. The significant positive determinants of profit inefficiency (negative impact on profit efficiency) are off-farm employment, credit non-availability, water constraint, and late fertilizer application while the significant negative determinants of profit inefficiency (positive impact on profit efficiency) are education and village.

In summary, from above reviews, SFA and DEA are two popular methods of efficiency analysis. Stochastic Frontier Analysis (SFA) uses econometric techniques to measure the efficiency and/or inefficiency. It calculates the single regression through the observed data and is assumed to apply to each individual observation or it estimates the average efficiency (CHARNES *et al.*, 2000). Hence, it requires a specific functional form such as Cobb-Douglas function, translog function, quadratic function of the production function or cost function or profit function to estimate the parameters of this multivariate regression analysis. The efficiency and/or inefficiency attach to the error term of the regression estimation. In this method, it has to impose the specific assumptions on the error term which is composite error term (CHARNES *et al.*, 2000). This error term composes the statistical random error term (stochastic noise) and inefficiency term ($e_i = v_i + u_i$). The random error term (v_i) is assumed to be independently and identically distributed with zero mean and constant variance ($v_i \sim N(0, \sigma_v^2)$), while the inefficiency term (u_i) is assumed to be independently and identically distributed and truncations at zero (SHARMA *et al.*, 1999). These specific functional form and

error term assumptions, however, are the disadvantage or weakness of this approach (SEIFORD and THRALL, 1990).

Data Envelopment Analysis (DEA), in contrast, utilizes the linear programming techniques to measure the efficiency and/or inefficiency. It constructs a linear piecewise curve from the observed data. It, therefore, does not require any assumptions about functional form and the distribution of error terms. Nevertheless, it requires specification of calculation orientation and returns to scale assumptions on the analysis. DEA measures the optimization for each individual observation or DMU relative to all other DMUs in the observed population. It provides the results that each DMU lie on or below the (best-practice) frontier (CHARNES *et al.*, 2000). In this method is assumed that the observed data have no stochastic noise and then all deviations from the frontier reflect inefficiency of each DMU. The choices of orientation of analysis are possible as maximization of outputs or minimization of inputs or no orientation. The choices of envelopment surface are possible as CRS or VRS. In addition, two-stage DEA analysis is widely applied for measuring efficiency and the results of this analysis can help assist managerial decision making and guide public policy. More details of DEA analysis are discussed in Chapter 4.

However, recent studies on efficiency or performance of rice farms have been focused only on technical and/or economic efficiency. The environmental efficiency studies on agriculture have predominantly concerned with livestock production system, such as dairy farms and pig farms, while studies on crop production system have focused on the production of sugar beet and cotton. Therefore, to our knowledge, this study is an initial study that attempts to consider the undesirable outputs in efficiency analysis of rice production systems.

3.3 Environmental efficiency measurement: Undesirable outputs in DEA

According to the increasingly concern of global environmental problems, undesirable outputs of production activities such as greenhouse gas emission, air pollution, water pollution are progressively focusing and trying to incorporate these undesirable outputs in DEA model as environmental efficiency measurement.

COOPER *et al.* (2007) (in chapter 13) proposed to apply a slacks-based measure efficiency (SBM) which is non-radial and non-oriented efficiency measure for environmental efficiency measurement. They also proposed to consider inputs and (good and bad) outputs as separable and/or non-separable items. In electricity utility industries, for example, emission of nitrogen oxides and sulfur dioxides are bad and non-separable outputs because emissions are closely related with or proportional to fuel consumption. They argued that the radial models neglect slacks, and then when applying with undesirable outputs the slacks in undesirable outputs are

not accounted for in the efficiency measure. Moreover, oriented models focus on input-oriented or output-oriented efficiency is minor subject in measuring efficiency.

WOSSINK and DENAUX (2006) investigated environmental efficiency using input-oriented DEA approach in order to calculate pollution-decreasing environmental efficiency. They treated the environmental impact of the pesticide as inputs, not as undesirable output. The environmental impact of insecticide, herbicide, fungicide, growth regulators, and defoliants are proxies by leaching potential values. This environmental efficiency model is similar to the model for the technical efficiency model, but put the environmental impact of each input instead of the amount of the observed inputs.

ASMILD and HOUGAARD (2006) assessed environmental efficiency of pig farms in Denmark using output-oriented DEA approach. In this study, in order to avoid choosing a specific method to model undesirable outputs, they disaggregated the undesirable nutrients surplus into nutrient inflows and outflows. The environmental outputs are the physical amount of nitrate, phosphorus, and potassium removed from the field. The objective of this environmental efficiency model was to maximize nutrient removal, given the applied chemical fertilizer and nutrients in manure which are the potentially harmful surplus was minimized.

COELLI *et al.* (2005) argued that the methods which incorporate pollution variable as an input or undesirable output variable into a production technology of efficiency models are not consistent with the materials balance condition. They purposed alternative method of environmental efficiency measure which incorporating materials balance condition in the production model. The environmental efficiency of a firm equals to the ratio of minimum nutrients over observed nutrients and can be decomposed into technical and allocative components. The case study of phosphorus emission on Belgian pig farms was performed. They suggested that this method can directly be applicable to other livestock farms.

KUOSMANEN (2005) purposed the model which to treat the undesirable emissions as outputs and assume the weak disposability of these undesirable outputs, while the desirable outputs and inputs are under free (strong) disposable assumption. The weak disposability assumption means that it is possible to abate the harmful emissions by decreasing the level of production activity.

SEIFORD and ZHU (2002) summarized that there are five possibilities for dealing with undesirable outputs in the BCC model: 1) ignore the undesirable outputs, 2) treat the undesirable outputs in the non-linear model, 3) treat the undesirable outputs as outputs and adjust the distance measurement in order to restrict the expansion of the undesirable outputs, 4) treat the undesirable outputs as inputs, and 5) apply a monotone decreasing transformation to the undesirable outputs and then use the adapted variables as outputs. They proposed the

alternative method to treat undesirable factors in the standard DEA model under VRS (BCC model) which still preserves the linearity and convexity of BCC model. A linear monotone decreasing transformation was applied to treat the undesirable outputs. The data were transformed by multiplying each undesirable output by -1, and then finds a proper translation vector to let all negative undesirable outputs be positive. Under the output-oriented BCC model, they concluded that this method allows the enlargement of desirable outputs and the reduction of undesirable outputs and can be applied to other situations when some inputs need to be increased to improve the performance.

DE KOEIJER *et al.* (2002) measured environmental efficiency of sugar beet farms in the Netherlands using input-oriented DEA approach. They treated the environmental impact of the nitrogen fertilizer and herbicides as inputs, not as undesirable output. The environmental impact of nitrogen fertilizer was calculated in terms of nitrogen surplus from the difference between total nitrogen input and quantity of nitrogen in the sugar beet output. The environmental impact of herbicides was calculated in terms of environmental impact points (EIP) based on the effects on aquatic organisms, soil organism, and leaching to ground water.

SCHEEL (2001) reviewed the previous studies and two approaches to incorporate undesirable outputs in DEA are classified. There are direct and indirect approaches. The direct approach uses the original output data but modify the structure of the technology set (T) assumptions in order to treat the undesirable outputs appropriately. In contrast, the indirect approach transforms the values of the undesirable outputs by a monotone decreasing function in order to include the transformed data as normal or desirable outputs or as inputs in the technology set. In case of incorporating the transformed data as outputs, the data transformation can be based on additive inverse, multiplicative inverse, and weak disposable approaches. In case of incorporating the transformed data as inputs, it abstracts from the input-output structure which is defined by the nature of production process. In addition, non-separating efficiency measure are purposed to assess the efficiency for both desirable and undesirable outputs under the assumption that any change of outputs levels involves both desirable and undesirable outputs.

REINHARD *et al.* (2000) measured environmental efficiency of dairy farms in the Netherlands using SFA and DEA approaches. In DEA model, environmental impacts were treated as (environmental detrimental) inputs. Three environmental detrimental inputs: nitrogen surplus, phosphorus surplus, and energy were considered in both input-oriented and output-oriented assumption. They discussed that DEA model satisfies curvature and monotonicity restrictions by construction and can apply to calculate environmental efficiency for multiple environmentally detrimental inputs model.

3.4   Efficiency use of nitrogen fertilizer in rice farming systems

Nitrogen (N) fertilizer is one of the major mineral nutrients for rice production. Most of farmers apply inorganic N-fertilizers to the soil for plant uptake during production period in order to obtain higher yields. Due to physical laws, rice can never completely used or uptake these N-fertilizers. Therefore, efficiency use of the N-fertilizers should be concerned to meet rice crop's demand because the excessive use of it creates air and water pollutions by the nitrogen cycle processes (mineralization, ammonia volatilization, denirification, and nitrification).

Denitrification transforms nitrogen nitrate form (NO_3^-) into dinitrogen gas (N_2), nitric oxide gas (NO), and nitrous oxide gas (N_2O). Nitrous oxide is a greenhouse gas and it is 200-300 time more efficient than carbon dioxide gas (KYUMA, 2004). The nitrous oxide gas emission has become increasingly significant and it may be considered to be a larger problem than methane gas in the future (BREILING *et al.*, 2005). In addition, nitrification transforms nitrogen nutrients into nitrate form (NO_3^-) which can be drained and leached to surface and ground water. Nitrate leaching is economically and environmental undesirable.

KYUMA (2004) summarized N-fertilizer loss from paddy soil in Japan. The experiment was applied nitrogen balance method. The results show that 38 percent and 29 percent of total N-fertilizer applied are up taken by rice and remaining in the soil, respectively. Moreover, 20 percent and 13 percent of total N-fertilizer applied are lost due to the atmosphere by denitrification and drainage, respectively.

PATHAK *et al.* (2004) investigated nitrogen loss from paddy fields in Thailand by using nitrogen balance approach. The application rate of 37 kg of N-fertilizer per ha was split into three times of application. They found that 13.6 percent and 19 percent of the total amount of N-fertilizer applied are lost to the atmosphere and hydrosphere, respectively.

According to ROY and MISRA (2003), they projected that N-use of rice farming in Thailand was 56 kg of N per ha in 1997 and will increase to 65 kg of N per ha in 2015. In addition, they calculated the N-use efficiency by assume that 20 kg of N is needed for the production of one ton of rice. The estimation of N-use efficiency in Thailand was 42.8 percent in 1997 and will increase to 46.3 percent in 2015. They suggested that appropriate fertilizer application methods and information of plant demand would help to reduce losses of N-fertilizers.

The magnitude of these losses varies depending on the farm management practices, soil properties, and agro-ecosystem conditions (WASSMANN *et al.*, 2000; LI *et al.*, 2004; CHOUDHURY and KENNEDY, 2005). The types of fertilizer of coated urea (KYUMA, 2004), controlled-release or slow-release, and nitrification inhibitors (CHOUDHURY and KENNEDY, 2005) should be introduced to use because it is possible to reduce N-fertilizer by 30-40 percent

of the ordinary dose. However, due to high cost of these types of fertilizer, it may be compensated by savings in labor and fertilizer use (KYUMA, 2004).

3.5 Policy instruments for internalizing the negative externality from agriculture

Negative externality from agriculture is a special case of pollutants because they can diffuse to soil, water and air. Internalization of negative externality needs policy instruments which aim to manage or reduce the external effects. The experiences of agricultural environmental policies in European countries and North America are recently discussed in PRETTY *et al.* (2001) and WEERSINK and WOSSINK (2005).

PRETTY *et al.* (2001) suggest three promising policy instrument options to discourage negative externality and to support changes in farmers' behavior and practices, i.e. environmental taxes, subsidies and incentives, and institutional and participatory mechanisms. Under opened economy, the market prices for agricultural inputs (especially chemical pesticides and fertilizers) do not echo the full costs of farming. Environmental taxes or pollution payments on those inputs can help to internalize some of these external effects cost because farmers would think to use these inputs more efficient. Moreover, the environmental tax measure would offer double dividend by reducing the environmental pollutions and promoting social welfare. Alternatively measure, farmers can be encouraged to change to low or non-polluting technologies and practices by offering subsidies and incentives for adoption of those technologies. However, institutional and participatory mechanisms also need as a supplementary measure to encourage farmers for adoption of good or more sustainable practices, to provide information, training by extension or advisory services.

WEERSINK and WOSSINK (2005) review major agri-environmental policy options and their conditions for success as summarized in Table 3.5.

Table 3.5 Types, examples and conditions necessary for success of major agri-environmental policies

Type of policy	Examples	Conditions necessary for success
Advisory measures		
Education programs	Demonstration farms	Environmental impacts of individual actions and/or the profitability of BMPs is unknown to those contributing to the problem
R&D	Profitable BMPs, adaptation strategies	Underlying bio-physical process of problem and profitable solutions are not known
Labeling/certification	Organic products, ISO 14000	Demand exists for environmental performance attribute in final consumer good
Institutional support		
Defining property rights	Selling hunting access	Property rights missing for high-value natural asset where there is sufficient demand for quality attributes
Liability laws/performance bonds	Suing for damages from spill	Polluting events are infrequent, the impact of the event is significant, few parties involved and cause/effect well understood
Command and control regulations		
Performance-based standards	Emission controls on engines	Emissions or proxies of environmental performance can be measured at reasonable cost
Design-based standards	Restrictions availability and use of pesticide	Practice or input can be easily observed and directly linked to environmental performance. Standard should be targeted.
Economics instruments		
Performance-based	Taxes on excess nutrients	Emissions or proxies of environmental performance can be measured at reasonable cost
Design-based	Fertilizer taxes, subsidies for BMPs	Inputs have to be price sensitive if taxed, and subsidies targeted to contributors of problem for BMPs that effectively prevent it
Tradable rights	Emission trading schemes, input quotas	Exchange units are homogeneous and easily measured, there is a demand for units, and low costs of exchange

Source: adapted from WEERSINK and WOSSINK, 2005
Remarks: BMPs = Best management practices

3.6   Concluding remarks

To measure efficiency of agricultural production, there are two popular methods of analysis: stochastic frontier analysis (SFA) and data envelopment analysis (DEA). Efficiency can be analyzed in terms of technical efficiency and/or economic efficiency. In practice, one can measure efficiency of each activity based on the availability of the observed data. Technical efficiency or production efficiency requires only technical data (input and output information), while economic efficiency requires the input and/or output quantity data, together with input and/or output price data as well as producer's behavioral assumption, i.e. cost minimization, revenue maximization, profit maximization. Recently, some studies try to analyze environmental efficiency by integrating negative environmental effects into the efficiency model.

4   Research Methodology

4.1   Data collection

4.1.1   Secondary data

Secondary data were gathered from various sources such as books, journals, research reports, statistic reports which related to productivity and efficiency analysis, rice production, agricultural production, agricultural and environmental situations, agricultural and environmental policies etc. In addition, data of regional, provincial and community levels were collected which give precise information for selecting the research areas. It includes agricultural areas, rice planted areas, number of agricultural households, number of rice farming households, demographical, social and economic characteristics, irrigation projects, provincial and government policies on agricultural sector and rice production.

4.1.2   Primary data

The main rice farming area in southern Thailand, the Songkhla Lake Basin, was selected as study area. Primary data of this study based on farm level cross-section data of the crop year 2004/05. The survey was conducted during July to October 2005.

4.1.2.1 Sampling method

In southern Thailand, rice is predominantly grown on the eastern coast particularly around Songkhla Lake Basin (SLB), i.e. part of Nakhon Sri Thammarat, Phatthalung, and Songkhla provinces. The two-stages sampling was employed for population frame. First stage, therefore, Phatthalung and Songkhla provinces were selected as primary sampling unit. The main rice farming districts of these two provinces were listed (Table 4.1). Then second stage, the district where has the highest proportion of rice planted area of each province as well as irrigation canal was selected as secondary sampling unit. Table 4.1 gives that the Ranot district in Songkhla province and Muang district in Phatthalung province were selected.

Table 4.1: Population frame for farm household survey

Study area	Location (District)	Agricultural area (ha)	Rice planted area (ha)	% of rice planted area	% of rice farming household
Songkhla[1/]					
	Ranot	*32,317*	*22,866*	*70.76*	*74.09*
	Krasaesin	6,984	3,850	55.13	59.50
	Sa Ting Pra	8,974	6,670	74.33	78.11
	Sing Ha Nakhon	13,068	8,208	62.81	38.28
	Muang	6,929	1,208	17.44	35.03
	Khuan Naeng	13,955	5,818	41.69	58.47
	Total	**82,226**	**48,620**	**59.13**	**56.62**
Phatthalung[2/]					
	Muang	*31,755*	*21,857*	*68.83*	*82.57*
	Khuan Kha Nun	37,189	20,334	54.68	79.98
	Kao Chai Suon	20,777	8,398	40.42	64.40
	Bang Kaew	8,570	2,990	34.89	44.18
	Pak Pa Yoon	24,645	7,437	30.18	41.14
	Total	**122,936**	**61,016**	**49.63**	**69.19**

Source: [1/] SAO (Songkhla Agricultural Office), 2004

[2/] PAO (Phatthalung Agricultural Office), 2004

Later the stratified random sampling was applied for sample selection. It divided the population of two selected districts into two stratums, which separated according to two production ecosystems viz. Irrigated Rice Production System and Rain-fed Rice Production System. Then the sub-districts of these two districts were listed. Finally, simple random sampling was applied to select the rice farm households. The sampling method of this study is summarized in Figure 4.1.
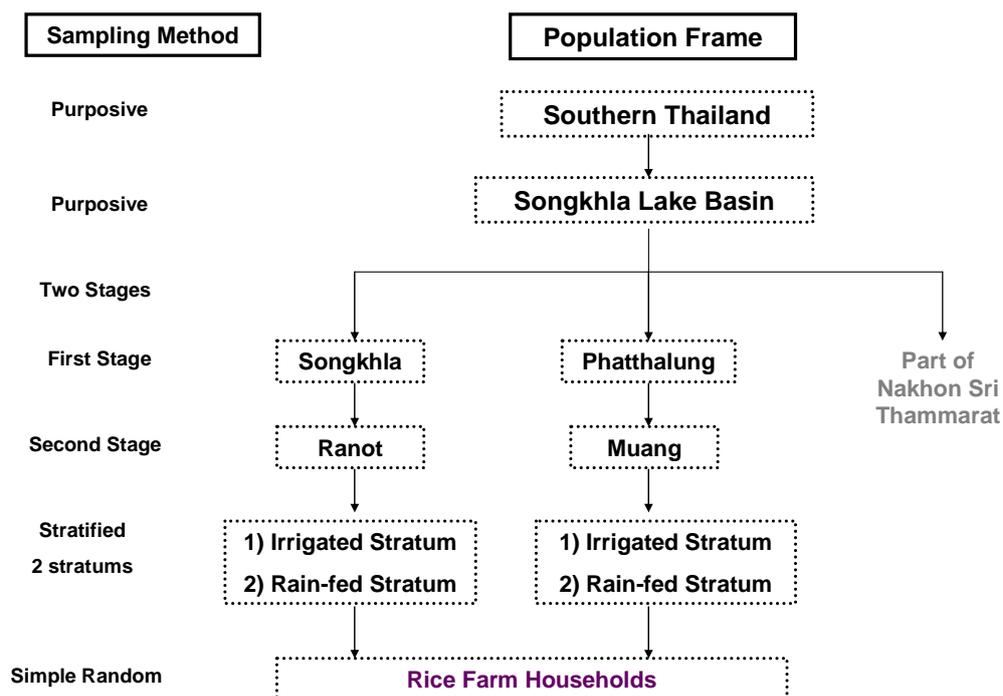
Figure 4.1 Sampling method of primary household data

4.1.2.2 Sample sizes

The rice farm household samples were randomly selected from 18 villages, 9 sub-districts of Songkhla and Phatthalung provinces. The sample size was considered according to sampling error at 10%, which calculates by using Yamane formula. The calculated sample size was 198 farm households (Table 4.2). However, the actual samples of 247 farm households were collected, 120 farms from Songkhla and 127 farms from Phatthalung. They were stratified according to the major production ecosystems, 127 farms from irrigated area and 120 farms from rain-fed area. The details of location of the samples are presented in Table 4.3.

Table 4.2: Sample sizes for farm household survey

Study area	Location (District)	No. of rice farming household	Sample size for sampling error 10% [1]	Actual sample size by production systems		
				Irrigated	Rain-fed	Total
Songkhla	Ranot	7,866	99	60	60	120
Phatthalung	Muang	12,740	99	67	60	127
Total			198	127	120	247

Source: SAO, 2004
        PAO, 2004
Remark: [1] used Yamane formula $n = N/1+N(e^2)$

Table 4.3: Rice farm household samples in the study area

Study area	Number of samples		
	Irrigated area	Rain-fed area	Total
Songkhla: Ranot			
- Ban Khaow	31	-	31
- Ban Mai	29	-	29
- Klong Dan		30	30
- Pang Yang		30	30
Sub-total	*60*	*60*	*120*
Phatthalung: Muang			
- Tham Nan	37	-	37
- Chai Buri	30	-	30
- Tha Kae	-	32	32
- Lum Pam	-	18	18
- Na Nod	-	10	10
Sub-total	*67*	*60*	*127*
Total	**127**	**120**	**247**

4.1.2.3 *Rice farming and farm household information*

In order to collect rice farm household information, the questionnaire was used as the research instrument. Semi-structured and structured questionnaires were prepared in Thai. The semi-structured questionnaire was used for interviewing key informants, while the structured questionnaire was used for interviewing individual rice farmers.

The key informants of this study were agricultural officers and research officers in regional, provincial, and district levels, irrigation project officers, head of sub-districts, head of villages, and head of water user groups.

For the individual rice farmer interview, the pre-testing of structured questionnaire was done for 10 farm households in both Songkhla and Phatthalung provinces. Then the edited version of questionnaire was used for interviewing rice farmer in the study area. In addition, the six enumerators were trained to understand each question in the questionnaire and how to ask the questions in order to get answer of each variable.

The following lists of information were included in the structured questionnaire:

1) Household characteristics; number of members, age, gender, education, main occupation, member of farmer group or other organizations, distance from home to rice field

2) Household background in rice production; years of experience, objective of rice farming, rice varieties used, new seed replacement, extension service contact

3) Farm practices and management; soil management, water management, chemical fertilizer and pesticide management, sources of farm information

4) Land tenure and land use; farm sizes, land tenure, rice planted areas

5) Rice production input quantity uses and prices; land, labor, machine, seed, variety, fertilizer, pesticide, herbicide

6) Production output and prices; paddy yield, amount of household consumption, sell quantity, where to sell

7) Farm asset and liability; present value of assets, amount and sources of household debt

8) Problems and obstacles on rice production

9) Farmers' perception on negative environmental effects of rice farming

4.2   Data analysis

The primary farm household data were the main source of information used for analysis. In this study, four categories data analysis were needed to fulfill the research objectives. Descriptive statistic analysis and profitability analysis were used to investigate the existing rice production systems. Data envelopment analysis was used to assess technical efficiency, economic (cost efficiency) and environmental efficiency. Finally, the descriptive and efficiency analysis results were used as variables in Tobit regression analysis to investigate the factors affecting the efficiency of rice production systems. The research framework of data collection and data analysis is summarized below in Figure 4.2.
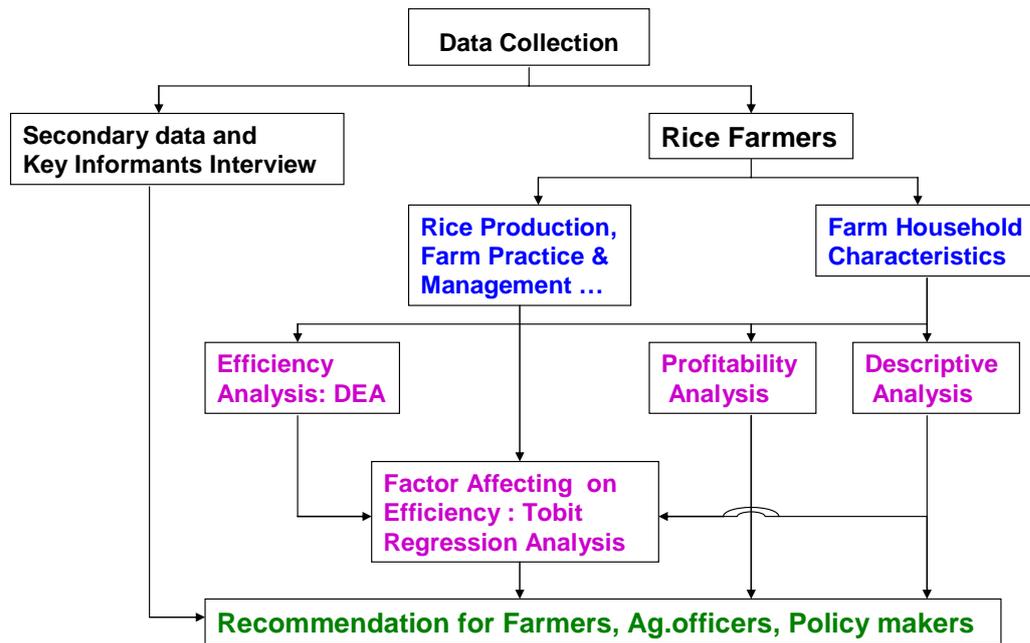
Figure 4.2: Research analytical framework

4.2.1   Descriptive statistic analysis

The descriptive statistic analysis was used to summarize the important characteristics of the respondents (rice farmers) by using simple statistic analysis, i.e. frequency, percentage, mean, mode, standard deviation, variance, maximum, minimum, range. In addition, t-test was used to test for differences of farm and farmer characteristics between two agro-ecosystems. The non-parametric Mann-Whitney U test was used to test for differences of efficiency scores between farms in irrigated and rain-fed areas.

4.2.2   Cost-revenue and profitability analysis

The cost-revenue and profitability analysis were used to evaluate rice farm performances of the major crop year 2004/05. This analysis was based on per unit of land in hectare.

4.2.2.1 Cost analysis of rice production

In traditional of cost theory, short run production cost items are categorized into variable costs and fixed costs. In rice production, the variable costs mean the cost that do vary with the quantity of paddy output produced, while the fixed costs mean the cost that do not vary with the quantity of paddy output produced (MANKIW, 1998).

Let assume that the input vector is x and input price vector is w. Then total variable cost (TVC) of rice production consists of expenses or costs of labor (w_1x_1), seed (w_2x_2), diammonium phosphate (DAP) fertilizer (w_3x_3), urea fertilizer (w_4x_4), plant protection chemical (w_5x_5), fuel (w_6x_6), and capital opportunity cost (w_7x_7). Whereas total fixed cost (TFC) comprises only land opportunity cost in terms of land rental fee (w_8x_8). Therefore, total cost (TC) of rice production is derived from the sum of total variable costs and total fixed costs or as the following equations (8)-(10):

$$TVC = w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5 + w_6x_6 + w_7x_7 \qquad (8)$$

$$TFC = w_8x_8 \qquad (9)$$

$$TC = TVC + TFC = w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5 + w_6x_6 + w_7x_7 + w_8x_8 \quad (10)$$

4.2.2.2 Revenue analysis of rice production

On revenue side, revenue from rice production is the amount that a farm receives form the sales of paddy output. Let assume that paddy rice (y) is only one output from the production and the paddy price is p, then total revenue (TR) from rice production is derived from paddy output multiply by paddy price or $TR = py$

4.2.2.3 Profitability analysis of rice production

Two indicators can be calculated to show the profit from rice production, i.e. gross margin and profit. Gross margin or net revenue is derived from total revenue minus total variable cost, while profit is derived from total revenue minus total cost or can be written as (11) and (12):

Gross margin or Net revenue = Total revenue - Total variable costs

$$= py - (w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5 + w_6x_6 + w_7x_7) \quad (11)$$

Profit = Total revenue - Total costs = Gross margin - Total fixed costs

$$= py - (w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5 + w_6x_6 + w_7x_7 + w_8x_8) \qquad (12)$$

4.2.3 Efficiency analysis: Data Envelopment Analysis

Efficiency or performance analysis is a relative concept (COELLI *et al.*, 1998). It relates to production analysis and measures the production in a ratio form. Efficiency measurement is an ex-post evaluation, which can be apply to micro level of decision making units (DMUs) or private firms, non-profit organizations as well as to compare the performance of industrial,

regional, and national levels (COOPER *et al.*, 2006). The efficiency analysis results can help guide on efficiency improvement for DMUs and/or policy makers.

4.2.3.1 DEA Method

The first empirical efficiency measurement was illustrated in FARRELL's paper. FARRELL (1957) proposed efficiency measurement of a firm which developed upon the work of DEBREU (1951). FARRELL (1957) explained his ideas by using simple model. The simple model assumed that a firm using two inputs to produce a single output under constant returns to scale condition and then he generalized this model to the case of many inputs and outputs. This efficiency measure consists of two components: technical efficiency and price or allocative efficiency and then these two components are combined to provide a measure of overall or economic efficiency.

The data envelopment analysis (DEA) was first proposed by Charnes, Cooper, and Rhodes (CCR) in CHARNES *et al.* (1978). They extended Farrell's work by developing the fractional linear programming method of DEA. DEA is a nonparametric approach, which based on linear programming problem solving in order to construct the piecewise frontier. DEA optimizes on each individual observation with an objective of calculating a discrete piecewise frontier determined by the set of Pareto-efficient DMUs. The efficient DMUs lie on the frontier while the inefficient ones lie below the frontier. The inefficient DMUs can improve their performance to reach the efficient frontier by either decreasing their current input levels or increasing their current output levels (SEIFORD and ZHU, 2002).

Data Envelopment Analysis is used to measure the relative efficiency or performance of DMUs of both private profit organizations and non profit organizations. The DEA application in agricultural production has been shown an increasing trend over last ten years. DEA can be applied in multiple input-multiple output cases. Moreover, the advantages of DEA are noted that it can identify sources and amounts of inefficiency in each input and each output for each entity or farm, and identify the benchmark members of the efficient set used to effect these evaluations (COOPER *et al.*, 2006). The majority use of DEA is to calculate technical efficiency of DMUs, which required only quantity data of inputs and outputs (LOVELL, 1993).

Charnes, Cooper, and Rhodes (CCR) model

CHARNES *et al.* (1978) proposed the CCR model to measure efficiency of each DMU by solving envelopment form of fraction and linear programming (LP) problems. They assumed three restrictions on frontier technology: constant return to scale (CRS), strong disposability of inputs and outputs, and convexity of feasible input-output combinations (LOVELL, 1993). The CCR model seeks radial (proportional) reduction in input or radial expansion in output.

Banker, Charnes and Cooper (BCC) model

Banker, Charnes and Cooper (1981) presented the BCC model by relaxing one restriction of the CCR model. The BCC model assumed variable returns to scale (VRS) in stead of CRS. The BCC, hence, differs from the CCR model only adding the convexity constraint in linear programming problem. This VRS assumption provides the frontier, which envelops the data more tightly than CRS assumption (LOVELL, 1993). Similar to the CCR model, the BCC seeks radial (proportional) reduction in input or radial expansion in output.

Apart from the CCR and BCC models, COOPER *et al.* (2007) summarized that there are two types of efficiency measures in DEA: radial and non-radial. The differences between these two measures are in the characteristics of input or output items. Most DEA models can be categorized into four classes: 1) radial and oriented, 2) radial and non-oriented, 3) non-radial and oriented, and 4) non-radial and non-oriented (COOPER *et al.*, 2007). Radial means that a proportional reduction or enlargement of inputs/outputs is the major concern in efficiency measurement, while oriented indicates input-oriented or output-oriented. The radial approach is represented by the CCR and BBC model. The non-radial approach or slacks-based measure (SBM) utilizes (input and output) slacks directly. The details of the SBM can be explored in Chapter 4 of COOPER *et al.* (2006).

The basic DEA analysis requires two choices of formulation: choice of orientation and choice of envelopment surface. The choice of orientation or focus of analysis is possible as maximization of outputs or minimization of inputs or no orientation. The choice of envelopment surface is possible as CRS (conical hull) or VRS (convex hull) (Charnes et al., 2000; Lovell, 1993). In addition, DEA analysis requires one solution of LP problem for each DMU; *n* DMUs need *n* solution of LP problem. The outcomes of DEA analysis are efficiency scores, which represent as performance indicators: one is best performance and zero is worst performance.

4.2.3.2 Aims of efficiency analysis

Due to the rice farmers in southern Thailand confront economic problems of low income and high cost of rice production, input-oriented DEA approach is related to solve the problems. The input-oriented measure aims to minimize inputs combination as well as minimize pollution from fertilizer application holding the output or rice yield constant. Therefore, improvement of farm efficiency by reducing of inputs use can automatically reduce in cost of production or increase the gross margin from rice production. In addition, the improvement of farm efficiency will keep the existing product market condition or will not enlarge the supply quantity.

In this study, therefore, the standard BCC-DEA model under input-oriented approach was applied to assess technical efficiency, economic efficiency, and environmental efficiency of rice farms. The objective of technical efficiency analysis is trying to minimize all inputs with the current level of rice yield. The objective of economic efficiency analysis is trying to minimize cost of production, while the environmental efficiency analysis aims to minimize the pollution from nitrogen fertilizer application.

Two-stage DEA methodology of efficiency analysis was focused. The two-stage DEA procedure begins with calculating efficiency scores from DEA model. Then these efficiency scores are used as dependent variables in the second stage by regress the efficiency scores against a set of explanatory variables. The dependent variables in this case are bounded between zero and one, The Tobit regression technique is used to investigate and explain the factor affecting the technical, economic, and environmental efficiency of rice production systems. The explanatory variables for second stage comprise farmer characteristics, farm-specific characteristics, and production environment variables. The regression results provide the information, which can help guide efficiency improvement for producers and policy makers.

4.2.3.3 Technical efficiency analysis

Measurement concept of technical efficiency

Lovell (1993) cited that a measure of technical efficiency was introduced by Debreu (1951) and Farrell (1957) or so-called Debreu-Farrell measure. Technical efficiency (TE) is a function which measures a production frontier. It can be measured by input-oriented (TE_I) or input-reducing focus and output-oriented (TE_O) or output-increasing focus.

In this study, input-oriented measure was applied. In input-oriented, the production frontier explains the minimum amount of inputs required to achieve the given levels of output. In other words, TE_I refers to the ability of DMUs to minimize input use in order to achieve the given levels of output or assesses "how much can input quantities be proportionally reduced without changing the quantities produced?" (Coelli et al., 1998). It can be written as (13):

$$TE_I(y,x) = \min\left\{\theta : \theta x \in L(y)\right\} \tag{13}$$

The input-oriented measure of technical efficiency can be illustrated in Figure 4.3. Input vector X^A can be contracted radially reduction to $\theta^A X^A$ and still remain capable of producing output vector y, but input vector X^B and X^C cannot be contracted radially reduction and still remain capable of producing output vector y because they are already on the frontier.
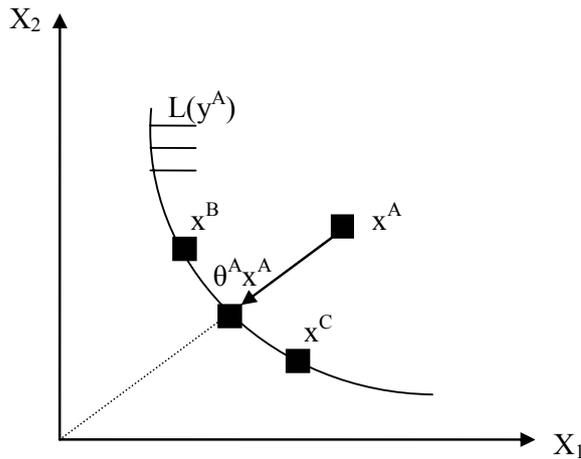
Figure 4.3: Input-oriented measure of technical efficiency (N=2)

Source: Adapted from KUMBHAKAR and LOVELL, 2003

Thus, the technical efficiency analysis is the ratio form of actual productivity (output per unit of input) and frontier (best practice) productivity (WOSSINK and DENAUX, 2006). It, therefore, requires technical data or input and output quantity data for analysis. If a DMU's actual productivity equal to frontier productivity or lies on the frontier, it is perfectly technical efficient. On the contrary, if a DMU's actual productivity less than frontier productivity or lies below the frontier, it is technical inefficient.

The choice of envelopment surface of production frontier can be under CRS or VRS assumption. In this study, VRS technology was assumed. Suppose that production function, $y = f(x_1, x_2)$ and increase all inputs by the same proportion k which k is a positive scalar. Consider the function (14):

$$y(k) = f(kx_1, k\,x_2) \tag{14}$$

then constant returns to scale (CRS) occurs when a proportional increase in all inputs results in the same proportional increase in output or can be written as (15):

$$CRS: \ f(kx_1, k\,x_2) = k\,f(x_1,\,x_2) \tag{15}$$

Therefore the production frontier under CRS condition is a linear line from the origin. Hence, the analysis results of input-oriented technical efficiency (TE_I) equal to output-oriented technical efficiency (TE_O). In Figure 4.4, firm A is technical inefficient, it lies below the frontier. It can produce the amount Y^A by reduction the input use from A to A^I_{CRS} due to input use inefficiency or can expand the amount of output from A to A^O by using the same level of input (X^A) due to output inefficiency. The input reduction distance of A-A^I_{CRS} equals to the output expansion distance of A-A^O.
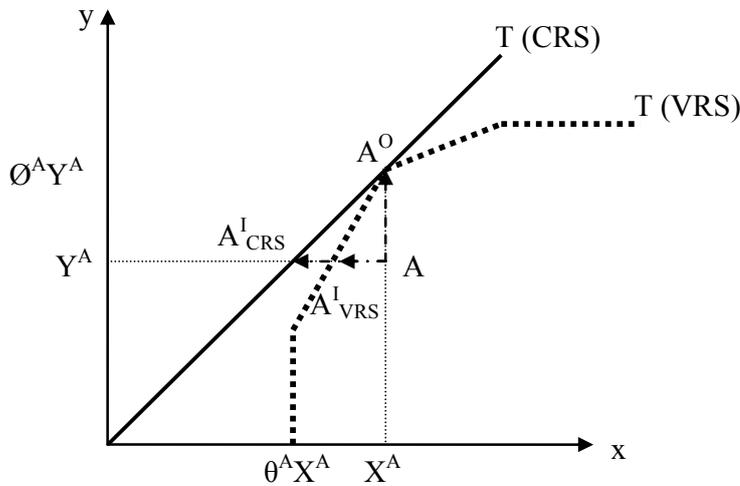
Figure 4.4: Returns to scale and technical efficiency
Source: Adapted from KUMBHAKAR and LOVELL, 2003 and COELLI *et al.*, 1998

Variable Returns to Scale (VRS) occurs when a proportional increase in all inputs results more than or less than proportional increase in output. It can be divided into increasing returns to scale (IRS) and decreasing returns to scale (DRS). The IRS occurs when a proportional increase in all inputs results in the more than proportional increase in output, while the DRS occurs when a proportional increase in all inputs results in the less than proportional increase in output (COELLI *et al.*, 1998, p 18). IRS and DRS can also be written as (16) and (17):

$$\text{IRS: } f(kx_1, k\,x_2) > k f(x_1, x_2) \tag{16}$$

$$\text{DRS: } f(kx_1, k\,x_2) < k f(x_1, x_2) \tag{17}$$

Therefore the production frontier under VRS condition is a convex curve from the origin. In this case, the analysis results of input-oriented technical efficiency (TE_I) do not equal to output-oriented technical efficiency (TE_O). Again, Figure 4.4 represented the relation between technical efficiency and VRS. Firm A is technical inefficient, it lies below the frontier. It can produce the amount Y^A by reduction the input use from A to its frontier (A^I_{VRS}) due to input use inefficiency or can expand the amount of output from A to A^O by using the same level of input (X^A) due to output inefficiency. But under VRS, the input reduction distance of A- A^I_{VRS} does not equal to the output expansion distance of A-A^O.

Moreover, technical efficiency can be decomposed into two components: pure technical efficiency and scale efficiency. The CCR model (CRS) yields an objective evaluation of overall or global efficiency while the BCC model (VRS) estimates pure technical efficiency at the

given scale of operation (CHARNES *et al.*, 2000). The scale efficiency (SE) can be calculated by ratio of CRS-efficiency score to VRS efficiency score or as (18):

$$SE = \frac{\theta^*_{CCR}}{\theta^*_{BCC}} \tag{18}$$

Model specification of technical efficiency

Two models of technical efficiency are constructed in order to minimize all inputs use and still attain the same level of output. These two models differ in terms of fertilizer forms. Model I, fertilizers were treated in commercial formulas (DAP, Urea), while they were converted into nutrient composition (nitrogen fertilizer, phosphorus fertilizer) in model II.

Linear programming framework of the model was constructed as (19) by following DE KOEIJER *et al.* (2002). The efficiency of n farms is assessed by solving n LP models. The assumptions of this model are as follows:

- Farm *j* (j = 1, 2,…, n) produces a single output (y_j) using a combination of inputs X_{ij} (i = labor, machine, seed, fertilizers)
- Input oriented production frontier under variable returns to scale (VRS)

$$\min_{\Delta, \lambda} \Delta j \tag{19}$$

subject to
$$\sum_{j=1}^{n} y_j \lambda_j - y_j \geq 0; \ \lambda_j \geq 0 \ for \ \forall_j,$$

$$x_{ij}\Delta_j - \sum_{i=1}^{m} x_{ij}\lambda_j \geq 0,$$

$$\sum_{j=1}^{n} \lambda_j = 1,$$

$$0 \leq \Delta \leq 1$$

where Δj is a scalar which indicates the technical efficiency scores of the j-th farm (if $\Delta j = 1$, the farm is on the frontier and is technical efficient under variable returns to scale, but if $\Delta j < 1$, then the farm lies below the frontier and is technical inefficient);

y_j is a 1×n vector of single output produced by the n farms;

x_{ij} is a m×n input matrix;

λ_j is a n×1 vector of weight value, $\forall_j$ denotes "for all j"

From the LP problem, let assume that the observed activities (x_j, y_j) belong to production possibility set (P). Then minimize Δ that reduces the input vector x radically to Δx while remaining in P. The Δ is scalar represent of technical BCC-efficiency value, which varies in range of zero and one (COOPER *et al.*, 2006).

In words, the relative technical efficiency of any DMU is calculated by forming the ratio of a weighted sum of outputs to a weighted sum of inputs. The weights (λ or multipliers) for both outputs and inputs are selected in a way that calculates the Pareto efficiency measure of each DMU subject to the constraint that no DMU can have a relative efficiency score greater than unity. DEA produces a piecewise empirical extremal production surface, which in economic terms represents the revealed best practice production frontier (CHARNES *et al.*, 2000). In efficiency analysis, a DMU is fully efficient (Pareto-Koopmans efficiency) if and only if it is not possible to improve any input or output without worsening some other input or output (COOPER *et al.*, 2006).

4.2.3.4 Economic efficiency analysis

Measurement concept of economic efficiency

Economic efficiency (EE) measurement requires the input and/or output quantity data, together with input and/or output price data as well as producer's behavioral assumption. The behavioral assumption of producer can be cost minimization, or profit maximization, or revenue maximization then the frontier of each behavioral assumption is needed to measure. In this part, only the cost minimization behavioral assumption is discussed.

Cost efficiency is related to input-oriented technical efficiency with try to reduce cost of production at given input prices and output level. The input-oriented technically efficient producer may not be a cost efficient.

Let assume that the producers or farmers use a nonnegative vector of inputs, denoted $x = (x_1,..., x_N) \in R_+^N$, to produce a nonnegative vector of outputs, denoted $y = (y_1,..., y_M) \in R_+^M$, face a positive vector of input prices, denoted $w = (w_1,..., w_N) \in R_{++}^N$ and seek to minimize cost of producing the output vector *y*, then the existing cost given by $w^T x = \sum_n w_n x_n$

In case the input prices information are known, the technically efficient producer may use inappropriate input combinations at given the input prices. The input-oriented technically efficiency analysis is necessary but not sufficient for the achievement of cost efficiency. The measure of cost efficiency (CE) is given by the ratio of minimum cost to observed cost or can be written as (20). In addition, the measure of cost efficiency is bounded between zero and one.

$$CE(y, x, w) = c(y, w) / w^T x \tag{20}$$

A cost frontier is a function which explains the minimum expenditure required to produce a scalar of output, given input prices (KUMBHAKAR and LOVELL, 2003). The cost frontier can be written as (21):

$$c(y, w) = \min_x \left\{ w^T x : x \in L(y) \right\} = \min_x \left\{ w^T x : D_I(y, x) \geq 1 \right\} \tag{21}$$

Cost efficiency can be decomposed into two components: technical efficiency and input allocative (price) efficiency. The cost efficiency composition can be written as (22):

$$CE(y, x, w) = TE_I(y, x) \cdot AE_I(y, x, w) \tag{22}$$

In Figure 4.5, for example, at the first stage, firm A uses the combination of inputs at point x^A and input unit prices W^A to produce output y^A at production cost $W^{AT}x^A$. However, firm A can produce at technical efficiency level by reducing the combination of inputs use to $\theta^A x^A$ in order to produce the same output y^A at production cost $W^{AT}(\theta^A x^A)$. But at the technical efficiency level, firm A does not produce output y^A at the cost efficiency level. Thus, firm A can minimize its cost by reducing input use combination to x^* to produce the same output y^A at production cost $W^{AT}x^*$. In other words, the cost efficiency is given by the ratio of expenditure at x^* (which equal to expenditure at x^P) to expenditure at x^A or $W^{AT}x^*/ W^{AT}x^A$.
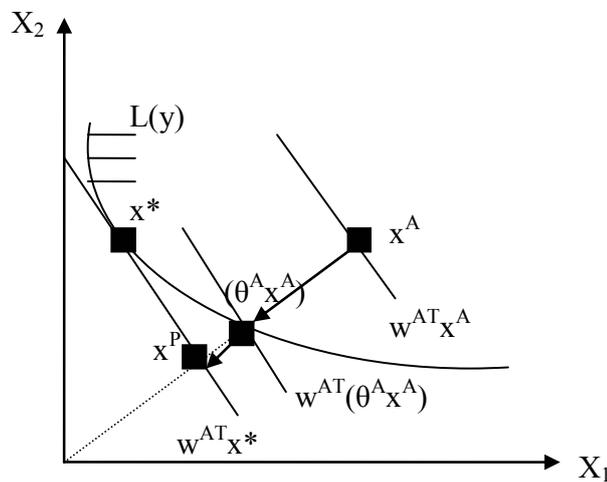
Figure 4.5: Measurement and decomposition of cost efficiency (N=2)
Source: Adapted from KUMBHAKAR and LOVELL, 2003

In addition, in Figure 4.6 presents the cost efficiency point on the cost frontier. It shows that firm A can output y^A by reducing input use and its cost from existing cost ($W^{AT}x^A$) to cost efficiency level ($W^{AT}x^*$) when input prices are available.
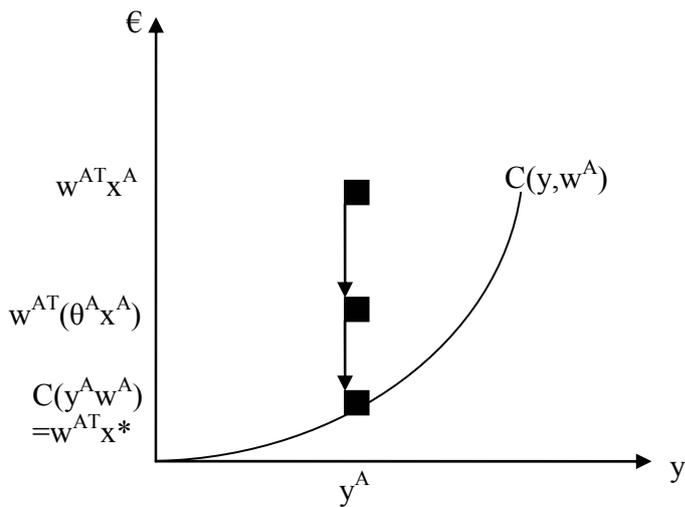
Figure 4.6: Cost frontier and measurement of cost efficiency (M=1)

Source: Adapted from KUMBHAKAR and LOVELL, 2003

Model specification of economic efficiency

In this study, economic efficiency model is focused on input-oriented in order to minimize cost of all inputs use and still attain the same level of output. Therefore the cost minimization or cost efficiency model was constructed.

Linear programming framework of the model was constructed as (23) by adapted from DHUNGANA *et al.* (2004). The efficiency of n farms is assessed by solving n LP models. The assumptions of the model are as follows:

- Farm *j* (j = 1, 2,…, n) produces a single output (y_j) using a combination of inputs X_{ij} (i = labor, machine, seed, DAP-fertilizer, Urea-fertilizer) under the unit price of inputs w_{ij}
 - Input oriented under VRS

$$MC_j\left(y_j, x_{ij}*, w_{ij}\right) = \min_{x_{ij}*, \lambda_j} w_{ij}\, x_{ij}* \qquad (23)$$

Subject to $\qquad \sum_{j=1}^{n} y_j \lambda_j - y_j \geq 0; \ \lambda_j \geq 0 \ for \ \forall_j,$

$$x_{ij}* - \sum_{j=1}^{n} x_{ij}\lambda_j \geq 0,$$

$$\sum_{j=1}^{n} \lambda_j = 1,$$

where $\qquad MC_j\left(y_j, x_{ij}*, w_{ij}\right)$ is the minimum total cost ;

$\qquad y_j$ is a 1×n vector of single output produced by the n farms;

$\qquad x_{ij}$ is a m×n input matrix;

w_{ij} represents the unit price for input i used by farm j ;

λ_j is a n×1 vector of weight value, $\forall_j$ denotes "for all j"

4.2.3.5 Environmental efficiency analysis

Measurement concept of environmental efficiency

The environmental efficiency measurement of this study is based on the technical efficiency concept, but considered only environmental detrimental inputs holding other input constant. In order to minimize environmental effects of those environmental detrimental inputs, then the environmental detrimental inputs are treated in terms of environmental effects.

Model specification of environmental efficiency

In this study, environmental efficiency model was constructed in order to minimize pollutions from chemical N-fertilizer application. The environmental pollution variables were integrated into standard BCC-DEA model as input variables in order to minimize environmental pollution holding the desirable output constant and free disposability of input and output are assumed.

Nitrogen fertilizer (N) as environmental detrimental input is the key input, which causes the environmental pollutions (S). Following the study of PATHAK *et al.* (2004)(Pathak et al., 2004), the total amount of nitrogen applied has been classified into two fractions of environmental pollutions, (1) 19 percent leached into surface and ground water (S_1) and (2) 13.6 percent converted into greenhouse gases (S_2). It can be written as (24) and (25):

$$S = S_1 + S_2; \ S_1 = 0.190 \ N; \ S_2 = 0.136 \ N \tag{24}$$

$$S = 0.190 \ N + 0.136 \ N = 0.326 \ N \tag{25}$$

In other words, the results of PATHAK *et al.* (2004) can imply that the negative externalities from nitrogen fertilizer always exist even it is applied at very low level. The environmental pollutions from rice production show a linear relationship to the total amount of nitrogen applied. Hence input oriented approach, we treat these undesirable outputs as polluting inputs, which are leachable and emittable fractions of nitrogen fertilizers.

Linear programming problem of this model is as (26) and model assumptions are as follow;

- Farm *j* (j = 1, 2,…, n) produces a single output (y_j) and applies a combination of N-fertilizer which create the environmental pollutions S_{kj} (k = N-leaching, N-emission)

- Assuming the same level of other conventional inputs use

- Input oriented production frontier under VRS

$$\min_{\theta,\lambda} \theta j \qquad (26)$$

subject to $\qquad \sum_{j=1}^{n} y_j \lambda_j - y_j \geq 0; \ \lambda_j \geq 0 \ for \ \forall_j,$

$$S_{kj}\theta_j - \sum_{k=1}^{r} S_{kj}\lambda_j \geq 0,$$

$$\sum_{j=1}^{n} \lambda_j = 1,$$

$$0 \leq \theta \leq 1$$

where $\qquad \theta j$ is a scalar which indicates the environmental efficiency scores of the j-th farm;

y_j is a 1×n vector of single output produced by the n farms;

S_{kj} is a r×n pollution of environmental detrimental input matrix;

λ_j is a n×1 vector of weight value, and $\forall_j$ denotes "for all j"

Data envelopment analysis program (DEAP version 2.1) was used for DEA analysis. The efficiency analysis based on 3 frontiers were carried out: 1) Meta frontier, which analyses all farms data (n=247) and represents the southern rice farm performances, 2) Irrigated frontier, which analyses irrigated farms data (n=127) and represents the irrigated rice farm performances, and 3) Rain-fed frontier, which analyses rain-fed farms data (n=120) and represents the rain-fed rice farm performances.

Moreover, the statistical comparison the DEA scores between two agro-ecosystems was performed on the Meta frontier. Since the theoretical distribution of the efficiency score in DEA is usually unknown, the non-parametric Mann-Whitney U test was used to test for the differences of efficiency scores between two agro-ecosystems.

4.2.4 Tobit regression analysis

Tobit regression analysis was applied to investigate the factors affecting the efficiency of rice farms. The several variables hypothesized to affect efficiency include farmer characteristics, farm practices, and production environment as presented in Table 4.4.

The farmer characteristics consisted of years of attending in formal school (EDU), years of experience in growing rice (EXPERIENCE), number of household full-time labors (HH LABOR), rice farming objective (FARM OBJ), and land ownership (LAND TENURE). These variables were hypothesized to have a positive effect on farmer's technical efficiency, economic efficiency and environmental efficiency.

Table 4.4: Definition of variables used in Tobit regressions

Variable	Definition	Expected sign of affect on		
		TE	EE	ENE
Farmer characteristics				
EDU	Years attended in formal school	+	+	+
EXPERIENCE	Years experience growing rice	+	+	+
HH LABOR	Number of full-time household labors	+	+	+
FARM OBJ	1 for commercial objective 0 otherwise	+	+	+
LAND TENURE	1 for own the farm land 0 otherwise	+	+	+
Farm practices				
FARM SIZE	Size of farm	+	+	-
RICE VARIETY	1 for modern variety 0 otherwise	+	+	-
SEED REPLACEMENT	Number of paddy crops before new seed replacement	-	-	-
Production environment				
ECOSYSTEM	1 for irrigated area 0 for rain-fed area	+	+	-
PROVINCE	1 for Songkhla 0 for Phatthalung	+	+	+
SHRIMP EFFECT	1 for external effect from shrimp farming 0 for no external effect from shrimp farming	-	(NC)	(NC)

Remark: NC = not included in the model

The farm practices comprised size of rice farm (FARM SIZE), type of rice variety (RICE VARIETY), and number of paddy crops before new seed replacement (SEED REPLACEMENT). FARM SIZE and RICE VARIETY were hypothesized to have a positive effect on technical and economic efficiency, whereas, have a negative effect on environmental efficiency because increase in farm size and use of modern variety trend to apply more N-

fertilizer. SEED REPLACEMENT is hypothesized to have a negative effect on technical, economic, and environmental efficiency

The production environments consisted of rice agro-ecosystem (ECOSYSTEM), geographic location (PROVINCE), and negative external effect from shrimp farming (SHRIMP EFFECT). ECOSYSTEM was hypothesized to have a positive effect on technical and economic efficiency, while have a negative effect on environmental efficiency. PROVINCE is hypothesized to have a positive effect on technical, economic, and environmental efficiency. SHRIMP EFFECT is hypothesized to have a negative effect on technical efficiency.

The tobit regression function can be written as follows:

Efficiency = f (farmer characteristics, farm practices, production environment)

TE = f (EDU, EXPERIENCE, HH LABOR, FARM OBJ, LAND TENURE, FARM SIZE, RICE VARIETY, SEED REPLACEMENT, ECOSYSTEM, PROVINCE, SHRIMP EFFECT)

EE = f (EDU, EXPERIENCE, HH LABOR, FARM OBJ, LAND TENURE, FARM SIZE, RICE VARIETY, SEED REPLACEMENT, ECOSYSTEM, PROVINCE)

ENE = f (EDU, EXPERIENCE, HH LABOR, FARM OBJ, LAND TENURE, FARM SIZE, RICE VARIETY, SEED REPLACEMENT, ECOSYSTEM, PROVINCE)

4.2.4.1 Tobit model specification

Since the individual DEA efficiency score varies between at 0.00 and 1.00, this means the efficiency scores are double-truncated or censored at 0 and 1. Tobit regression model which can apply for this type of dependent variable is two-limit tobit model (Maddala, 1999) where 0 is lower limit and 1 is upper limit. The model is defined as (27):

$$y_j* = \beta_0 + \sum_{m=1}^{k} \beta_m x_{jm} + \mu_j, \quad \mu_j \sim IN(0, \sigma^2) \tag{27}$$

where y_j* is latent variable representing the efficiency score of farm j;

β is a vector of unknown parameters;

X_{jm} is a vector of explanatory variables m (m = 1,…, k) for farm j which is known constant and hypothesized as determinants of efficiency;

μ_j is an error term that is independently and normally distributed, with mean zero and a constant variance σ^2

Denoting y_j as the observed dependent variables,

$$y_j = \quad \begin{array}{l} 1 \\ y_j* \\ 0 \end{array} \left\{ \begin{array}{ll} \text{if} & y_j* \geq 1 \\ \text{if} & 0 < y_j* < 1 \\ \text{if} & y_j* \leq 0 \end{array} \right.$$

4.2.4.2 Model estimation

The latent variable or the dependent variable in above regression equation cannot have a normal distribution because its value varies between 0 and 1. The Ordinary Least Square (OLS) estimation will give biased estimates (Maddala, 1999). Therefore, the alternative approach is using the maximum likelihood estimation, which can yield the consistent, efficient, and asymptotically normally distributed estimates for unknown parameters vector.

Following Maddala (1999, p.161), the likelihood function for estimation β and σ of this model is given by (28)

$$L(\beta, \sigma \,/\, y_j, x_j, L_{1j}, L_{2j})$$

$$= \prod_{y_j = L_{1j}} \Phi\left(\frac{L_{1j} - \beta' x_j}{\sigma}\right) \prod_{y_j = y_j*} \frac{1}{\sigma} \phi\left(\frac{y_j - \beta' x_j}{\sigma}\right) \prod_{y_j = L_{2j}} 1 - \Phi\left(\frac{L_{2j} - \beta' x_j}{\sigma}\right) \tag{28}$$

here $L_{1j} = 0$ (lower limit) and $L_{2j} = 1$ (upper limit)

where $\Phi(\cdot)$ and $\phi(\cdot)$ are distribution function and density function of the standard normal, respectively

Denoting $\Phi\left(\dfrac{L_{1j} - \beta' x_j}{\sigma}\right)$ and $\Phi\left(\dfrac{L_{2j} - \beta' x_j}{\sigma}\right)$ by Φ_{1j} and Φ_{2ij}, respectively, with corresponding definitions for ϕ_{1j} and ϕ_{2j}, we get the expressions for E(y_j) as follows:

The conditional expectation of y_j is

$$E(y_j \,/\, L_{1j} < y_j* < L_{2j}) = \beta' x_j + E(u_j \,/\, L_{1j} - \beta' x_j < u_j < L_{2j} - \beta' x_j)$$

$$= \beta' x_j + \sigma \frac{\phi_{1j} - \phi_{2j}}{\Phi_{2j} - \Phi_{1j}}$$

The unconditional expectation of y_j is given by

$$E(y_j) = P(y_j = L_{1j}) \cdot L_{1j} + P(L_{1j} < y_j{}^* < L_{2j}) \cdot E(y_j / L_{1j} < y_j < L_{2j}) + P(y_j = L_{2j}) \cdot L_{2j}$$

$$= \Phi_{1j} L_{1j} + \beta' x_j (\Phi_{2j} - \Phi_{1j}) + \sigma(\phi_{1j} - \phi_{2j}) + (1 + \Phi_{2j}) L_{2j}$$

In practice, since the log function is monotonically increasing function, it is simpler to work with the log of likelihood function rather than likelihood function and the maximize values of these two functions are the same (GREENE, 2003: p 469-472).

LIMDEP software version 7.0 is used for two-limit Tobit regression analysis. The marginal effects of this model can be calculated from the LIMDEP results of as (GREENE, 1995):

$$\partial E(y_j / x_j) / \partial x_{jm} = \beta_m \cdot probability\ of\ noncensored\ observation$$

The two-limit Tobit regression analysis was based on technical, economic, environmental efficiency analysis results, and it can be grouped as: 1) factor affecting the efficiency of all farms, 2) factor affecting the efficiency of irrigated farms, and 3) factor affecting the efficiency of rain-fed farms.

5 Empirical Findings of the Field Study

The empirical findings of the field study describe the existing situation of rice farm households, which aim to answer the first objective of this study. The major rice production of the crop year 2004/05, farm practices and management, and farm household characteristics data of 247 rice farm households were obtained by interviews. The respondents were the ones who make decisions concerning all activities of rice faming or rice farm managers. The sample farm data were collected during July-October 2005. In addition, the sample farms were categorized by agro-ecosystems: 127 farms were located in irrigated areas and 120 farms in rain-fed areas.

The descriptive statistic analysis and cost-revenue and profitability analysis were used to summarize the important characteristics of respondents and to evaluate rice farm performances. In the following sections, background information of the study area is presented. Then the rice farm household information is explained. Farm household information is presented in terms of all sample farms representative of southern Thailand and is compared between agro-ecosystems, i.e. irrigated farms and rain-fed farms.

5.1 Background information of the study area

5.1.1 General background information

Southern Thailand has a long coastline, which western coastline is on the Andaman Sea (Indian Ocean) and eastern coastline is on the Gulf of Thailand (Pacific Ocean) (Figure 5.1). It comprises 14 provinces with 8.5 million populations. The fact that the contribution of agricultural sector in southern gross regional product is 35 percent (NESDB, 2004) highlights the importance of agricultural sector in the local economy.

Rice is predominantly grown on the eastern coast particularly around Songkhla Lake Basin (SLB), i.e. part of Nakhon Sri Thammarat, Songkhla, and Phatthalung provinces. Ranot district of Songkhla, and Muang district of Phatthalung provinces were selected as the study area (Figure 5.2). The location of the study area is about 900 kms south from the capital city (Bangkok). In addition, the Ranot district is approximately 90 kms from center of Songkhla province while the Muang district is only 0.20 kms from center of Phatthalung province.

The general information of the location of those two districts, the Muang district of Phatthalung is relatively more crowded than the Ranot district of Songkhla. The population density of Muang district is 287 people per sq. km. while of the Ranot district is 184 people per sq. km. In addition, 43 percent of total households of the Muang district are in municipality area while 39 percent of Ranot district are in municipality area.

Figure 5.1: Land use map of the southern Thailand
Source: PSU, 2005

Figure 5.2: Land use map of Songkhla Lake Basin and the study area
Source: PSU, 2005

At the provincial levels, however, per capita of gross provincial product (GPP) of Songkhla is relatively higher than Phatthalung. Moreover, the per capita GPP of Phatthalung is the second lowest among 14 provinces in southern region (NESDB, 2004). The GPP structure of Songkhla, agriculture contributed 25 percent to the GPP while it contributed 32 percent to the GPP of Phatthalung.

Ninety percent of crop production households in Songkhla and Phatthalung provinces apply chemical fertilizers while 27 percent used chemical pesticide (NSO, 2004). Rice planted areas of these two provinces share 36 percent of total rice planted areas of southern region (OAE, 2005). In addition, approximately 45 percent of rice planted areas in these two provinces are under irrigated projects. The characteristics of the study area are summarized in Table 5.1.

Table 5.1: Summarized of some characteristics of the study area

Item	Songkhla province	Ranot district	Phatthalung province	Muang district
Distant from district to provincial center (km)[1]	-	94	-	0.2
Total areas (sq.km)[1]	7,393.89	406.77	3,424.47	427.42
Population density (per sq.km)[1]	175	184	147	287
Number of dwellings[1]	343,577	19,505	134,264	34,194
HH in municipality area (%)	49	39	28	43
Per capita of Gross Provincial Products (THB)[2]	92,614	-	40,266	-
Use of chemical fertilizer in crop production (% of Ag.HH)[1]	90	-	90	-
Use of chemical pesticide in crop production (% of Ag.HH)[1]	27	-	27	-
Rice planted Areas (% of the southern region)[3]	17	-	19	-
Irrigated rice areas (% of rice planted areas)[3]	44	-	47	-

Source: [1] NSO, 2004   [2] NESDB, 2004   [3] OAE, 2005

5.1.2   Land use conflicts between rice farming and shrimp farming

Rice and shrimp farming are two important economic activities in rural southern Thailand that compete each other in land allocation leading to land use conflicts. Rice and shrimp farming are monoculture farming systems, which cannot be produced in the same fields. It can be observed that the conversion of rice fields to shrimp farms extended to the inlands, though contained to coastal areas initially, making more areas be saline which is essential condition for shrimp cultivation but deleterious for rice farming.

Even though shrimp area occupies a smaller proportion in land use compared to rice, the increasing of conversion of mangrove forests and rice fields to shrimp farms has significant effects on the ecological system and rice production in coastal areas. The higher short term financial benefit of shrimp farming prompts the conversion of rice farms. The issue of conversion from rice fields to shrimp farms is significant on the eastern coastline, especially in the Ranot district of Songkhla province. The trend of rice planted areas is not different from the general trend of the agricultural land use of the region which reported a decline from 66,350 ha in 1993 to 58,975 ha in 2002. But the shrimp cultivation areas show a reverse trend. In 2002, there were 1,773 shrimp farms in Songkhla province, which covered 2,452 ha or 10 percent of shrimp farming areas in southern Thailand and produced 10,914 tons of shrimp (OAE, 2005).

Shrimp farming activities are not only creating negative production externality to other shrimp farms but also affecting other activities nearby, especially rice fields. The shrimp farming external effects originate from untreated wastewater and the saline effluences discharged to common irrigation canals, groundwater, adjacent rice fields, and coastal ecosystems (THONGRAK et al., 1997; PAEZ-OSUNA, 2001). The negative effects of such discharges include the salinization of soil retard the plant growth, reduction of the rice yields and grain quality and destruction of the soil properties (KHACHATHONG, 2004; ALI, 2006). Another issue is the persistence of these effects over a longer time period (TOWATANA et al., 2002). These conversions to shrimp farming are unsustainable because of the multiple issues of water quality decline, viral and bacterial disease outbreaks, sediment disposal difficulties that lead to a quick decline in shrimp yields (CHARERNJIRATRAGUL et al., 2003; BARBIER and COX, 2004). Moreover, farms are routinely abandoned after 5-6 years of production and reclamation of abandoned ponds is very complicated, costly, and economically infeasible (PAEZ-OSUNA, 2001; TOWATANA et al., 2002; CHARERNJIRATRAGUL et al., 2003; BARBIER and COX, 2004).

Presently, most of the shrimp farms are small-scale intensive production units (CHARERNJIRATRAGUL et al., 2003) which use the high stocking and feeding rates creating highly polluted wastewater as an undesirable by-product. In addition, the cultured shrimp species has been changed from Black Tiger shrimp (Penaeus monodon) to White shrimp

(*Litopenaeus vannamei*) because the latter gives higher yield and less susceptible to the diseases.

5.2   Rice farm household characteristics

In this section, characteristics of rice farm households, i.e. main occupation, objective of rice farming, member of organization, human resources, and land resources of the households as well as household assets and debts are discussed.

5.2.1   Main occupation and member of organization

Rice farming is the main occupation of the sample households. The results of the survey showed that approximately 95 percent of the households in both agro-ecosystems are mainly produce rice. In addition, 75 percent of the sample households do not engage in other activities after harvesting their rice, and the remaining 25 percent grow vegetables or raise livestock (especially cows and buffaloes) (Table 5.2). This implies that way of life of the sample farm households depends very much on rice farming activities as well as rice culture and tradition.

The main objective of rice farming in the south of Thailand is to produce rice for household consumption or to enable food self-sufficiency of the household and to sell the surplus amounts to local market. In other words, most of the households are semi-subsistence or semi-commercial rice producers. According to the field study results, 72 percent of total sample households were semi-commercial rice producers, and 14 percent equally were subsistence and commercial rice producers (Table 5.2). Commercial rice producers are farmers who sell all paddy rice produce and purchase milled rice from the market for their household consumption.

In irrigated agro-ecosystems, approximately 8 percent and 80 percent of irrigated farms were subsistence and semi-commercial rice producers, respectively (Table 5.2). In contrast, approximately 21 percent and 64 percent of rain-fed farms were subsistence and semi-commercial rice producers, respectively. This implies that the rice farmers in irrigated areas can produce more surplus amounts than the farmers in rain-fed areas.

More than half of the respondent households were members of the Bank of Agriculture and Agricultural Cooperatives (BAAC), an agency where farmers can obtain short-term and long-term loans and participate in the paddy mortgage project. In addition, they were members of agricultural cooperatives, village saving groups, farmer groups and women groups. Only 17 percent of the respondent households were not members of any group or organization.

Table 5.2: Characteristics of rice farm households in southern Thailand

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Main occupation			
Rice farming	96.85	95.00	95.95
Tree plantation	-	0.83	0.40
Off-farm activity	3.15	4.17	3.64
Objective of rice farming			
Subsistence farming	7.87	20.83	14.17
Semi-commercial farming	79.53	64.17	72.06
Commercial farming	12.60	15.00	13.77
Member of group/organization*			
BAAC	54.33	57.50	55.87
Agricultural cooperatives	26.77	18.33	22.67
Village saving group	18.90	24.17	21.46
Women group	6.30	9.17	7.69
Farmer group	5.51	5.83	5.67
Village fund	4.72	4.17	4.45
Non-member	16.54	16.67	16.60

Source: field survey
Remark: * farmers can be member of more than one group or organization

5.2.2   Human resources

The average farm family of the respondent households was of medium size, which means that it consisted of 4 members. The results showed no statistically significant difference in average farm family between irrigated and rain-fed areas (Table 5.3). This family size is relatively similar to the average family size of rice farmers in Taiwan, whose family size consists of 3.67 members (HUANG et al., 2002), but relatively smaller than the average family size of rice farmers in Nepal (7.83 members) (DHUNGANA et al., 2004) as well as in Ghana (8.4 members)(ABDULAI and HUFFMAN, 2000).

The farm family labor force was calculated in terms of male-equivalent unit (ME) by adjusting age and gender of farm family labor. The results showed that half of family members or approximately two persons were household labors working in rice farming. The results also showed no statistically significant difference in average household labors between irrigated and rain-fed areas (Table 5.3). The number of farm family labors of this study is consistent with the findings in the central and northeast regions which have only two adults working on the farm

(PINGALI *et al.*, 1997). The calculation of farm family labor force in ME for all samples, for example, is presented in Table 5.4.

Table 5.3: Human resources of rice farm households in southern Thailand

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Farm family size (members)			
Mean	3.88	3.94	3.91
Standard deviation	1.39	1.62	1.51
t-value		-0.31^{NS}	
Farm family labor (ME)			
Mean	1.53	1.70	1.62
Standard deviation	0.06	0.79	0.70
t-value		-1.91^{NS}	

Source: field survey
Remark: NS = statistically non-significant

Table 5.4: The calculation of farm family labor in male-equivalent unit for all samples

Age	Male-equivalent scale[1]				Average members per household				ME unit
	Full-time		Part-time		Full-time		Part-time		
	Male	Female	Male	Female	Male	Female	Male	Female	
< 15 years	0.50	0.50	0.25	0.25	-	-	-	-	0.00
15-60 years	1.00	0.80	0.50	0.40	0.68	0.68	0.21	0.19	1.41
> 60 years	0.60	0.60	0.30	0.30	0.17	0.15	0.03	0.03	0.21
Farm family labor in the south (ME per household)									1.62

Source: field survey
[1] adapted from KIATPATHOMCHAI, 1995

5.2.3   Land resources

Rice farmers in the study area were small farm holders on fragmented land holdings. The average rice farm size of the sample farms was approximately 2.8 ha, which is lower than the average farm size of the country (3.7 ha) and of the southern region (3.5 ha) (OAE, 2005). Moreover, this farm size was divided into two to three paddy plots and average plot size was 1.5 ha. The results showed no statistically significant differences in average farm size and plot size between irrigated and rain-fed areas (Table 5.5). Nevertheless, this farm size is larger than average rice farm size in China, which is only 0.43 ha (HOSSAIN, 1998).

The sample farmers were asked about land tenure of rice fields. Land ownership has influences on investment incentives and the availability of resources to finance farm investment as well as land improvement investment (FEDER and ONCHAN, 1987). The results of the survey showed that approximately 80 percent of the respondent households were farming on their own land and the remaining farming on rented land. Results were similar in both irrigated and rain-fed areas (Table 5.5).

The location of the paddy plots of the sample farms were not far away from their home: the average distance was 1.7 kilometers (Table 5.5). Motorcycle and bicycle were popular modes of transportation for farmers going to their fields. The results showed no statistically significant difference in average distance from farmers' home to the paddy fields between irrigated and rain-fed areas. Most of the paddy fields were in plain areas or so-called low land rice fields.

Table 5.5: Land resources of rice farm households in southern Thailand

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Farm size (ha)			
Mean	2.85	2.81	2.83
Standard deviation	2.25	2.95	2.61
t-value	0.12^{NS}		
Plot size (ha)			
Mean	1.54	1.41	1.48
Standard deviation	1.59	1.76	1.67
t-value	0.69^{NS}		
Land tenure (%)			
Owned	82.68	82.50	82.59
Rented	17.32	17.50	17.41
Distance from home to paddy field (km)			
Mean	1.63	1.79	1.71
Standard deviation	1.68	3.54	2.74
t-value	-0.45^{NS}		

Source: field survey
Remark: NS = statistically non-significant

5.2.4 Farm assets and debts

In this study, farm fixed assets are presented in terms of present market (closing) values. They were calculated using a straight-line method of depreciation by assuming zero salvage value. The following farm assets were considered: paddy land (present market values), walking tractor (15 years useful life), pumping machine (10 years useful life) and water pipe (8 years useful life).

The results of the survey showed that water pumping machines and water pipes were more important assets in irrigated than in rain-fed areas. However, the farmers in rain-fed areas whose paddy fields were located close to the natural reservoir invested in this equipment as well. The average total value of farm assets was 657,047 THB or approximately 13,140 euros per household. The average total value of farm assets of irrigated farms was higher than that of rain-fed farms due to higher land values (Table 5.6).

Results concerning on farm debts showed that 70 percent of the respondent households have had debts and most of them were borrowing money for rice farming purposes from both institutional and non-institutional sources. The average amount of debts of the household was 90,000 THB or approximately 1,800 euros on the average. The results showed that the farmers had average total debts lower than average total assets, but higher than average total assets excluding land values.

Table 5.6: Farm assets and debts of rice farm households in southern Thailand

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Farm assets (THB/farm)			
- paddy land values	681,267	590,806	636,723
- walking tractor	16,337	18,464	17,370
- water pumping machine	2,746	1,376	2,080
- water pipe	1,260	465	874
Total assets	701,610	611,111	657,047
Total assets excluding land values	20,343	20,305	20,324
Farm debts			
No (%)	26.77	30.00	28.34
Yes (%)	73.23	70.00	71.66
Total debts (THB/farm)	93,376	85,417	89,599

Source: field survey

5.2.5 Organization of farm business

Farm business can be organized as sole proprietorship, partnership, or corporation (VARIAN, 2003). In the case of rice farms, they were the sole proprietorship form of business organization: rice farms were owned and operated by individual farm households. The owner managed the rice farm day-to-day and was ultimately responsible for the success or failure of the farm performances.

5.3 Farmer characteristics

Farm management has become a very complex mission for farm managers and farmers during recent years. Farmers have to face and adjust to the changing environment and new technologies. This section describes the characteristics of rice farmers who act as farm managers with respect to age, gender, education and experiences.

5.3.1 Age and gender of rice farmers

The average age of rice farmers of the all samples was 50.93 years old. The average age of rice farmers in irrigated areas was slightly lower than in rain-fed areas, but the difference in average age was statistically not significant between these two agro-ecosystems (Table 5.7). Moreover, approximately 42 percent of farmers were male.

The average age of farmers of this survey was relatively lower than the average age of rice farmers in northern Thailand (54.16 years) (CHAOWANAPOONPOL *et al.*, 2005) and in Taiwan (58.29 years) (HUANG *et al.*, 2002), but higher than the average age of rice farmers in Ghana (39.2 years) (ABDULAI and HUFFMAN, 2000) and Nepal (47.15 years) (DHUNGANA *et al.*, 2004).

5.3.2 Education and experiences of rice farmers

Educational level and experiences of rice farmers are used to investigate the human capital of rice farms. Approximately 75 percent of the rice farmers finished the primary school; the average duration of schooling of whole samples was 5.69 years. Farmers in the irrigated areas had on average more years of schooling than in rain-fed areas, although the differences in average years of schooling were not statistically significant between these two agro-ecosystems (Table 5.7). This finding is relatively similar to the average duration of schooling of the rice farmers in northern Thailand (5.02 years) (CHAOWANAPOONPOL *et al.*, 2005). Furthermore, the duration of schooling of this study is relatively lower than average schooling years of the rice farmers in Taiwan (7.00 years) (HUANG *et al.*, 2002), but higher than average schooling of the rice farmers in Ghana (3.66 years) (ABDULAI and HUFFMAN, 2000) and Nepal (4.22 years) (DHUNGANA *et al.*, 2004).

More than 50 percent of the rice farmers have had experiences with rice farming for more than 20 years. In other words, the farmers had an average of 27 years of experiences in rice farming. The farmers in the irrigated areas had relatively lower experience than in rain-fed areas. Nevertheless this difference was statistically not significant between these two agro-ecosystems (Table 5.7). Farming experience is relatively higher than the average experiences of the rice farmers in northern Thailand (24 years) (CHAOWANAPOONPOL *et al.*, 2005).

Table 5.7: Characteristics of rice farmers in southern Thailand

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Age (years)			
Mean	50.04	51.87	50.93
Standard deviation	12.16	13.26	12.71
t-value	-1.13[NS]		
Gender (%)			
Female	59.06	57.50	58.30
Male	40.94	42.50	41.70
Education (years)			
Mean	6.06	5.30	5.69
Standard deviation	3.39	2.99	3.22
t-value	1.85[NS]		
Experiences in rice farming (years)			
Mean	26.07	28.25	27.13
Standard deviation	13.71	14.27	13.99
t-value	-1.22[NS]		

Source: field survey
Remark: NS = statistically non-significant

5.4   Rice production: Resources and farm management

5.4.1   Land resources management

5.4.1.1 Rice cropping pattern

Rice is a monoculture farming system in the study area. The duration of each crop production, from land preparation till harvest, lasts approximately six months. The planting period in the southern region differs from the other regions of the country, which is mainly because of differences in geographical latitude location and weather conditions.

As expected, most of the farmers in irrigated areas planted rice in two crops a year: the major (wet) crop and the second (dry) crop. For the crop year 2004/05, rice cropping patterns of the two agro-ecosystems are shown in Figure 5.3. In irrigated areas, the duration of the major crop was from October to March. Then, after harvesting the rice of the major crop, the farmers started a second crop, which continued from April to September. In contrast, in rain-fed areas, rice could be grown only for the major crop which was similar in duration to the major crop in irrigated areas. The exact planting period of each farm depended on the rice varieties used and on water resources or amounts of rainfalls. This cropping pattern may indicate that the farmers in irrigated areas who produced two rice crops per year can get higher benefits or income (from rice) than the farmers in rain-fed areas.

Year 2004				Year 2005								
Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.

Irrigated Area

Major Crop or Wet Season   **Second Crop**

Rain-fed Area
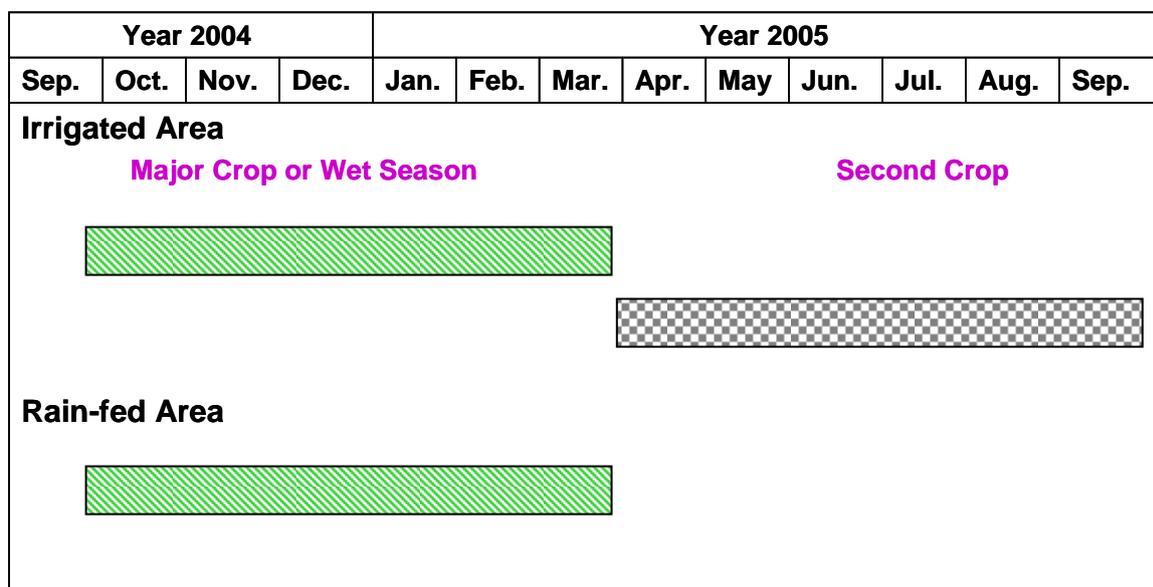
Figure 5.3: Rice cropping pattern of two agro-ecosystems in the crop year 2004/05
Source: field survey

5.4.1.2 Soil type and soil property testing

As the field study was done in the Ranot district, Songkhla province and the Muang district, Phatthalung province, information on soil types of the study areas was collected from the Land Development Department (LDD). Most of the soils in the Ranot district are classified as Ranot series, while most of the soils in the Muang district are classified as Bang Nara series (LDD, 2006). The Ranot series is characterized by medium levels of soil fertility. It is the most suitable soil for rice farming while it is less suitable for rubber tree plantations. However, also the Bang Nara series is suitable for rice farming, although its fertility is lower as compared to the Ranot series.

The sample farmers were asked how frequently they test the soil quality of their rice fields. Soil analysis is an important tool for rice farmers since it provides information about the current soil conditions and helps to allocate nutrients, especially chemical fertilizers, in an efficient way. The results of the survey showed that approximately 80 percent of the sample farms have never checked their soil properties and quality, and only 8 percent of the sample farms regularly tested their soils (Table 5.8). In summary, the farmers have been growing rice for more than 20 years but most of their rice fields have never been tested for soil properties.

These findings show that different soil types in two provinces may be responsible for differences in efficiency of rice production, and lack of soil property testing may lead to inefficiency of use of fertilizers.

Table 5.8: Soil quality testing of rice farms

Soil testing	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Never	71.65	84.17	77.73
Tested only once long time ago	19.69	9.17	14.57
Tested regularly	8.66	6.67	7.69

Source: field survey

5.4.2   Labor management

Rice farming is highly labor intensive. Labor is involved in every process of production, i.e. land preparation, seeding preparation and planting, crop care, harvesting, and post-harvesting. Presently, tractors and combined harvesting machines are widely used for rice production in southern Thailand.

5.4.2.1 Human labor management

As discussed earlier in section 5.2.2, the average farm family labor was half of the households' member or 1.6 male equivalent units. Most of the farmers utilized their family's labor for the following activities: seed preparation and seed broadcasting, water management, fertilizer and pesticide applications. Due to farmers' concern about side effects of chemical inputs (fertilizer and pesticide) on their health, some farmers employed labor for all chemical inputs applications and some hired labor only for pesticide applications.

One of the important activities related to the human labor requirements is planting method. The planting of rice in Thailand can be divided into two major methods: seedling transplanting and direct seeding (broadcasting). The direct seeding can be categorized into dry seed direct seeding and pre-germinated direct seeding. The direct seeding planting method requires less intensive

labor and water than seedling transplanting. However, direct seeding planting method requires more intensive land preparation process to avoid weed problem (DOAE, 2002) otherwise more herbicide need to be applied (ISVILANONDA and WATTANUTCHARIYA, 1994).

Direct seeding method becomes very popular in the study area, due to the labor shortage and high labor opportunity cost. The results of the survey showed that 95 percent of the whole sample farmers were planting rice by using direct seeding method. In addition, the pre-germinated direct seeding method was popular for growing rice in the study area (Table 5.9). Most of the farmers (95 percent) in irrigated areas were using pre-germinated direct seeding method. While approximately 73 percent and 19 percent of the farmers in rain-fed areas were using pre-germinated and dry seed broadcasting, respectively.

These findings show that the existing farm family labor forces may be sufficient for producing rice at the present time because the patterns of using human labor are changed to depend much more on mechanical power. The details of machinery use are discussed in the following sub-section.

Table 5.9: Planting method of rice farming in the crop year 2004/05

Planting method	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Dry seed broadcasting	2.36	19.17	10.53
Pre-germinated seed broadcasting	95.28	72.50	84.21
Seedling transplanting	2.36	8.33	5.26

Source: field survey

5.4.2.2 Machinery management

Mechanization as human labor-saving technology becomes very popular use in rice production in southern Thailand, especially involving in land preparation and harvesting activities. The farmers have to utilize their farm machinery during the rice production process: use walking tractors or hired tractors for land preparation and use water pumping machines for control of water levels in the rice fields.

The results of the survey showed that approximately 50 percent of the farmers hired tractors for land preparation and most of farmers ploughed their land two times before growing rice. In addition, all farmers (100 percent) hired the combined harvesting machines to harvest the paddy rice from their fields.

5.4.3   Rice variety and seed management

5.4.3.1 Rice variety and diversity of rice variety

Rice variety is known as one of technologies for rice production. Rice variety can be grouped as 1) glutinous and non-glutinous 2) modern and traditional 3) photoperiod sensitive and non-photoperiod sensitive.

The results showed that all farmers were growing non-glutinous rice. Approximately 60 percent of farms planted modern varieties, i.e. Chai Nat 1, Suphan Buri 1, Suphan Buri 2, and Pathum Thani 1. Chai Nat 1 was the most popular modern variety (85 percent of modern varieties). The other properties of these modern varieties are non-photoperiod sensitive. In fact, these modern varieties have been grown and suitable for growing in the central plain and lower northern parts of Thailand, particularly it is suitable for irrigated areas (DOAE, 2000; DOAE, 2002). The milled rice of these modern varieties can be used for both domestic consumption and export.

In addition, the remaining 40 percent of farms planted traditional varieties, i.e. Khao Dok Mali 105, Chiang Phatthalung, Leb Nok Pattani, Malay, Kreb Maek, Kree Hom, Kaab Dam, Keam Thong Phatthalung, and Sung Yood. The widespread of traditional varieties were Chiang Phatthalung and Leb Nok Pattani, which grown by 51 percent and 32 percent of traditional varieties, respectively (Table 5.10). These traditional varieties are suitable for southern Thailand. The other properties of these varieties are photoperiod sensitive. The milled rice of these varieties can only be used for domestic consumption.

In irrigated areas, 71 percent of irrigated farms planted modern varieties, and Chai Nat 1 was grown by 91 percent of these farms. The remaining 29 percent of irrigated farms planted traditional varieties, and Chiang Phatthalung was planted by 78 percent of these farms.

In rain-fed areas, 53 percent of rain-fed farms planted traditional varieties. Chiang Phatthalung and Leb Nok Pattani were planted by 34 percent and 39 percent of these farms, respectively. The remaining 47 percent of rain-fed farms planted modern varieties, and Chai Nat 1 was grown by 77 percent of these farms.

From this finding, it can be concluded that Chai Nat 1 is the modern variety while Chiang Phatthalung is the traditional variety, which widespread planted in both agro-ecosystems. Moreover, Leb Nok Pattani is the traditional variety, which is popular used in rain-fed areas. The diversity of rice variety is found in traditional variety. The increasing use of the modern varieties in southern region is probably because of the non-photoperiod sensitive property, which farmers can calculate the exact harvesting day.

Table 5.10: Rice variety and seed management

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Type of rice variety			
Modern	**70.87**	**46.67**	**59.11**
Chai Nat 1	91.11	76.78	84.93
Others	8.89	23.22	15.07
Traditional	**29.13**	**53.33**	**40.89**
Chiang Phatthalung	78.38	34.38	51.48
Leb Nok Pattani	18.42	39.06	31.68
Others	3.20	26.56	16.84
New seed replacement			
Replaced every crop	16.54	15.00	15.79
Replaced every 2 crops	22.83	14.17	18.62
Replaced every 3 crops	9.45	14.17	11.74
Replaced every 4 crops	4.72	0.83	2.83
Replaced after > 4 crops	46.46	55.84	51.01

Source: field survey

5.4.3.2 New seed replacement

The rice seed can be collected from the paddy rice of this season and used for planting in the next season. However, if the farmers keep their grain as rice seed from the same seed lots over time, it will be affected on reducing yields and grain quality due to the genetic erosion of seed. The recommendation for new seed replacement, one seed lot can be used for farming three to four crops and then have to replace or change to use the new seed lot (DOAE, 2002).

The results of the survey showed that only 15 percent of the farmers replaced new seed every season. On the contrary, 51 percent of the farmers replaced new seed after they used or planted it for more than four seasons (Table 5.10). This means that the farmers bought new seed lot once and have used it for more than four crops by collecting seed from their paddy rice and keeping it for the next season.

These findings show that number of crop before new seed replacement may affect on the efficiency of rice production. Especially in case of the farmers collect their own seed from their paddy rice, farmers should have enough knowledge and skills to select and produce the pure genetic seed and good seed quality. Therefore, the farmers may need more information or training on these issues, which would be provided by research and extension officers or rice seed distribution center.

5.4.4 Environmental detrimental inputs management

5.4.4.1 Fertilizer

All farmers in the study area applied chemical fertilizers for rice production. Two types of chemical fertilizers: Diammonium phosphate (DAP) and Urea were used. Most of the farmers applied chemical fertilizers two times per crop. The farmers usually apply DAP as a basal fertilizer at 20-25 days after pre-germinated seed broadcasting and approximately one month later, they apply urea as dressing fertilizer. In addition, the results of the survey showed that farmers did not apply green manure and organic fertilizers as other sources of nitrogen on the rice fields.

5.4.4.2 Insecticide and fungicide

In rice production process, various types of chemical insecticide and fungicide are applied. As all farms results, 37 percent of farms applied chemical insecticide and fungicide for pest control and plant protection during rice production process. Approximately 50 percent of farms in irrigated areas applied chemical insecticide and fungicide, while only 24 percent of farms in rain-fed areas applied them (Table 5.11). Most of the farmers, who used chemical insecticide and fungicide, applied them only once per crop. This finding shows that the rain-fed farmers applied less insecticide and fungicide than the irrigated farmers. It is probably related to the high proportion of modern varieties planted in irrigated areas.

5.4.4.3 Herbicide

Only 20 percent of all sample farms applied chemical herbicide for weed control during rice production process. Approximately 27 percent of farms in irrigated areas applied chemical herbicide, while only 12 percent of farmers in rain-fed areas applied it (Table 5.11). Again similar to the chemical insecticide and fungicide applications, most of the farmers applied chemical herbicide only once per crop. This finding shows that the rain-fed farmers applied less chemical herbicide than the irrigated farmers.

However, the most important environmental detrimental input for rice production in the south of Thailand is chemical fertilizer, which is applied in all rice farms.

Table 5.11: Environmental detrimental inputs management

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Chemical fertilizer use			
No	0.00	0.00	0.00
Yes	100.00	100.00	100.00
Chemical insecticide and fungicide use			
No	51.18	75.83	63.16
Yes	48.82	24.17	36.84
Chemical herbicide use			
No	73.22	87.50	80.16
Yes	26.77	12.50	19.84

Source: field survey

5.4.5 Water management

5.4.5.1 Sources of water for rice production in the study area

Rice is a crop with high water demands. It requires approximately 6,500 cubic meters of water per crop per ha. In both agro-ecosystems, main source of water use for the major crop is rainfall. In irrigated areas, nevertheless, water from the irrigation projects can be provided during late of the major season.

Thus, rice farming in southern Thailand is inevitably affected by variation of weather conditions especially the amount of rainfall. During the field study, rainfall statistics in the study area were collected and summarized in Table 5.12. Average rainfall in the province of Songkhla has been lower than in that of Phatthalung over the past nine years (1996-2004). In the year 2004, annual rainfall was lower than the nine years average in both provinces. Especially during the production period (October to February) of the major crop year 2004/05, the accumulate rainfall was much lower than nine years average (1996/97-2004/05). This may imply that rice farms in the study area faced a drought problem during the major crop year 2004/05.

The Ranot irrigation project serves as water source for the irrigated study areas in the Ranot district, Songkhla while the Na Tom irrigation project serves the irrigated study areas in the Muang district, Phatthalung. In the major crop year 2004/05, the Ranot irrigation project was pumping water for irrigation during December 2004- February 2005 (RIP, 2005) whereas the Na Tom irrigation project was able to supply water during November-December 2004 (NTIP, 2005).

Table 5.12: Rainfall statistics in the study area during the major crop year 2004/05

Item	Rainfall (mm.)	
	Songkhla[1]	Phatthalung[2]
Average annual rainfall of 1996-2004	2,363.0	2,705.1
Average rainfall of 2004	1,910.4	1,942.3
Average accumulative rainfall of Oct.- Feb. 1996-2005	1,618.9	1,794.0
Accumulative rainfall of Oct.- Feb. 2004-2005	1,252.6	1,204.0

Source: [1]RIP (Ranot Irrigation Project), 2005

[2]NTIP (Na Tom Irrigation Project), 2005

5.4.5.2 *Water management during production period*

During rice growing period, approximately 57 percent of the farmers had to look after rice in the fields by checking flooded levels every week especially in the early stage of rice vegetation (Table 5.13). Normally the flooded levels in the rice fields are controlled at 10-20 cm. If flooded levels are below the requirement levels and water in the nearby canals is available, the farmers will use water pumping machines to pump the water from the canals into their fields.

Before harvesting paddy rice, farmers have to drain water out of the fields. The results of the survey showed that most of the farmers (82 percent) drained the water to the nearby canals (Table 5.13). This drainage water is probably a source of nitrate leaching to the surface and groundwater.

Table 5.13: Farmers' water management for rice production

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Water level control and management			
Checking every week	60.63	54.17	57.49
Checking every two weeks	16.54	10.83	13.77
Checking depends on situation	22.83	35.00	28.74
Water drainage before harvesting			
No drainage	11.02	25.00	17.81
Drain into small canal / natural reservoir nearby the field	88.98	75.00	82.19

Source: field survey

5.4.5.3 Drainage water quality

As the previous results, 82 percent of the farmers drained the water to the nearby canals before harvesting rice. In this section, drainage water quality of rice production is focused. The drainage water quality data were collected from the Pollution Control Department (PCD) and Regional (southern) Environmental Office (REO) of Thailand.

The quality of drainage water from rice fields is presented in terms of biological oxygen demand (BOD). The major crop production drained 5,125 cubic meters per ha and the second crop drained 3,050 cubic meters per ha (PCD, 2005). In other words, the major crop drained much more amount of water than the second crop to the environment. In contrast, BOD figures of the major crop were lower than the second crop. However, the BOD results in both crops were below the maximum level of water pollution index, which is 20 mg per liter. The details are as presented in Table 5.14.

Table 5.14: Comparison of drainage water quality between the major crop and second crop of rice production in Thailand

	Rice production	
Water quality	Major crop	Second crop
Drainage water from rice field (cu.m./ha)	5,125	3,050
BOD (mg/lit)	2.4	5.5
BOD (kg/ha/day)	0.03	0.04

Source: PCD, 2005

The water quality of Songkhla Lake Basin (SLB) is investigated by sampling from 30 stations, 3 periods of time in a year (REO, 2006). The data of Ranot and Na Tom stations during 2004-2005 were used as a proxy of water quality of rice production in the crop year 2004/05. Let assume that the water sampling results of August 2004, November 2004, and March 2005 were represented of before planting, during production, and after harvesting periods, respectively.

The results of Ranot station showed that the figures of all indicators during production were lower than before planting and after harvesting. While the results of Na Tom station showed that the figures of all indicators during production were lower than before planting and after harvesting except BOD. The BOD figure during production of Na Tom station was relatively higher than before planting, but lower than after harvesting. The water quality indicators during rice production period are presented in Table 5.15.

Table 5.15: Water quality of the study area during rice production process of the major crop year 2004/05

Indicator	Ranot station			Na Tom station		
	Before planting (Aug, 2004)	During production (Nov, 2004)	After harvesting (Mar, 2005)	Before planting (Aug, 2004)	During production (Nov, 2004)	After harvesting (Mar, 2005)
Water temperature (^{o}C)	32.0	27.0	33.0	30.0	26.0	32.0
pH	7.7	6.8	7.4	7.6	6.9	7.0
Salinity (ppt)	0.0	0.0	0.0	0.0	0.0	0.0
DO (mg/l)	4.600	0.600	4.200	7.400	6.800	3.400
BOD (mg/l)	5.660	2.100	4.700	0.820	1.100	2.600
NO_2-N (mg/l)	0.015	0.003	0.002	0.005	0.006	0.015
NO_3-N (mg/l)	0.170	0.051	0.217	0.030	0.063	0.122
NH_3-N (mg/l)	0.440	0.023	0.120	0.170	0.020	0.110

Source : REO, 2006

Moreover, the results showed that nitrate nitrogen (NO_3-N) after harvesting of both stations was highest compare to before planting and during production. However, the nitrate nitrogen results were very much below the drinking water standards of the World Health Organization (WHO), which allows maximum level of nitrate contamination at 10 mg per liter.

5.4.6   Rice farming information

Information about rice farming is very important for the farmers to enhance their knowledge on new technology innovations, and production and market situations, which can be used to improve their production. Approximately 70 percent of farmers were contacted by agriculture extension officers.

The farmers were asked about sources of rice farming information. Approximately 60 percent of the farmers have got information from the discussions with their neighboring farmers. In addition, 60 percent of the farmers have got information from government officers, i.e. the extension office and rice research center (Table 5.16). These findings show that the agriculture officers from both extension offices and research centers are very important as sources of rice farming information.

Table 5.16: Source of rice farming information of the farmers in the study area

Item	Agro-ecosystem		Southern region (n=247) (%)
	Irrigated (n=127) (%)	Rain-fed (n=120) (%)	
Extension officer contact			
No	27.56	31.67	29.55
Yes	72.44	68.33	70.45
Source of rice farming information*			
Neighboring farmers	62.99	56.67	59.92
Extension office	48.82	44.17	46.56
Research office/center	16.54	12.50	14.57
Radio/Television	11.02	9.17	10.12
Government printed document	10.24	9.17	9.72
Newspaper/Magazine	2.36	0.83	1.62
Ag-chemical shop/company	7.87	5.83	6.88
Own experience	9.45	16.67	12.96

Source: field survey

Remark * one farmer can get information from more than one source

5.5 Inputs use and paddy rice output of rice production in southern Thailand

As discussed in previous section, the farmers in the study area were fragmented landholders. Thus, details of amount of inputs (factors) use and paddy rice output per plot of the major crop year 2004/05 were interviewed. Rice production inputs can be divided into fixed inputs and variable inputs, while the (desirable) output is paddy rice. In this section, paddy rice and paddy as well as output are used as interchangeable words. The average inputs and output per ha are discussed. These findings are used further for efficiency analysis: technical, economic, and environmental. The details of efficiency analysis are discussed in Chapter 6.

5.5.1 Inputs use of rice production

5.5.1.1 Fixed inputs

In this study, land is only one fixed input, which uses for short run rice production. The average plot size of the whole sample was 1.48 ha. In agro-ecosystems, the average plot size of the irrigated farms was 1.54 ha, while of the rain-fed farms was 1.41 ha (Table 5.17).

Table 5.17: Average inputs use and average paddy rice output of rice production in the major crop year 2004/05

Variable	Unit	Agro-ecosystem				Southern region (n=247)	
		Irrigated (n=127)		Rain-fed (n=120)			
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Inputs							
Land (plot)	ha	1.54	1.59	1.41	1.76	1.48	1.67
Labor	man-hr / ha	27.21	11.96	24.80	11.08	26.04	11.58
Machine	THB / ha	3,286.17	1,370.62	3,296.18	2,005.46	3,291.03	1,562.50
Seed	kg / ha	152.84	37.34	149.91	38.26	151.41	37.74
DAP	kg / ha	186.36	52.33	180.42	53.32	183.48	52.79
Urea	kg / ha	110.20	44.21	102.04	36.17	106.24	40.63
Output							
Paddy rice	kg / ha	3,695.47	838.85	3,111.15	698.19	3,411.59	825.75
t-value		5.15**					

Source: field survey

5.5.1.2 Variable inputs

The major variable inputs for rice production consist of human labor, machine labor, seed, and chemical fertilizers. Human labor is involved in every process of production, i.e. land preparation, seeding preparation and planting, crop care and harvesting. The all farm results showed that the average labor requirements per ha was 26.04 man-hour. The machine labor is presented as cost (money term) because the farmers have to hire machine and pay the hired cost per ha. The all farm results showed that the average machine labor cost was 3,291 THB per ha.

Average seed rate was 151.41 kg per ha. This seed rate is higher than recommended seed rate for direct seeding method, which is ranging between 95 and 125 kg per ha (DOAE, 2002). The chemical fertilizer can be divided into amounts of DAP and urea. Average DAP and urea fertilizers rates were 183.48 and 106.24 kg per ha, respectively. Moreover, the average of all variable inputs use per ha in irrigated farms were higher than in rain-fed farms, except the machine labor cost. The details of variable inputs use in irrigated and rain-fed areas are presented in Table 5.17.

5.5.2 Paddy rice output and output management

5.5.2.1 Paddy rice output

The paddy output of the whole sample farms was ranging between 2.5– 5.5 ton per ha. The average of paddy rice output in irrigated areas was 3.69 ton per ha, while in rain-fed areas was 3.11 ton per ha. The differences of output between irrigated and rain-fed farms were statistically significant.

5.5.2.2 Output management

Output management is related to the objective of rice farming of each farm. The subsistence farms kept the paddy for household consumption, semi-commercial farms kept amounts of paddy for whole year household consumption and sell the excess amounts, and commercial farms sold all paddy rice to the market. Approximately 85 percent of whole sample farms sold their paddy after harvesting.

In addition, no farmer joined the paddy mortgage project. Two basic marketing channels of paddy rice were observed: the farmers sold their paddy at farm-gate and/or at milling-gate. Most of the semi-commercial and commercial farms sold their paddy at farm-gate to the middlemen and only 5 percent sold their paddy at milling-gate (Table 5.18). In case of the farmers sold paddy at milling-gate, it means that those farmers have to do one marketing function: transportation.

Table 5.18: Paddy output management

Item	Agro-ecosystem		Southern region (%)
	Irrigated (%)	Rain-fed (%)	
Management of output	(n=127)	(n=120)	(n=247)
Keep for household consumption only	7.87	18.33	12.96
Sell paddy after harvesting	92.13	81.67	87.04
Point of sell	(n=117)	(n=98)	(n=215)
At farm-gate	94.02	97.96	95.81
At milling-gate	5.98	2.04	4.19
Paddy form for selling	(n=117)	(n=98)	(n=215)
Green paddy after harvesting	98.29	91.84	95.35
Dry paddy at 14-15% moisture content	1.71	8.16	4.65

Source: field survey

Two selling forms of paddy were observed: green paddy which has high moisture content, and dry paddy which has 14-15 percent moisture content. Most of the farmers (95 percent) sold their paddy as green paddy to the market (Table 5.18). In case of the farmers sold their paddy as dry paddy, it means that those farmers have to do one marketing function; simple processing.

Due to high moisture content of green paddy and the farmers have not enough space to store their paddy during the drying process, farmers have to sell their paddy immediately after harvesting. Therefore, rice farmers were price takers, have low power to negotiate for higher prices. They have to accept the middlemen or millers' buying prices. This implies that the green paddy market structure is closed to oligopsony structure (a few buyers can set the buying price).

5.6 Profitability of rice production

In this section, ex-post evaluation of farm performances in terms of profitability of rice production per ha and per kg of paddy are investigated. Profits are defined as total revenue minus total cost. Therefore, apart from the quantity of inputs use, price information of each type of input and output were obtained from the farmers as well.

Using the data on given quantity and price of input, the cost of rice production can be calculated. The total costs of rice production can be divided into fixed costs and variable costs. In this study, fixed cost was derived from land rental fee, and variable costs were grouped into labor costs, material costs, and capital opportunity costs. The labor costs were divided into several production activities: land preparation, seeding preparation and planting, crop maintenance, and harvesting costs. The material costs were divided into seed, DAP fertilizer, urea fertilizer, plant protection chemical, and fuel costs. The capital opportunity costs were calculated by summing of labor and material costs multiplied by the borrowing interest rate (10 percent per annum) during the rice production period, in this case was six months. On the other hand, total revenue of rice production was derived from paddy output multiplied by paddy price.

The following details comprise profitability of all farms (southern region), of irrigated farms, and of rain-fed farms.

5.6.1 Profitability of the southern region

The total costs of rice production of southern region was 14,710 THB per ha. Total fixed cost and total variable costs were 23 percent and 77 percent of the total costs, respectively. Approximately 50 percent of total variable costs were labor costs, while material costs shared 46 percent of the total variable costs. As part of material costs, chemical fertilizer costs shared 30

percent of the total variable costs, and seed cost shared approximately 12 percent of the total variable costs (Table 5.19).

Table 5.19: Profitability of rice production of southern region in the major crop year 2004/05

Item	Southern region		
	Value (THB/ha)	% of TC	% of TVC
1. Variable costs			
1.1 Labor costs	5,592.83	38.02	49.26
- land preparation	2,204.52	14.99	19.41
- seeding preparation and planting	513.66	3.49	4.52
- crop maintenance	622.75	4.23	5.48
- harvesting	2,251.90	15.31	19.83
1.2 Material costs	5,221.33	35.49	45.98
- seed	1,332.49	9.06	11.73
- DAP fertilizer	2,019.61	13.73	17.79
- Urea fertilizer	1,362.13	9.26	12.00
- plant protection chemical	358.41	2.44	3.16
- fuel/lubrication	148.69	1.01	1.31
1.3 Capital opportunity cost	540.69	3.68	4.76
1.4 Total variable costs (TVC)	11,354.85	77.19	100.00
2. Fixed cost: Land rental fee	3,355.26	22.81	
3. Total costs (TC)	14,710.11	100.00	
Average yield (kg/ha)	3,411.59		
Average cost (THB/kg)	4.31		
Average paddy price (THB/kg)	5.64		
Revenue (THB/ha)	19,229.21		
Gross margin (THB/ha)	7,874.36		
Profit (THB/ha)	4,519.10		
Gross margin (THB/kg)	2.31		
Profit (THB/kg)	1.32		

Source: field survey

On the other hand, the revenue of rice production of the southern region was 19,229 THB per ha. The total revenue-total costs ratio was 1.31, while the total revenue-total variable costs ratio was 1.69. Then gross margin or net revenue can be derived from total revenue minus total variable costs. The gross margin of rice production of southern region was 7,874 THB per ha or 2.31 THB per kg of paddy.

Profitability is derived from total revenue minus total costs or from gross margin minus fixed costs. Hence, the profitability of rice production of the southern region was 4,519 THB per ha or 1.32 THB per kg of paddy (Table 5.19).

5.6.2   Profitability of irrigated farms

The total costs of rice production of the irrigated farms was 15,713 THB per ha, which was relatively higher than the average of the region. The total fixed cost shared 26 percent of the total costs, which was higher than the average of the region due to the higher land rental fee in irrigated areas. The total variable costs shared 74 percent of the total costs. The structure of total variable costs was similar to the region structure. Approximately 50 percent of total variable costs were labor costs. The main proportion of labor costs was hired machine cost for land preparation and harvesting. The material costs shared 46 percent of total variable costs. Chemical fertilizer costs shared 30 percent of the total variable costs, and seed cost shared approximately 12 percent of the total variable costs (Table 5.20).

On the other hand, the revenue of rice production of irrigated farms was 20,878 THB per ha, which was relatively higher than the average of the region due to the higher paddy output. The total revenue-total costs ratio was 1.33, while the total revenue-total variable costs ratio was 1.79.

The gross margin of rice production of the irrigated farms was 9,227 THB per ha or 2.50 THB per kg of paddy. The profitability rice production of the irrigated farms was 5,165 THB per ha or 1.40 THB per kg of paddy (Table 5.20).

5.6.3   Profitability of rain-fed farms

The total costs of rice production of the rain-fed farms was 13,386 THB per ha, which was slightly lower than the average of the region. The total fixed cost shared 19 percent of total cost, which was lower than the average of the region and irrigated farms due to lower land rental fee in these areas. The total variable costs shared 81 percent of the total costs. The structure of total variable costs was similar to the structures of southern region and irrigated areas. Approximately half of total variable costs were labor costs. The material costs shared 46 percent of total variable costs. Chemical fertilizer costs shared 30 percent of the total variable costs, and seed cost shared approximately 12 percent of the total variable costs (Table 5.20).

The revenue of rice production of rain-fed farms was 17,492 THB per ha, which was relatively lower than irrigated farms due to lower paddy output. The total revenue-total costs ratio was 1.31, while the total revenue-total variable costs ratio was 1.61.

The gross margin of rice production of the rain-fed farms was 6,676 THB per ha or 2.15 THB per kg of paddy. The profitability rice production of the rain-fed farms was 4,106 THB per ha or 1.32 THB per kg of paddy (Table 5.20).

(Additional information, the results from the group discussion showed that the farmers would be satisfied if paddy price farm-gate is 7 THB per kg.)

Table 5.20: Profitability of rice production by agro-ecosystems in the major crop year 2004/05

Item	Agro-ecosystem					
	Irrigated area			Rain-fed area		
	Value (THB/ha)	% of TC	% of TVC	Value (THB)	% of TC	% of TVC
1. Variable costs						
1.1 Labor costs	5,683.02	36.17	48.78	5,304.83	39.63	49.04
- land preparation	2,283.17	14.53	19.60	1,979.91	14.79	18.30
- seeding preparation and planting	508.90	3.24	4.37	518.71	3.88	4.80
- crop maintenance	651.04	4.14	5.59	541.62	4.05	5.01
- harvesting	2,239.91	14.26	19.23	2,264.58	16.92	20.94
1.2 Material costs	5,412.61	34.45	46.46	4,996.49	37.33	46.19
- seed	1,392.40	8.86	11.95	1,269.09	9.48	11.73
- DAP fertilizer	2,069.80	13.17	17.77	1,966.50	14.69	18.18
- Urea fertilizer	1,411.25	8.98	12.11	1,310.16	9.79	12.11
- plant protection chemical	390.48	2.49	3.35	302.06	2.26	2.79
- fuel/lubrication	148.69	0.95	1.28	148.69	1.11	1.37
1.3 Capital opportunity cost	554.75	3.53	4.76	515.06	3.85	4.76
1.4 Total variable costs (TVC)	11,650.37	74.15	100.00	10,816.38	80.80	100.00
2. Fixed cost: Land rental fee	4,062.50	25.85		2,569.44	19.20	
3. Total costs (TC)	15,712.87	100.00		13,385.82	100.00	
Average yield (kg/ha)	3,695.47			3,111.15		
Average cost (THB/kg)	4.25			4.30		
Average paddy price (THB/kg)	5.65			5.62		
Revenue (THB/ha)	20,877.96			17,492.42		
Gross Margin (THB/ha)	9,227.59			6,676.04		
Profit (THB/ha)	5,165.09			4,106.59		
Gross Margin (THB/kg)	2.50			2.15		
Profit (THB/kg)	1.40			1.32		

Source: field survey

5.7   Rice farm household income

Sources of farm household income can be divided into on-farm income and off-farm income. The on-farm income comprises income from rice production, and from other agricultural activities. Besides rice production, the sample farm households earned additional agricultural income from livestock, vegetable and fishery productions. Moreover, they earned off-farm income from owning grocery shops as well as working as labors or employees in non-agricultural activity.

The results of farm household income are presented by agro-ecosystems in Table 5.21. The average annual household income of irrigated farms was relatively higher than the rain-fed farms because the irrigated farms can produce rice two crops in a year. The average annual household income of irrigated farms was 156,841.92 THB, while the average annual household income of rain-fed farms was 94,928.75 THB. Rice farmers in the south is being poorer than other farmers who engaged in rubber and fruit tree plantations, fishery as well as vegetable cultivation (OAE, 2000).

Table 5.21: Average annual household income in the crop year 2004/05

	Agro-ecosystem	
Source of income	Irrigated area	Rain-fed area
On-farm (THB)	126,399.24	61,274.58
Rice production		
- Major crop[1]	59,502.18	49,153.70
- Second crop[2]	59,502.18	-
Other agricultural activities	7,394.88	12,120.88
Off-farm (THB)	30,442.68	33,654.17
Total income (THB)	156,841.92	94,928.75
Farm family size (members)[3]	3.88	3.94
Income per member (THB)	40,423.17	24,093.59
Income per member per month (THB)	3,368.60	2,007.80

Source: field survey

[1] revenue per ha from Table 5.20 multiplied be average farm size
[2] assumed the same amount as the major crop
[3] from Table 5.3

5.8 Problems and obstacles of rice farming in southern Thailand

The farmers were asked their opinion on problems and obstacles of rice farming. The opinion was measured by a five-point Likert scale. This scale measures the opinion or reactions of farmers on a set of statements. For example, problem of water shortage (1=no problem, 2=tolerable, 3=moderate problem, 4=severe problem, 5=the most severe problem). These reactions were analyzed and calculated as average score and mode of each statement. A set of statements and farmers' opinion are presented in Table 5.22.

The results showed that the most severe and severe problems of rice production in southern Thailand were 1) high cost of chemical inputs (chemical fertilizer and pesticide), 2) water shortage or drought, which was related to the rainfall statistics in the study area, 3) low output price, which was related to low negotiation power of the farmers, and 4) low land productivity.

Table 5.22: Farmers' opinion on problems and obstacles of rice production in southern Thailand

Problems and obstacles	Average score of problem (mode)		
	Irrigated area	Rain-fed area	Southern region
High cost of chemical inputs	4.10 (4)	4.13 (4)	4.11 (4)
Water shortage/drought	3.98 (5)	3.79 (5)	3.89 (5)
Low output price	3.85 (4)	3.73 (4)	3.79 (4)
Low land productivity	3.87 (4)	3.63 (4)	3.76 (4)
Pest menace	3.34 (4)	3.19 (4)	3.27 (4)
High debt	3.01 (3)	2.94 (4)	2.98 (3)
Lack of capital	2.91 (4)	2.96 (4)	2.94 (4)
Low soil fertility/soil quality	2.81 (1)	2.89 (1)	2.85 (1)
Lack of governmental support	2.91 (3)	2.76 (3)	2.84 (3)
Flooding	2.61 (1)	3.06 (4)	2.83 (1)
Chemical use affected on farmer's health	2.63 (3)	2.67 (3)	2.65 (3)
Ineffective of extension services	2.64 (3)	2.59 (3)	2.62 (3)
Low seed quality	2.53 (1)	2.47 (1)	2.50 (1)
Lack of technical knowledge	2.29 (3)	2.29 (3)	2.29 (3)
Non-availability of good variety	2.24 (1)	2.22 (1)	2.23 (1)
Labor shortage	1.99 (1)	2.05 (1)	2.02 (1)

Source: field survey

5.9   Farmers' perception on negative externality of rice production

The farmers were asked their perception on negative environmental effects of rice farming. The opinion was measured by a five-point Likert scale. This scale measures the farmers' perceptions or reactions on a set of statements. For example, chemical pesticide application can create the water pollution (1= strongly do not agree; 2= do not agree; 3= slightly agree; 4=agree; 5=strongly agree). These reactions were analyzed and calculated as average score and mode of each statement. A set of statements and farmers' opinion are presented in Table 5.23.

According to the average score results, farmers were slightly agree to the statement of use of chemical pesticide and fertilizer in rice farming process can create water pollution. In addition, mode or the most frequency of the answer was 4. This means that most of the farmers agree to these statements.

In contrast, to the statement of flooding condition of rice farming can create global warming problem, the average score (2.17) tended to do not agree to this statement. Moreover, mode or the most frequency of the answer was 1, which means most of the farmers strongly do not agree to this statement.

This finding shows that the farmers have got information about the negative effect of chemical inputs on the environment, but lack of information about the negative effect of rice farming condition on the environment.

Table 5.23: Farmers' perception on negative environmental effects of rice farming

Statement	Average score of perception (mode)		
	Irrigated Area	Rain-fed area	Southern region
Chemical pesticide application can create the surface water pollution.	3.39 (4)	3.12 (4)	3.26 (4)
Chemical pesticide application can create the groundwater contamination.	3.25 (4)	3.10 (4)	3.18 (4)
Chemical fertilizer application can create the surface water pollution.	3.01 (4)	2.80 (4)	2.91 (4)
Chemical fertilizer application can create the groundwater contamination.	2.96 (4)	2.81 (4)	2.89 (4)
Flooding in the rice field can create the global warming problem.	2.25 (1)	2.08 (1)	2.17 (1)

Source: field survey

5.10 Concluding remarks

The rice farm households had similar characteristics. The results showed no statistically significant differences between two agro-ecosystems in average farm family size, average farm family labor, average farm size, average education and experiences of farm manager. On rice farming practices, all rice farmers applied chemical fertilizers during production process and most of the rice farmers have never checked or known the soil properties of their land. However, the results showed statistically significant differences between two agro-ecosystems in land productivity or rice yield per ha.

Rice farm performances, the important cost compositions of rice production were variable costs: labor, seed, and chemical fertilizers, which shared 50, 12, and 30 percent of total variable costs, respectively. Gross margin and profitability of rice production of the irrigated farms were relatively higher than the rain-fed farms.

6 Empirical Results of Efficiency Analysis

This chapter presents the empirical results of the technical, economic, and environmental efficiency analyses as well as the Tobit regression results. The standard BCC-DEA model under the input-oriented approach was applied to calculate the frontier of observed data. The DEA efficiency analysis was carried out based on 3 frontiers: 1) Meta frontier, which analyzes all farms data (n=247) and represents the southern rice farm performances, 2) Irrigated frontier, which analyzes irrigated farms data (n=127) and represents the irrigated rice farm performances, and 3) Rain-fed frontier, which analyzes rain-fed farms data (n=120) and represents the rain-fed rice farm performances.

The results of each efficiency analysis are presented in the following order, beginning with data set of the analysis then the average efficiency level and ending with the investigation of inputs use of the best practice farms (BPFs). The BPFs information can be used as a benchmark to improve the efficiency of rice production in southern Thailand. Moreover, the Tobit regression results are presented as factors affecting the efficiency of all farms, irrigated farms, and rain-fed farms, respectively.

6.1 Technical efficiency analysis

In this study, the input-output data of the individual farm were used to analyze the technical efficiency. The combination of inputs: labor, machine, seed, and fertilizers were allocated to produce a single desirable output. Two models of technical efficiency were constructed, which differed in terms of fertilizer forms. In Model I, fertilizers were treated in commercial formulas (DAP, Urea), while commercial formulas were converted into nutrient compositions (Total nitrogen fertilizer, Total phosphorus fertilizer) in Model II.

6.1.1 Technical efficiency of rice production systems: Model I

6.1.1.1 Data set of technical efficiency analysis

The data set of combination of input use of the individual farm was considered. In Model I, the combination of inputs consisted of labor, machine, seed, DAP fertilizer, and urea fertilizer, which were used to produce paddy rice. In case of fertilizers, for example, the average rate of DAP and urea fertilizers were approximately 180 and 105 kg per ha, respectively. The descriptive statistics of sample variables of Model I are summarized in Table 6.1.

Table 6.1: Descriptive statistics of the sample variables of Model I

Variable	Unit	Agro-ecosystem				Southern region (n=247)	
		Irrigated (n=127)		Rain-fed (n=120)			
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Inputs							
Labor	man-hr / ha	27.21	11.96	24.80	11.08	26.04	11.58
Machine	THB / ha	3,286.17	1,370.62	3,296.18	2,005.46	3,291.03	1,562.50
Seed	kg / ha	152.84	37.34	149.91	38.26	151.41	37.74
DAP	kg / ha	186.36	52.33	180.42	53.32	183.48	52.79
Urea	kg / ha	110.20	44.21	102.04	36.17	106.24	40.63
Output							
Rice yield	kg / ha	3,695.47	838.85	3,111.15	698.19	3,411.59	825.75

6.1.1.2 Technical efficiency results

According to the Meta frontier results, 43 out of 247 farms or 17 percent of sample farms were on the Meta frontier. Of these 23 farms were located in irrigated areas. The average levels of technical efficiency of Model I were 0.866 for the whole sample farms, and 0.866 and 0.867 for farms located in irrigated and rain-fed areas, respectively. This means, that the sample farms could potentially reduce their all inputs amounts by approximately 13 percent and still attain the current output level. In addition, the non-parametric Mann-Whitney U test (2-tailed) was applied to test for differences of technical efficiency scores between farms in irrigated and rain-fed areas. The results showed that there were no statistically significant differences in technical efficiency between these two agro-ecosystems.

The Irrigated frontier results showed that 32 out of 127 farms or 25 percent of irrigated farms were on the Irrigated frontier. The average efficiency score was 0.898. This means that on the average rice farms in irrigated areas use the combination of inputs inefficient; they could potentially reduce their all inputs by 10 percent and still attain the existing level of output.

The Rain-fed frontier results showed that 41 out of 120 farms or 34 percent of rain-fed farms are on the Rain-fed frontier. The average efficiency score was 0.921. This means that on the average rice farms in rain-fed areas could potentially reduce their all inputs amounts by 8 percent and still attain the current output level. The results of Model I are presented in Table 6.2.

(Numerical example of DEA technical efficiency score calculation is presented in the Appendix).

Table 6.2: Average technical efficiency scores of Model I

Rice production systems	Technical efficiency score of Model I		
	Mean (TBPFs)	Min.	S.D.
Meta frontier	0.866 (43)	0.531	0.099
Irrigated area	0.866 (23)	0.561	0.102
Rain-fed area	0.867 (20)	0.531	0.096
Mann-Whitney U Test (2-tailed)	7,598		
(Sig.)	0.969 [NS]		
Irrigated frontier	0.898 (32)	0.600	0.096
Rain-fed frontier	0.921 (41)	0.543	0.092

Remark: NS = statistically non-significant

TBPFs = number of technical best practice farms

6.1.1.3 Technical best practice farms

In this part, the inputs, which technical best practice farms (TBPFs) used per ton of paddy rice produced were investigated and compared to the average farm. The results showed that the TBPFs on the Meta frontier used all inputs less than the average. In case of seed rate, for example, the TBPFs needed 17 percent less seeds than the average farm.

Similarly to the results of the TBPFs on the Irrigated frontier and the Rain-fed frontier, the farmers of TBPFs used resources more efficient than the average farm. The details of each input use of average farms and TBPFs are presented in Table 6.3.

Table 6.3: Inputs use of the technical best practice farms of Model I

Variable	Unit	Meta frontier		Irrigated frontier		Rain-fed frontier	
		Mean	TBPFs	Mean	TBPFs	Mean	TBPFs
Inputs							
Land	ha / ton	0.29	0.27	0.27	0.25	0.32	0.30
Labor	man-hr / ton	7.63	5.65	7.36	5.66	7.97	7.15
Machine	THB / ton	964.66	826.71	889.24	752.05	1,059.47	983.57
Seed	kg / ton	44.38	36.77	41.36	34.96	48.18	41.81
	(kg / ha)	(151.41)	(136.41)	(152.84)	(142.45)	(149.91)	(137.09)
DAP	kg / ton	53.78	46.16	50.43	45.09	57.99	52.44
Urea	kg / ton	31.14	22.44	29.82	20.53	32.80	28.65
N-fertilizer	kg N / ton	22.93	17.71	21.79	16.66	24.37	21.57
	(kg N / ha)	(78.23)	(65.70)	(80.51)	(67.89)	(75.81)	(70.73)
P-fertilizer	kg P_2O_5 / ton	10.76	9.23	10.09	9.02	11.60	10.49
Output							
Rice yield	kg / ha	3,411.59	3,709.74	3,695.47	4,074.80	3,111.15	3,278.96

6.1.2 Technical efficiency of rice production systems: Model II

6.1.2.1 Data set of technical efficiency analysis

The data set of input-output of the individual farm was considered. In Model II, the combination of inputs consisted of labor, machine, seed, total nitrogen fertilizer, and total phosphorus fertilizer, which were used to produce paddy rice. The total nitrogen (N) fertilizer and total phosphorus (P) fertilizer amounts were converted from the nutrient composition in DAP fertilizer (N-P-K: 16-20-0) and urea fertilizer (N-P-K: 46-0-0). In case of fertilizers, for example, the average rate of total nitrogen and total phosphorus fertilizers were approximately 78 kg and 36 kg per ha, respectively. The descriptive statistics of sample variables are summarized in Table 6.4.

Table 6.4: Descriptive statistics of the sample variables of Model II

Variable	Unit	Agro-ecosystem				Southern region (n=247)	
		Irrigated (n=127)		Rain-fed (n=120)			
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Inputs							
Labor	man-hr / ha	27.21	11.96	24.80	11.08	26.04	11.58
Machine	THB / ha	3,286.17	1,370.62	3,296.18	2,005.46	3,291.03	1,562.50
Seed	kg / ha	152.84	37.34	149.91	38.26	151.41	37.74
N-fertilizer	kg N / ha	80.51	18.13	75.81	15.77	78.23	17.16
P-fertilizer	kg P_2O_5 / ha	37.27	10.47	36.08	10.66	36.70	10.56
Output							
Rice yield	kg / ha	3,695.47	838.85	3,111.15	698.19	3,411.59	825.75

6.1.2.2 Technical efficiency results

According to the Meta frontier results, 37 out of 247 farms or 15 percent of sample farms were on the Meta frontier. Of these 19 farms were located in irrigated areas. The average levels of technical efficiency of Model II for the whole sample farms, irrigated farms, and rain-fed farms were 0.859, 0.858, and 0.859, respectively. This means, in principle, that the sample farms could potentially reduce their inputs by approximately 14 percent and still attain existing level of output. In addition, the non-parametric Mann-Whitney U test (2-tailed) was applied to test for differences of technical efficiency scores between farms in irrigated and rain-fed areas. The results showed that there were no statistically significant differences in technical efficiency between these two agro-ecosystems.

The Irrigated frontier results revealed that 28 out of 127 farms or 22 percent of irrigated farms were on the Irrigated frontier. The average efficiency score was 0.892. This means that on the average rice farms in irrigated areas use the combination of inputs inefficient; they could potentially reduce their all inputs by 10 percent and still attain the current output level.

The Rain-fed frontier results showed that 37 out of 120 farms or 31 percent of rain-fed farms were on the Rain-fed frontier. The average efficiency score was 0.914. This means that on the average rice farms in rain-fed areas can potentially reduce their inputs by 9 percent and still attain the existing level of output. The results of Model II are presented in Table 6.5.

Table 6.5: Average technical efficiency scores of Model II

Rice production systems	Technical efficiency score of Model II		
	Mean (TBPFs)	Min	S.D.
Meta frontier	0.859 (37)	0.530	0.100
Irrigated area	0.858 (19)	0.561	0.103
Rain-fed area	0.859 (18)	0.530	0.096
Mann-Whitney U Test (2-tailed)	7,611		
(Sig.)	0.987 ^{NS}		
Irrigated frontier	0.892 (28)	0.600	0.098
Rain-fed frontier	0.914 (37)	0.543	0.094

Remark: NS = statistically non-significant

TBPFs = number of technical best practice farms

6.1.2.3 Technical best practice farms

In this part, the inputs, which technical best practice farms (TBPFs) used per ton of paddy rice produced were investigated and compared to the average farm. The results showed that the TBPFs on the Meta frontier of Model II used all inputs less than the average. In case of seed rate, for example, the TBPFs needed 16 percent less seeds than the average farm.

Similarly to the results of the TBPFs on the Irrigated frontier and the Rain-fed frontier, the farmers of TBPFs used combination of inputs more efficient than the average farm. The details of each inputs use of TBPFs are presented in Table 6.6.

Table 6.6: Inputs use of the technical best practice farms of Model II

Variable	Unit	Meta frontier		Irrigated frontier		Rain-fed frontier	
		Mean	TBPFs	Mean	TBPFs	Mean	TBPFs
Inputs							
Land	ha / ton	0.29	0.26	0.27	0.24	0.32	0.30
Labor	man-hr / ton	7.63	6.27	7.36	5.71	7.97	7.13
Machine	THB / ton	964.66	819.16	889.24	753.76	1,059.47	852.07
Seed	kg / ton	44.38	37.13	41.36	35.73	48.18	40.80
	(kg/ha)	(151.41)	(140.95)	(152.84)	(148.84)	(149.91)	(135.15)
DAP	kg / ton	53.78	42.68	50.43	42.17	57.99	49.27
Urea	kg / ton	31.14	24.30	29.82	21.87	32.80	30.07
N-fertilizer	kg N / ton	22.93	18.01	21.79	16.81	24.37	21.72
	(kg N /ha)	(78.23)	(68.37)	(80.51)	(70.03)	(75.81)	(71.95)
P-fertilizer	kg P_2O_5 / ton	10.76	8.54	10.09	8.43	11.60	9.85
Output							
Rice yield	kg / ha	3,411.59	3,796.11	3,695.47	4,165.85	3,111.15	3,312.50

In summary, the average levels of technical efficiency and number of the TBPFs of Model I were slightly higher than Model II. The average levels of technical inefficiency were approximately 14 percent for whole sample farms, and 10 percent and 8 percent for irrigated and rain-fed farms, respectively. Therefore, the farmers of inefficient farms can improve their technical efficiency by learning from the TBPFs and adjusting the combination of inputs close to the benchmark (TBPFs). The direct consequences of this technical efficiency improvement are all inputs reduction and the farmers gain financial benefit from these cost savings.

The technical best practice farms applied 17-22 kg N-fertilizer to produce one ton of paddy rice, whereas the average of southern region farms applied 22.93 kg N-fertilizer to produce one ton of paddy rice. In other words, the TBPFs applied N-fertilizer in range of 66-72 kg per ha, which were relatively higher than recommendation rate of Agricultural Extension Department. The optimum rate of total N-fertilizer for rice production in clayey soil and non-photoperiod sensitive variety is 55 kg N-fertilizer per ha (DOAE, 2002).

In addition, the technical best practice farms used 35-42 kg of seed to produce one ton of paddy rice, while the average of southern region farms used 44.38 kg of seed. In other words, the TBPFs used seed rate ranging between 135-149 kg per ha. These figures were relatively higher than recommendation of seed rate of Rice Research Institution and FAO. The optimum seed rate for direct seeding is ranging between 94-125 kg per ha (RRI and FAO, 2003), which help induce good aeration in paddy fields.

6.2 Economic efficiency analysis

In this analysis, rice farmers were assumed to produce rice at cost minimization level. Thus economic efficiency model is focused on input-oriented in order to minimize cost of all inputs use and still attain the same level of output. Hence, the input-output quantities and the unit price of each input were needed for the cost efficiency analysis.

6.2.1 Data set of economic efficiency analysis

The data set of the technical efficiency of Model I (Table 6.1) was again used and incorporated with the input prices information of each input. In case of fertilizers, for example, the average prices of DAP and urea fertilizers were approximately 11 and 13 THB per kg, respectively. In other words, the average prices of N-fertilizers, which calculated from the nutrient composition in DAP and urea fertilizers were approximately 68.75 and 28.26 THB per kg N, respectively. The details of input prices are presented in Table 6.7.

Table 6.7: Descriptive statistics of the sample variables of economic efficiency model

Input price	Unit	Agro-ecosystem				Southern region (n=247)	
		Irrigated (n=127)		Rainfed (n=120)			
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Labor*	THB/ hour	18	-	18	-	18	-
Seed	THB/kg	9.08	1.93	8.45	1.88	8.77	1.93
DAP	THB/kg	11.14	0.62	10.93	0.42	11.04	0.54
Urea	THB/kg	12.83	0.41	12.84	0.39	12.84	0.40

Remark: * minimum wage rate per hour of the study area

6.2.2 Economic efficiency results

According to the Meta frontier results showed that 4 out of 247 farms or only 2 percent of sample farms were on the Meta frontier. Of these 3 farms were located in irrigated areas. The average levels of economic or cost efficiency were 0.676 for the whole sample farms, and 0.681 and 0.671 for farms in irrigated and rain-fed areas. This means, in principle, that the sample farms could potentially reduce their overall cost of rice production by approximately 32 percent and still attain the current output level. In addition, the non-parametric Mann-Whitney U test (2-tailed) was applied to test for differences of economic efficiency scores between farms in irrigated and rain-fed areas. The results showed that there were no statistically significant differences in economic efficiency between these two agro-ecosystems.

The Irrigated frontier results reveal that 3 out of 127 farms or only 2 percent of irrigated farms were on the Irrigated frontier. The average economic efficiency score was 0.717. This means that rice farms in irrigated areas use the combination of inputs at cost inefficient level; they could potentially reduce their overall cost by 29 percent and still attain the current output level.

The Rain-fed frontier results showed that 5 out of 120 farms or 4 percent of rain-fed farms were on the Rain-fed frontier. The average economic efficiency score was 0.704. This means that the farms in rain-fed areas could potentially reduce their overall cost by 30 percent and still attain the existing level of output. The results of economic efficiency analysis are presented in Table 6.8**.**

Table 6.8: Average economic efficiency scores of rice production systems

Rice production systems	Means of efficiency score		
	Technical (TBPFs)	Allocative (ABPFs)	Economic (EBPFs)
Meta frontier	0.866 (43)	0.781 (4)	0.676 (4)
Irrigated area	0.866 (23)	0.786 (3)	0.681 (3)
Rain-fed area	0.867 (20)	0.775 (1)	0.671 (1)
Mann-Whitney U Test (2-tailed)	7,598	7,251	7,567
(Sig.)	0.969 [NS]	0.511 [NS]	0.925 [NS]
Irrigated frontier	0.898 (32)	0.799 (3)	0.717 (3)
Rain-fed frontier	0.921 (41)	0.763 (5)	0.704 (5)

Remark: NS = statistically non-significant

      TBPFs = number of technical best practice farms

      ABPFs = number of allocative best practice farms

      EBPFs = number of economic best practice farms

Moreover, the economic or cost efficiency can be decomposed into technical efficiency and input allocative efficiency. The cost efficiency can be calculated from multiplied technical efficiency by allocative efficiency scores. The Meta frontier results showed that 4 out of 43 technical best practice farms or only 9 percent were on the cost frontier. The Irrigated frontier results showed that 3 out of 32 technical best practice farms or only 9 percent were on the cost frontier. The Rain-fed frontier revealed that 5 out of 41 technical best practice farms or 12 percent were on the cost frontier.

6.2.3   Economic best practice farms

Further investigation, the inputs of economic best practice farms (EBPFs) used per ton of paddy rice produced and unit price of inputs were done and compared to the average farms. In terms of amount of inputs use, the results showed that the EBPFs on the Meta frontier used all combination of inputs less than the average except the labor input. This may imply that the EBPFs used their labors as substitution input with others, especially machine. Similarly to the results of the EBPFs on the Irrigated frontier and the Rain-fed frontier, they used all combination of inputs less than the average except the labor input.

In terms of unit price of inputs, the interesting results showed that the EBPFs paid the unit price for rice seed higher than the average. This may imply that the EBPFs concern on high seed quality, which may reflect in high seed price, but can produce more output than low quality. The details of each input use of EBPFs are presented in Table 6.9.

Table 6.9: Inputs use of the economic best performance farms

Variable	Unit	Meta frontier		Irrigated frontier		Rain-fed frontier	
		Mean	EBPFs	Mean	EBPFs	Mean	EBPFs
Inputs							
Land	ha / ton	0.29	0.21	0.27	0.18	0.32	0.26
Labor	man-hr / ton	7.63	8.18	7.36	7.79	7.97	9.03
Machine	THB / ton	964.66	505.43	889.24	485.71	1,059.47	907.30
Seed	kg / ton	44.38	35.46	41.36	27.70	48.18	47.65
DAP	kg / ton	53.78	48.22	50.43	53.42	57.99	38.70
Urea	kg / ton	31.14	17.52	29.82	16.15	32.80	27.02
N-fertilizer	kg N / ton	22.93	15.77	21.79	15.98	24.37	18.62
P-fertilizer	kg P_2O_5 / ton	10.76	9.64	10.09	10.68	11.60	7.74
Prices							
Seed	THB/kg	8.77	10.75	9.08	10.33	8.45	8.60
DAP	THB/kg	11.04	10.95	11.14	10.73	10.93	11.22
Urea	THB/kg	12.84	12.90	12.83	13.00	12.84	12.52
Output							
Rice yield	kg / ha	3,411.59	4,726.56	3,695.47	5,468.75	3,111.15	3,875.00

6.3 Environmental efficiency analysis

Environmental efficiency model of this study is focused on input-oriented in order to minimize pollution from N-fertilizer application and still attain the same level of output.

6.3.1 Data set of environmental efficiency analysis

The total nitrogen fertilizer data of technical efficiency of Model II (Table 6.4) was used to calculate the environmental pollution from nitrogen fertilizer application. The total amount of nitrogen applied was classified into two fractions of environmental pollutions, (1) 19 percent leached into surface and ground water and (2) 13.6 percent converted into greenhouse gases (PATHAK *et al.*, 2004). The average environmental pollutions per ha of irrigated agro-ecosystem are slightly higher than of rain-fed agro-ecosystem. See the details of data set for environmental efficiency analysis in Table 6.10.

Table 6.10: Descriptive statistics of the sample variables of environmental efficiency

Variable	Unit	Agro-ecosystem				Southern region (n=247)	
		Irrigated (n=127)		Rain-fed (n=120)			
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Inputs							
N-fertilizer	kg N / ha	80.51	19.39	75.81	16.13	78.23	17.89
Environmental pollution							
N-leaching	kg N / ha	15.30	3.45	14.40	3.00	14.86	3.26
N-emission	kg N / ha	10.95	2.47	10.31	2.15	10.64	2.33
Output							
Rice yield	kg / ha	3,695.47	838.85	3,111.15	698.19	3,411.59	825.75

6.3.2 Environmental efficiency results

The Meta frontier results showed that 5 farms or 2 percent of sample farms were the environmental best performance farms, which were on the Meta frontier. Of these 2 farms were located in irrigated areas. The average environmental efficiency score was 0.544. This means that the sample farms could potentially scale down the N-fertilizer application by 46 percent and still attain the current output level with a reduced level of environmental pollutions. Moreover, the non-parametric Mann-Whitney U test (2-tailed) was applied to test for differences of environmental efficiency scores between irrigated and rain-fed areas. The results showed that there were no statistically significant differences in environmental efficiency between these two agro-ecosystems.

The Irrigated frontier results showed that only 3 farms or 2 percent of irrigated farms were on the Irrigated frontier. The average environmental efficiency score was 0.549. This means that the irrigated farms could potentially reduce N-fertilizer application by 45 percent and still attain the existing level of output with a reduced level of environmental pollutions.

The Rain-fed frontier results revealed that 4 farms or 3 percent of rain-fed farms were the environmental best performance farms, which were on the Rain-fed frontier. The average environmental efficiency score was 0.578. This means that the rain-fed farms could potentially reduce N-fertilizer application by 42 percent and still attain the current output level with a reduced level of environmental pollutions. The environmental efficiency results are presented in Table 6.11.

In summary, the average environmental inefficiency score was approximately 45 percent relative to the frontier farms. This may be because the rice farmers believe that apply more chemical fertilizers would gain more rice yield.

Table 6.11: Average environmental efficiency scores of rice production systems

Rice production systems	Environmental efficiency score		
	Mean (ENBPFs)	Min	S.D.
Meta frontier	0.544 (5)	0.329	0.139
Irrigated area	0.544 (2)	0.329	0.143
Rain-fed area	0.543 (3)	0.333	0.135
Mann-Whitney U Test (2-tailed)	7,566		
(Sig.)	0.924 [NS]		
Irrigated frontier	0.549 (3)	0.329	0.143
Rain-fed frontier	0.578 (4)	0.333	0.164

Remark: NS = statistically non-significant

ENBPFs = number of environmental best practice farms

6.3.3   Environmental best performance farms

In this part, the inputs, which environmental best performance farms (ENBPFs) used per ton of paddy rice produces were investigated, and compared to the average farms. The results showed that the ENBPFs on the Meta frontier used all combination of inputs less than the average. Similarly to the results of the ENBPFs on the Irrigated frontier, they used all combination of inputs less than the average. In contrast, slightly differences to the Rain-fed frontier results, the ENBPFs on the Rain-fed frontier used all combination of inputs less than the average except the machine cost. The machine cost of ENBPFs was higher than the average. The details of each inputs use of ENBPFs are presented in Table 6.12.

Table 6.12: Inputs use of the environmental best performance farms

Variable	Unit	Meta frontier		Irrigated frontier		Rain-fed frontier	
		Mean	ENBPFs	Mean	ENBPFs	Mean	ENBPFs
Inputs							
Land	ha / ton	0.29	0.27	0.27	0.21	0.32	0.30
Labor	man-hr / ton	7.63	6.96	7.36	7.06	7.97	6.19
Machine	THB / ton	964.66	673.90	889.24	613.53	1,059.47	1,181.78
Seed	kg / ton	44.38	40.43	41.36	38.35	48.18	47.65
DAP	kg / ton	53.78	32.01	50.43	46.01	57.99	26.21
Urea	kg / ton	31.14	15.16	29.82	10.23	32.80	26.21
N-fertilizer	kg N / ton	22.93	12.10	21.79	12.07	24.37	16.25
P-fertilizer	kg P_2O_5 / ton	10.76	6.40	10.09	9.20	11.60	5.24
Environmental pollution							
N-leaching	kg N / ton	4.36	2.30	4.14	2.29	4.63	3.09
N-emission	kg N / ton	3.12	1.65	2.96	1.64	3.31	2.21
Output							
Rice yield	kg / ha	3,411.59	3,687.50	3,695.47	4,687.50	3,111.15	3,281.25

The ENEBPFs on the Meta and Irrigated environmental efficiency frontiers applied approximately 12 kg N-fertilizer to produce one ton of paddy rice, while the ENEBPFs on Rain-fed frontier apply approximately 16 kg N-fertilizer to produce one ton of paddy rice. According to ROY and MISRA (2003), they estimated N-use efficiency in Thailand by assuming that 20 kg N-fertilizer is needed for producing one ton of paddy rice. They also found that N-use efficiency on rice farming in Thailand was 42.8 percent in 1997 and will increase to 46.3 percent in 2015. This may imply that the best practice rice farmers in southern Thailand apply N-fertilizer slightly less than the average of the country.

From cost of rice production analysis of this study, fertilizer costs shared 30 percent of total variable costs. If the farmers can scale down the N-fertilizer by 45 percent, they will financially benefit from the cost savings of 13.5 percent of total variable costs or 1,530 THB per ha. Thus it could automatically reduce the gaseous emission and nitrate leaching, and this will be the social benefit for the society.

6.4   Comparison of efficiency analysis results

This section, the efficiency analysis results by frontiers: Meta frontier, Irrigated frontier, and Rain-fed frontier are summarized and compared.

6.4.1   Meta frontier

According to the technical efficiency (TE) of Meta frontier, the results showed that 43 out of 247 farms or 17 percent of sample farms were on the Meta frontier of Model I, while 37out of 247 farms or 15 percent of sample farms were on the Meta frontier of Model II. The average TE levels of Model I and Model II were 0.866 and 0.859, respectively. This means, in principle, that the sample farms could potentially reduce their all inputs by approximately 14 percent and still attain the current output level. The average TE of this study was relatively higher than the average TE of the rice farmers in the northeast region, which was 0.74 (KRASACHAT, 2003).

The economic efficiency (EE) results revealed that 4 farms or 2 percent of total sample farms were on the EE Meta frontier. The average level of economic efficiency was 0.676. This means, in principle, that the sample farms could potentially reduce their input costs by approximately 32 percent and still attain the existing level of output.

The environmental efficiency (ENE) results showed that 5 farms or 2 percent of total sample farms were on the ENE Meta frontier. The average level of environmental efficiency was 0.544. This means, in principle, that the sample farms can potentially reduce environmental emission from chemical N-fertilizer inputs by approximately 45 percent and still attain the existing level of output.

The distribution of technical, economic, and environmental efficiency scores of Meta frontier are presented in Figure 6.1.

Number of Farms

Figure 6.1: Distributions of technical (TE), economic (EE), and environmental (ENE) efficiency scores of the Meta frontier

6.4.2   Irrigated frontier

According to the TE Irrigated frontier, the results showed that 32 out of 127 farms or 25 percent of the irrigated farms were on the Irrigated frontier of Model I, while 28 farms or 22 percent of the irrigated farms were on the Irrigated frontier of Model II. The average TE levels of Model I and Model II were 0.898 and 0.892, respectively. This means, in principle, that the sample farms could potentially reduce their all inputs by approximately 10 percent and still attain the existing output level.

The EE Irrigated frontier results showed that 2 farms or 2 percent of the irrigated farms were on the EE Irrigated frontier. The average level of economic efficiency was 0.717. This means, in principle, that the sample farms could potentially reduce their input costs by approximately 28 percent and still attain the current output level.

The ENE Irrigated frontier results showed that 2 farms or 2 percent of the irrigated farms were on the ENE Irrigated frontier. The average level of environmental efficiency was 0.549. This means, in principle, that the sample farms could potentially reduce environmental emission from chemical N-fertilizer inputs by approximately 45 percent and still attain the existing level of output.

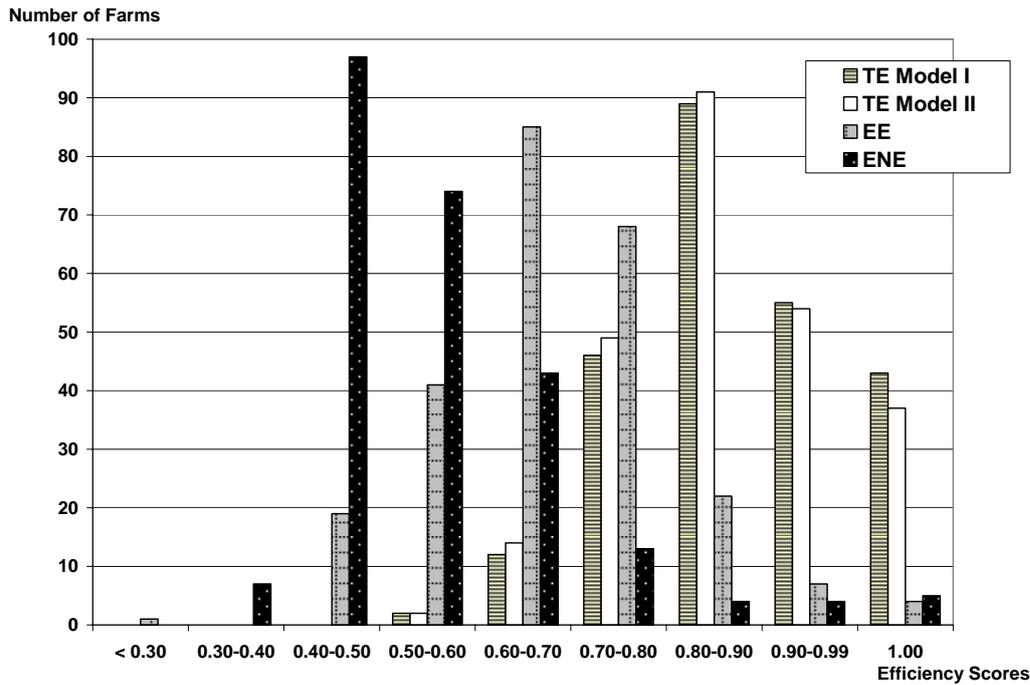The distribution of technical, economic, and environmental efficiency scores of the Irrigated frontier are presented in Figure 6.2.

Figure 6.2: Distributions of technical (TE), economic (EE), and environmental (ENE) efficiency scores of the Irrigated frontier

6.4.3 Rain-fed frontier

According to the TE Rain-fed frontier, the results showed that 41 out of 120 farms or 34 percent of the rain-fed farms were on the Rain-fed frontier of Model I, while 37 farms or 31 percent of the farms were on the Rain-fed frontier of Model II. The average TE levels of Model I and Model II were 0.921 and 0.914, respectively. This means, in principle, that the rain-fed farms could potentially reduce their all inputs amounts by approximately 8 percent and still attain the existing level of output.

The EE Rain-fed frontier results showed that 5 farms or 4 percent of the rain-fed farms were on the EE Rain-fed frontier. The average level of economic efficiency was 0.701. This means, in principle, that the sample farms could potentially reduce their all inputs cost by approximately 30 percent and still attain the existing level of output.

The ENE Rain-fed frontier results showed that 4 farms or 3 percent of total farms were on the ENE Rain-fed frontier. The average level of environmental efficiency was 0.578. This means, in principle, that the rain-fed farms could potentially reduce environmental emission from chemical fertilizer inputs by approximately 42 percent and still attain the current output level.

The distribution of technical, economic, and environmental efficiency scores of Rain-fed frontier are presented in Figure 6.3.
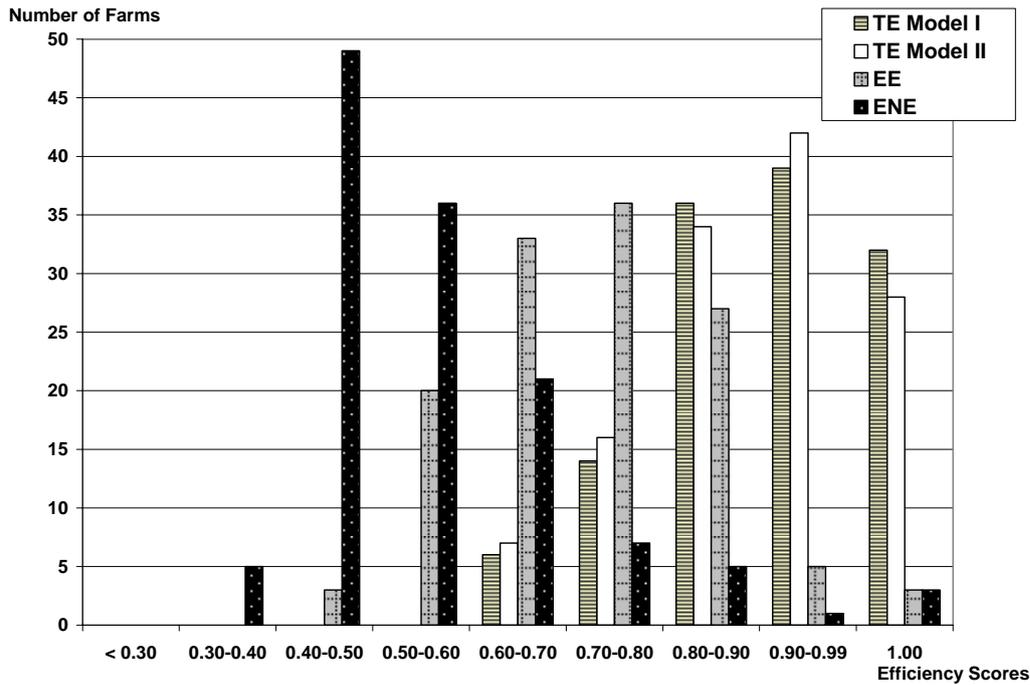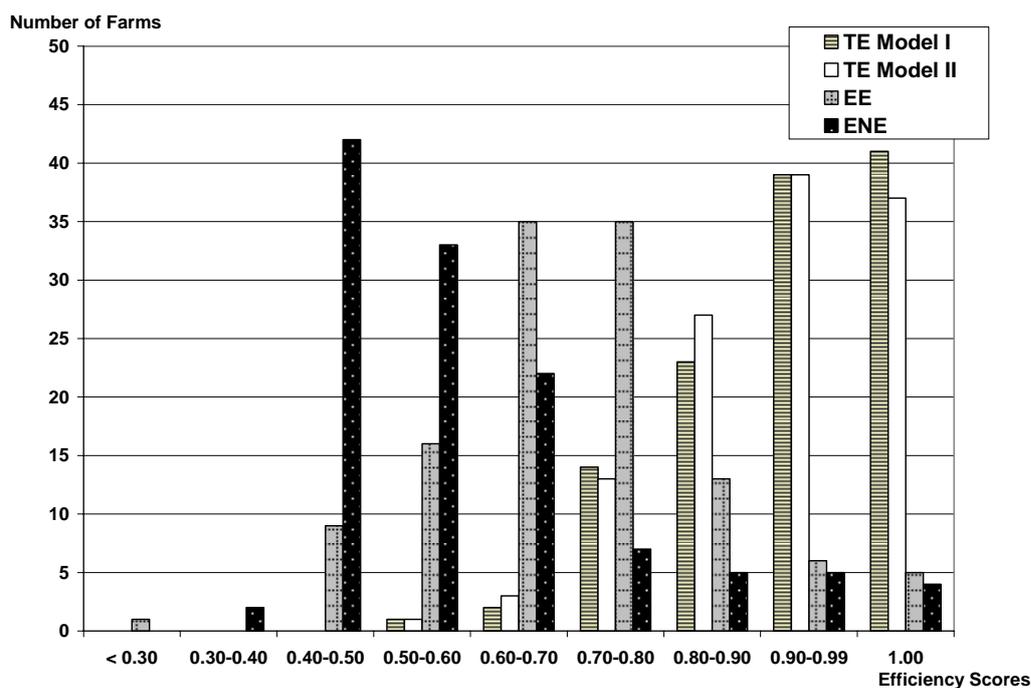
Figure 6.3: Distributions of technical (TE), economic (EE), and environmental (ENE) efficiency scores of the Rain-fed frontier

6.4.4 Benefits of efficiency improvement of rice production in southern Thailand

The results of efficiency analysis provide information about how much rice farmers could potentially improve their efficiency input uses. This improvement is a relative improvement in relation to the best practice farms. In other words, the best practice farms are the benchmarks for those farmers who have some potential for efficiency improvement. The average efficiency improvement from the efficiency results are summarized in Table 6.13.

Table 6.13: Summary of average potential efficiency improvement

Frontier	Potential improvement (%)			
	TE Model I	TE Model II	EE	ENE
Meta frontier	13.4	14.1	32.4	45.6
Irrigated frontier	10.2	10.8	28.3	45.1
Rain-fed frontier	7.9	8.6	29.6	42.2

In the following parts, the benefits of efficiency improvements of the Meta frontier are discussed, which lead to general suggestions for efficiency improvement of rice production in southern Thailand.

6.4.4.1 Technical efficiency improvement

From the concept of DEA efficiency analysis, technical efficiency improvement can be achieved by proportional reduction of all inputs while still attaining the same amounts of output. In this section, three alternatives for the reduction of inputs are presented: full improvement, 10 percent technical efficiency improvement, and 5 percent technical efficiency improvement. The amounts of each input reduction are summarized in Table 6.14.

Table 6.14: Variable inputs reduction for technical efficiency improvement

Variable	Unit	Sample Mean[1/]	Input use at levels of efficiency improvement			Range of input reduction
			Full (13.4 %)	10 %	5%	
Inputs						
Labor	man-hr / ha	26.04	22.55	23.44	24.74	1.30 - 3.49
Machine	THB / ha	3,291.03	2,850.03	2,961.93	3,126.48	164.55 - 441.00
Seed	kg / ha	151.41	131.12	136.27	143.84	7.57 - 20.29
DAP	kg / ha	183.48	158.89	165.13	174.31	9.17 – 24.59
Urea	kg / ha	106.24	92.00	95.62	100.93	5.31 – 14.24
N-fertilizer	kg N / ha	78.23	67.75	70.41	74.32	3.91 – 10.48
P-fertilizer	kg P_2O_5 / ha	36.70	31.78	33.03	34.86	1.84 – 4.92
Output						
Rice yield	kg / ha		3,411.59			

Remark: [1/] from Table 6.1 and Table 6.4

Nonetheless, reductions in the uses of seed and chemical fertilizer can be achieved more flexible in practice. For example, at the 10 percent level of technical efficiency improvement, the farmers could decrease the amounts of sown seed from 151.41 kg per ha to 136.27 kg per ha (15.14 kg of seed reduction) and still produce 3,411 kg of paddy. The farmers' direct benefits of technical efficiency improvement in terms of cost savings can then be calculated from the reduction amounts multiplied by the price per unit.

6.4.4.2 Economic efficiency improvement

From the concept of DEA efficiency analysis, economic efficiency improvement can be achieved by proportional reduction of all costs and still attain the same amounts of output. In this section, three alternatives for variable costs reduction are presented: full improvement, 20 percent economic efficiency improvement, and 10 percent economic efficiency improvement. The costs of each input reduction are summarized in Table 6.15.

The farmers' direct benefits of economic efficiency improvement can be considered in terms of cost savings or gross margin increasing. For example, at 10 percent level of economic efficiency improvement, the farmers could cut the total variable costs from 11,355 THB per ha to 10,219 THB per ha (1,135 THB reduction per ha) and still produce 3,411 kg of paddy. In other words, at 10 percent level of economic efficiency improvement, the gross margin per ha were increased 1,135 THB.

Table 6.15: Variable costs reduction for economic efficiency improvement

Unit: THB

Item	Sample average cost[1/] (THB/ha)	Cost of production at levels of efficiency improvement		
		Full (32.4%)	20%	10%
Variable costs				
Labor	5,592.83	3,780.75	4,474.26	5,033.55
Material	5,221.33	3,529.62	4,177.06	4,699.20
- seed	1,332.49	900.76	1,065.99	1,199.24
- DAP fertilizer	2,019.61	1,365.26	1,615.69	1,817.65
- Urea fertilizer	1,362.13	920.80	1,089.70	1,225.92
- plant protection chemical	358.41	242.29	286.73	322.57
- fuel/lubrication	148.69	100.51	118.95	133.82
Capital opportunity cost	540.69	365.52	432.57	486.64
Total variable costs	11,354.85	7,675.89	9,083.89	10,219.38
(cost reduction)	(0)	(3,678.97)	(2,270.97)	(1,135.49)
Average yield (kg/ha)		3,411.59		
Average variable costs (THB/kg)	3.33	2.25	2.66	3.00
Average paddy price (THB/kg)		5.64		
Revenue (THB/ha)		19,229.21		
Gross margin (THB/ha)	7,874.36	11,553.32	10,145.32	9,009.83

Remark: [1/] from Table 5.19

6.4.4.3 Environmental efficiency improvement

As discussed in Chapter 4, environmental efficiency analysis based on the technical efficiency concepts. Therefore, in this study, environmental efficiency improvement can be achieved by proportional reduction of chemical N-fertilizer, which leads to reduce N-leaching and N-emission and still attain the same amounts of output. In this section, three alternatives for chemical N-fertilizers reduction are presented: full improvement, 20 percent environmental efficiency improvement, and 10 percent environmental efficiency improvement. The amounts of chemical N-fertilizer and pollutions reduction are summarized in Table 6.16.

Table 6.16: Chemical N-fertilizer reduction for environmental efficiency improvement

Variable	Unit	Sample Mean[1/]	Input use at levels of efficiency improvement			Range of reduction
			Full (45.6 %)	20 %	10%	
Inputs						
DAP	kg / ha	183.48	99.81	146.78	165.13	18.35 – 83.67
Urea	kg / ha	106.24	57.79	84.99	95.62	10.62 – 48.45
Total N-fertilizer	kg N / ha	78.23	42.56	62.58	70.41	7.82 – 35.67
Environmental pollution						
N-leaching	kg N / ha	14.86	8.09	11.89	13.38	1.49 – 7.78
N-emission	kg N / ha	10.31	2.72	3.99	4.49	0.50 – 2.28
Output						
Rice yield	kg / ha		3,411.59			

Remark: [1/] from Table 6.1 and Table 6.10

The farmers' direct benefits of environmental efficiency improvement can be considered in terms of amounts of chemical fertilizer reduction and cost saving from the reduction amounts. For example, at 10 percent level of environmental efficiency improvement, the farmers can decrease amounts of N-fertilizer rate from 78.23 kg N per ha to 70.41 kg N per ha (7.82 kg N-fertilizer reduction) and still produce 3,411 kg of paddy. Then cost saving can be calculated from the reduction amounts multiplied by fertilizer prices.

In summary, benefits of the environmental efficiency improvement can be divided in to direct and indirect benefits. Direct benefit is financial benefit of cost saving to the rice farmers. Indirect benefits are economic benefit which stems from decreasing of imported fertilizer amounts and lead to foreign currency saving, and social-environmental benefit from pollution reduction in terms of greenhouse gases and nitrate leaching reduction.

6.5　Factors affecting the efficiency of rice production systems

Tobit regression analysis was applied to investigate the factors affecting the efficiency of rice farms. The explanatory variables that hypothesized effects on the efficiency were grouped into three categories: farmer characteristics (EDU, EXPERIENCE, HH LABOR, FARM OBJ, LAND TENURE), farm practices (FARM SIZE, RICE VARIETY, SEED REPLACEMENT), and production environment (ECOSYSTEM, PROVINCE, SHRIMP EFFECT). The mean values of these variables are presented in Table 6.17.

Table 6.17: Definition and mean value of variables used in the Tobit regressions

Variable	Definition	Mean value		
		All farms	Irrigated farms	Rain-fed farms
Farmer characteristics				
EDU	Years attended in formal school	5.69	6.06	5.30
EXPERIENCE	Years experience growing rice	27.13	26.07	28.25
HH LABOR	Number of full-time household labors	1.62	1.53	1.70
FARM OBJ[1]	1 for commercial	34	16	18
	0 otherwise	213	111	102
LAND TENURE[1]	1 for own the farm land	204	105	99
	0 otherwise	43	22	21
Farm practices				
FARM SIZE	Size of farm (ha)	2.83	2.85	2.81
RICE VARIETY[1]	1 for modern variety	146	90	56
	0 otherwise	101	37	64
SEED REPLACEMENT	Number of paddy crops before new seed replacement	3.55	3.42	3.68
Production environment				
ECOSYSTEM[1]	1 for irrigated area	127	-	-
	0 for rain-fed area	120	-	-
PROVINCE[1]	1 for Songkhla	120	60	60
	0 for Phatthalung	127	67	60
SHRIMP EFFECT[1]	1 for external effect from shrimp farming	30	-	30
	0 for no external effect from shrimp farming	217	-	90

Remarks: [1] each binary variable shows how many farmers are in the category

6.5.1 Factors affecting the technical efficiency

Two models of technical efficiency were constructed and analyzed. Thus the factors affecting the technical efficiency of these two models were investigated. This section presents the results in three sub-sections: all farms, irrigated farms, and rain-fed farms.

6.5.1.1 Factors affecting the technical efficiency of Model I

All farms

The significant factors affecting the technical efficiency of all farms were farm practices (FARM SIZE, RICE VARIETY, SEED REPLACEMENT) and production environment (PROVINCE, SHRIMP EFFECT). In contrast, farmer characteristics (EDU, EXPERIENCE, HH LABOR, FARM OBJ, LAND TENURE) and ECOSYSTEM had no explanatory effect on the technical efficiency of Model I (Table 6.18).

FARM SIZE and PROVINCE had statistically significant positive effects on technical efficiency of all farms at the 1 percent level. Due to the fact that most of the farmers were small farm holders, the results suggested that an increase in rice farm size by 1 percent would lead to an increase in the technical efficiency by 0.9 percent. In addition, the results indicated that rice farming in the Songkhla province would lead to attain higher level of technical efficiency. This may be due to the differences in soil types between the two provinces (see 5.4.1.2).

In contrast, RICE VARIETY, SHRIMP EFFECT, and SEED REPLACEMENT had statistically significant negative effects on technical efficiency at the 1, 5, and 10 percent level, respectively. These results suggested that the use of modern rice varieties, shrimp farming external effect on rice farms, and an increase in the number of paddy crops before new seed replacement would lead to a decrease in the level of technical efficiency. This may be because of the unsuitable modern varieties (Chainat 1, Suphanburi 60) for the environment of southern Thailand, effects of negative externality from shrimp farms on rice yield and grain quality, and a genetic erosion of seed or a decrease in seed quality when increasing in the number of paddy crops without new seed replacement.

Irrigated farms

Across irrigated farms, farmer characteristics have no explanatory effect on the technical efficiency. FARM SIZE, RICE VARIETY, and PROVINCE had significance effects on technical efficiency. PROVINCE and FARM SIZE had statistically significant positive effects on technical efficiency at the 1 and 10 percent level, respectively, whereas RICE VARIETY had statistically significant negative effect on technical efficiency at the 1 percent level (Table 6.18).

Table 6.18: Two-limit Tobit regression results of the technical efficiency of Model I

Explanatory variable	All farms	Irrigated farms	Rain-fed farms
	Coefficient	Coefficient	Coefficient
	(Std. Error)	(Std. Error)	(Std. Error)
CONSTANT	0.8933***	0.8838***	0.9947***
	(0.0407)	(0.0630)	(0.0654)
Farmer characteristics			
EDU	-0.0024	0.0014	-0.0058
	(0.0025)	(0.0039)	(0.0042)
EXPERIENCE	0.0001	0.0003	-0.0008
	(0.0006)	(0.0009)	(0.0009)
HH LABOR	0.0080	0.0277	0.0083
	(0.0104)	(0.0191)	(0.0155)
FARM OBJ	-0.0050	-0.0029	-0.0002
	(0.0218)	(0.0329)	(0.0388)
LAND TENURE	-0.0110	0.0043	-0.0039
	(0.0202)	(0.0302)	(0.0337)
Farm practices			
FARM SIZE	0.0093***	0.0085*	0.0034
	(0.0034)	(0.0051)	(0.0058)
RICE VARIETY	-0.0784***	-0.0956***	-0.0834**
	(0.0199)	(0.0312)	(0.0320)
SEED	-0.0076*	-0.0070	-0.0081
REPLACEMENT	(0.0044)	(0.0070)	(0.0071)
Production environment			
ECOSYSTEM	0.0073	-	-
	(0.0169)		
PROVINCE	0.0825***	0.0793***	0.1121***
	(0.0193)	(0.0276)	(0.0363)
SHRIMP EFFECT	-0.0563**	-	-0.0030
	(0.0270)		(0.0372)
Standard error of σ	0.0055	0.0086	0.0098
Log-likelihood function	122.4302	43.2714	25.4064
Number of observations	247	127	120

Remark: *, **, *** = significant at 10%, 5%, and 1% level, respectively

The results suggested that rice farming in the Songkhla province would lead to gain higher level of technical efficiency in irrigated areas. An increase in rice farm size by 1 percent would lead to an increase in the technical efficiency by 0.8 percent. In addition, the use of modern rice varieties would lead to a decrease in the level of technical efficiency.

Rain-fed farms

Across rain-fed farms, the significant factors affecting the technical efficiency were RICE VARIETY and PROVINCE. Farmer characteristics had no explanatory effect on the technical efficiency. RICE VARIETY had statistically significant negative effect on technical efficiency at the 5 percent level, while PROVINCE had statistically significant positive effect on technical efficiency at the 1 percent level (Table 6.18).

The results suggested that the use of modern rice varieties would cause a decrease in the level of technical efficiency, whereas rice farming in the Songkhla province would lead to a higher level of technical efficiency in rain-fed areas.

In summary, the common factors affecting the technical efficiency of all farms, irrigated and rain-fed farms were RICE VARIETY and PROVINCE. RICE VARIETY had statistically significant negative effect, while PROVINCE had statistically significant positive effect on technical efficiency. Farmer characteristics (EDU, EXPERIENCE, HH LABOR, FARM OBJ, LAND TENURE) had no explanatory effect on the technical efficiency. These results suggested that the use of existing modern rice varieties would cause a decrease in the level of technical efficiency. This may be because of the unsuitable modern varieties (Chainat 1, Suphanburi 60) for the environment of the southern region. On the other hand, rice farming in the Songkhla province would lead to gain higher level of technical efficiency. This may be due to differences in soil types between the two provinces.

6.5.1.2 Factors affecting the technical Efficiency of Model II

All farms

The significant factors affecting the technical efficiency of Model II were farm practices (FARM SIZE, RICE VARIETY, SEED REPLACEMENT) and production environment (PROVINCE, SHRIMP EFFECT). In contrast, farmer characteristics (EDU, EXPERIENCE, HH LABOR, FARM OBJ, LAND TENURE) and ECOSYSTEM had no explanatory power on the technical efficiency (Table 6.19).

PROVINCE and FARM SIZE had statistically significant positive effects on technical efficiency of all farms at the 1 and 5 percent level, respectively. The results suggested that rice farming in the Songkhla province would lead to gain higher level of technical efficiency. This

may be due to the differences in soil types between the two provinces. In addition, due to the fact that most of the farmers were small farm holders, the results suggested that an increase in rice farm size by 1 percent would lead to an increase in the technical efficiency by 0.9 percent.

In contrast, RICE VARIETY, SHRIMP EFFECT, and SEED REPLACEMENT had statistically significant negative effects on technical efficiency at the 1, 10, and 10 percent level, respectively. These results suggested that the use of modern rice varieties, shrimp farming external effect on rice farms, and an increase in the number of paddy crops before new seed replacement would cause a decrease in the level of technical efficiency. This may be because of the unsuitable modern varieties for the environment of southern Thailand, effects of negative externality from shrimp farms on rice yield and grain quality, and a genetic erosion of seed or a decrease in seed quality when increasing in the number of paddy crops without new seed replacement.

Irrigated farms

Across irrigated farms, the significant factors affecting the technical efficiency were RICE VARIETY and PROVINCE. Farmer characteristics had no explanatory effect on the technical efficiency. RICE VARIETY had statistically significant negative effect on technical efficiency at the 1 percent level, while PROVINCE had statistically significant positive effect on technical efficiency at the 1 percent level (Table 6.19). The results suggested that the use of modern rice varieties would cause a decrease in the level of technical efficiency, while rice farming in the Songkhla province would lead to attain higher level of technical efficiency in irrigated areas.

Rain-fed farms

Across rain-fed farms, farmer characteristics had no explanatory effect on the technical efficiency. RICE VARIETY, SEED REPLACEMENT, and PROVINCE had significance effects on technical efficiency. RICE VARIETY and SEED REPLACEMENT had statistically significant negative effects on technical efficiency at the 5 and 10 percent level, respectively. PROVINCE had statistically significant positive effect on technical efficiency at the 5 percent level (Table 6.19). The results suggested that the use of modern rice varieties and an increase in the number of paddy crops before new seed replacement would result in a decrease in the level of technical efficiency. However, rice farming in the Songkhla province would lead to a higher level of technical efficiency in rain-fed areas.

Table 6.19: Two-limit Tobit regression results of the technical efficiency of Model II

Explanatory variable	All farms Coefficient (Std. Error)	Irrigated farms Coefficient (Std. Error)	Rain-fed farms Coefficient (Std. Error)
CONSTANT	0.8765***	0.8656***	1.0061***
	(0.0400)	(0.0617)	(0.0645)
Farmer characteristics			
EDU	-0.0026	0.0014	-0.0051
	(0.0025)	(0.0038)	(0.0041)
EXPERIENCE	0.0000	0.0003	-0.0009
	(0.0005)	(0.0009)	(0.0009)
HH LABOR	0.0102	0.0294	0.0045
	(0.0103)	(0.0187)	(0.0153)
FARM OBJ	-0.0022	-0.0074	0.0107
	(0.0215)	(0.0322)	(0.0384)
LAND TENURE	-0.0007	0.0166	-0.0095
	(0.0197)	(0.0293)	(0.0334)
Farm practices			
FARM SIZE	0.0087**	0.0081	0.0033
	(0.0034)	(0.0050)	(0.0057)
RICE VARIETY	-0.0719***	-0.1003***	-0.0669**
	(0.0196)	(0.0307)	(0.0311)
SEED	-0.0079*	-0.0078	-0.0115*
REPLACEMENT	(0.0043)	(0.0068)	(0.0069)
Production environment			
ECOSYSTEM	0.0068	-	-
	(0.0166)		
PROVINCE	0.0778***	0.0849***	0.0855**
	(0.0189)	(0.0271)	(0.0349)
SHRIMP EFFECT	-0.0470*	-	0.0175
	(0.0265)		(0.0366)
Standard error of σ	0.0053	0.0083	0.0094
Log-likelihood function	133.7810	50.4446	31.0412
Number of observations	247	127	120

Remark: *, **, *** = significant at 10%, 5%, and 1% level, respectively

In summary, the common factors affecting the technical efficiency of all farms, irrigated and rain-fed farms of Model II were similar to the results of Model I. RICE VARIETY had statistically significant negative effect, while PROVINCE had statistically significant positive effect on technical efficiency. Farmer characteristics had no explanatory effect on the technical efficiency. The results suggested that the use of modern rice varieties would cause a decrease in the level of technical efficiency. This may be because of the unsuitable modern varieties (Chainat 1, Suphanburi 60) for the environment of southern Thailand. However, rice farming in the Songkhla province would lead to a higher level of technical efficiency. This may be due to the differences in soil types between the two provinces.

6.5.2 Factors affecting the economic efficiency

The factors affecting the economic efficiency results are presented in three sub-sections: all farms, irrigated farms, and rain-fed farms.

All farms

Across all farms, the significant factors affecting the economic efficiency were farmer characteristic (EXPERIENCE), farm practices (RICE VARIETY, SEED REPLACEMENT), and production environment (PROVINCE). EXPERIENCE, RICE VARIETY, and SEED REPLACEMENT had statistically significant negative effects on economic efficiency at the 5 percent level. PROVINCE had statistically significant positive effect on economic efficiency of all farms at the 1 percent significance level (Table 6.20).

The results suggested that an increase in the rice farming experience by 1 percent would lead to a decrease in the level of economic efficiency by 0.1 percent. In addition, the use of modern rice varieties and an increase in the number of paddy crops before new seed replacement would cause a decrease in the level of economic efficiency. However, rice farming in the Songkhla province would lead to gain higher level of economic efficiency.

Irrigated farms

Across irrigated farms, RICE VARIETY, SEED REPLACEMENT, and PROVINCE had significance effects on economic efficiency. RICE VARIETY and SEED REPLACEMENT had statistically significant negative effects on economic efficiency at the 1 and 5 percent level, respectively. PROVINCE had statistically significant positive effect on economic efficiency at the 1 percent level (Table 6.20).

Table 6.20: Two-limit Tobit regression results of the economic efficiency

Explanatory variable	All farms Coefficient (Std. Error)	Irrigated farms Coefficient (Std. Error)	Rain-fed farms Coefficient (Std. Error)
CONSTANT	0.7209*** (0.0394)	0.7974*** (0.0596)	0.8116*** (0.0658)
Farmer characteristics			
EDU	-0.0026 (0.0025)	-0.0025 (0.0037)	-0.0054 (0.0043)
EXPERIENCE	-0.0012** (0.0005)	-0.0009 (0.0009)	-0.0021** (0.0009)
HH LABOR	0.0024 (0.0102)	0.0149 (0.0183)	-0.0050 (0.0158)
FARM OBJ	0.0168 (0.0212)	0.0135 (0.0315)	0.0443 (0.0375)
LAND TENURE	-0.0157 (0.0196)	-0.0166 (0.0287)	-0.0198 (0.0343)
Farm practices			
FARM SIZE	0.0052 (0.0032)	0.0077 (0.0049)	-0.0000 (0.0057)
RICE VARIETY	-0.0487** (0.0191)	-0.0963*** (0.0301)	-0.0528* (0.0301)
SEED REPLACEMENT	-0.0102** (0.0043)	-0.0156** (0.0067)	-0.0109 (0.0072)
Production environment			
ECOSYSTEM	0.0216 (0.0147)	-	-
PROVINCE	0.1035*** (0.0186)	0.1061*** (0.0266)	0.1311*** (0.0347)
Standard error of σ	0.0048	0.0071	0.0082
Log-likelihood function	193.5722	92.0619	71.1343
Number of observations	247	127	120

Remark: *, **, *** = significant at 10%, 5%, and 1% level, respectively

The results suggested that the use of modern rice varieties and an increase in the number of paddy crops before new seed replacement would cause a decrease in the level of economic efficiency. However, rice farming in the Songkhla province would lead to a higher level of economic efficiency in irrigated areas.

Rain-fed farms

Across rain-fed farms results, the significant factors affecting the economic efficiency were EXPERIENCE, RICE VARIETY, and PROVINCE. EXPERIENCE and RICE VARIETY had statistically significant negative effects on economic efficiency at the 5 and 10 percent level, respectively. PROVINCE had statistically significant positive effect on economic efficiency at the 1 percent significance level (Table 6.20).

The results suggested that an increase in the rice farming experience by 1 percent would lead to a decrease in the level of economic efficiency by 0.2 percent. In addition, the use of modern rice varieties would cause a decrease in the level of economic efficiency. However, rice farming in the Songkhla province would lead to gain higher level of economic efficiency in rain-fed areas.

In summary, the common factors affecting the economic efficiency of all farms, irrigated and rain-fed farms was similar to the results of factors affecting the technical efficiency. RICE VARIETY had statistically significant negative effect, while PROVINCE had statistically significant positive effect on economic efficiency. These results suggested that the use of modern rice varieties would cause a decrease in the level of economic efficiency. However, rice farming in the Songkhla province would lead to gain higher level of economic efficiency.

6.5.3   Factors affecting the environmental efficiency

The factors affecting the environmental efficiency results are presented in three sub-sections: all farms, irrigated farms, and rain-fed farms.

All farms

Across all farms, the significant factors affecting the environmental efficiency were farmer characteristics (EXPERIENCE, LAND TENURE), farm practice (RICE VARIETY). Production environment had no explanatory effect on the environmental efficiency. EXPERIENCE had statistically significant positive effect on environmental efficiency at the 10 percent level. In contrast, LAND TENURE, and RICE VARIETY had statistically significant negative effects on environmental efficiency at the 10 percent level (Table 6.21).

Table 6.21: Two-limit Tobit regression results of the environmental efficiency

Explanatory variable	All farms Coefficient (Std. Error)	Irrigated farms Coefficient (Std. Error)	Rain-fed farms Coefficient (Std. Error)
CONSTANT	0.5586*** (0.0508)	0.5862*** (0.0758)	0.6446*** (0.0837)
Farmer characteristics			
EDU	-0.0011 (0.0032)	0.0042 (0.0047)	-0.0094* (0.0055)
EXPERIENCE	0.0013* (0.0007)	0.0019 (0.0012)	-0.0005 (0.0012)
HH LABOR	0.0181 (0.0131)	0.0027 (0.0232)	0.0395** (0.0201)
FARM OBJ	0.0322 (0.0274)	-0.0020 (0.0399)	0.0897* (0.0473)
LAND TENURE	-0.0483* (0.0253)	-0.0656* (0.0365)	-0.0126 (0.0435)
Farm practices			
FARM SIZE	-0.0008 (0.0041)	0.0031 (0.0062)	-0.0126* (0.0073)
RICE VARIETY	-0.0459* (0.0246)	-0.0298 (0.0381)	-0.0662* (0.0391)
SEED REPLACEMENT	-0.0076 (0.0055)	-0.0136 (0.0086)	-0.0135 (0.0092)
Production environment			
ECOSYSTEM	0.0177 (0.0508)	-	-
PROVINCE	0.0244 (0.0189)	-0.0038 (0.0338)	0.0912** (0.0442)
Standard error of σ	0.0063	0.0090	0.0104
Log-likelihood function	129.2228	62.0766	44.3511
Number of observations	247	127	120

Remark: *, **, *** = significant at 10%, 5%, and 1% level, respectively

The results suggested that an increase in the rice farming experience by 1 percent would lead to an increase in the level of environmental efficiency by 0.1 percent. The farmers' ownership on their land and the use of modern rice varieties would cause a decrease in the level of environmental efficiency.

Irrigated farms

Across irrigated farms, the significant factor affecting the environmental efficiency was farmer characteristic (LAND TENURE). Farm practices and production environment had no explanatory effect on the environmental efficiency (Table 6.21). LAND TENURE had statistically significant negative effect on environmental efficiency at the 10 percent level. The result suggested that the farmers' ownership on their land would cause a decrease in the level of environmental efficiency.

Rain-fed farms

Across rain-fed farms, the significant factors affecting the environmental efficiency were farmer characteristics (EDU, HH LABOR, FARM OBJ), Farm practices (FARM SIZE, RICE VARIETY), and production environment (PROVINCE). EDU, FARM SIZE, and RICE VARIETY had statistically significant negative effects on environmental efficiency at the 10 percent level. In contrast, HH LABOR and PROVINCE had statistically significant positive effects on environmental efficiency at the 5 percent level and FARM OBJ had statistically significant positive effect on environmental efficiency at the 10 percent level (Table 6.21).

The results suggested that an increase in years of schooling by 1 percent would cause a decrease in the level of environmental efficiency by 0.9 percent. An increase in rice farm size by 1 percent would cause a decrease in the level of environmental efficiency by 1 percent. In addition, the use of modern rice varieties would lead to a decrease in level of environmental efficiency. On the other hand, an increase in numbers of household full-time labor by 1 percent would lead to an increase in the level of environmental efficiency by 4 percent. Rice farming in the Songkhla province and the commercial objective of rice production would lead to gain higher levels of environmental efficiency.

In summary, there is no common factor affecting the environmental efficiency of all farms, irrigated and rain-fed farms. However, though rice farming process causes the environmental pollutions, but it produces very less amounts compare to industrial sector and of fossil emissions.

6.5.4 Summary of significant factors affecting the efficiency of rice production in southern Thailand

PROVINCE and RICE VARIETY were the common (dummy) variables affecting the efficiency of rice production in southern Thailand. However, in order to give more specific recommendations on improving efficiency of rice production, the significant factors affecting on efficiency of rice production are summarized and as presented in Table 6.22.

All farms

Across all farms, FARM SIZE, PROVINCE and EXPERIENCE had statistically significant positive effects on the efficiency. In contrast, RICE VARIETY, SEED REPLACEMENT, SHRIMP EFFECT, EXPERIENCE, and LAND TENURE had statistically significant negative effects on the efficiency. The results revealed that an increase in the rice farming experiences had positive effect on the environmental efficiency, but negative effects on the economic efficiency.

Irrigated farms

Across irrigated farms, FARM SIZE and PROVINCE had statistically significant positive effects on the efficiency. In contrast, RICE VARIETY, SEED REPLACEMENT, and LAND TENURE had statistically significant negative effects on the efficiency.

Rain-fed farms

Across rain-fed farms, PROVINCE, HH LABOR, and FARM OBJ had statistically significant positive effects on the efficiency. In contrast, EDU, FARM SIZE, and RICE VARIETY had statistically significant negative effects on the efficiency.

Table 6.22: Summary of significant factors affecting the efficiency of rice production

Efficiency	Positive effects	Negative effects
All farms		
TE Model I	FARM SIZE, PROVINCE	RICE VARIETY, SEED REPLACEMENT, SHRIMP EFFECT
TE Model II	FARM SIZE, PROVINCE	RICE VARIETY, SEED REPLACEMENT, SHRIMP EFFECT
EE	PROVINCE	EXPERIENCE, RICE VARIETY, SEED REPLACEMENT
ENE	EXPERIENCE	LAND TENURE, RICE VARIETY
Irrigated farms		
TE Model I	FARM SIZE, PROVINCE	RICE VARIETY
TE Model II	PROVINCE	RICE VARIETY
EE	PROVINCE	RICE VARIETY, SEED REPLACEMENT
ENE	-	LAND TENURE
Rain-fed farms		
TE Model I	PROVINCE	RICE VARIETY
TE Model II	PROVINCE	RICE VARIETY
EE	PROVINCE	EXPERIENCE, RICE VARIETY
ENE	HH LABOR, FARM OBJ, PROVINCE	EDU, FARM SIZE, RICE VARIETY

6.6   Concluding remarks

Data envelopment analysis under variable returns to scale assumption was applied to calculate technical, economic, and environmental efficiency of rice farms in southern Thailand. DEA calculated efficiency for individual farms, which relative to all other observed farms. In each efficiency analysis, three frontiers were constructed: Meta frontier, Irrigated frontier, and Rain-fed frontier. The results showed that it is possible for the inefficient farms to improve their technical, economic, and environmental efficiency. In addition, Tobit regression results showed common variables affecting on efficiency of rice production in southern Thailand were province and the use of modern rice varieties. Rice farming in the Songkhla province would lead to gain higher level of efficiency, whereas the use of modern rice variety would cause a decrease in the level of efficiency.

7   Conclusions and Recommendations

Rice farming in southern Thailand is not only significant in region's food security but also in rural employment, biodiversity, and cultural and tradition conservation. Rice production in this region is constrained by bio-physical and economic factors especially high cost of production and high application rate of chemical fertilizers. In addition, the actual outputs from rice production process are not only paddy rice but also the potential negative environmental effects. The flooded condition generates methane gas emission, while the excessive use of N-fertilizer causes the emission of nitrous oxide (and other nitrogen gases) and the leaching of nitrate. In this study, therefore, the efficiency of use of all combination of inputs and efficiency of use of chemical N-fertilizers as its excessive use causes the negative externalities are focused. In other words, this study is concerning both short-term and long-term views of rice farming systems in southern Thailand.

The objectives of this study are to investigate the existing rice production systems in southern Thailand and to assess the technical efficiency, economic efficiency, and environmental efficiency of rice production systems, then to investigate factors affecting the technical, economic and environmental efficiency of rice production systems in southern Thailand. In each efficiency analysis, three DEA frontiers under variable returns to scale (BCC-DEA) were constructed: Meta frontier, Irrigated frontier, and Rain-fed frontier. Two-limit Tobit regression analysis was used to investigate factors affecting the technical efficiency, economic efficiency, and environmental efficiency.

In this chapter, the main findings of each objectives of this study are summarized and derived to highlight the suggestions and policy recommendations. The recommendations for further research are discussed in the last section.

7.1   Summary of main findings

7.1.1   Main findings of the field study

The main rice farming area of southern Thailand, the Songkhla Lake Basin, was selected as the study area. Primary data of this study were based on farm-level cross-section data of the major rice crop year 2004/05. The survey was conducted during July-October 2005. The total of 247 rice farm household samples was randomly selected from 18 villages, 9 sub-districts of Songkhla and Phatthalung provinces. The sample farms were categorized by agro-ecosystems: 127 farms in irrigated area and 120 farms in rain-fed area.

Rice farm households of both agro-ecosystems had similar characteristics. Most of the households were semi-subsistence or semi-commercial rice producers and more than half of the respondent households were members of the Bank of Agriculture and Agricultural Cooperatives (BAAC). The average farm family size was medium, which consisted of 4 members and half of family members or two members were household labors working in rice farming. Rice farmers were small farm holders on fragmented land holdings. The average farm size was approximately 2.8 ha. The average duration of schooling was approximately 6 years, while the farmers had an average of 27 years of experiences in rice farming. The results showed no statistically significant differences between two agro-ecosystems in average farm family size, average farm family labor, average farm size, average education and experiences of rice farmers

On rice farming practices, rice is a monoculture farming system in the study area. The production duration from land preparation till harvest lasts approximately 6 months. The farmers have been growing rice for more than 20 years, but most of their rice fields have never been tested for the soil properties and quality. There were two different soil types (Ranot and Bang Nara series) in the two provinces of the study area. Tractor and combine harvesting machines were widely used for rice production in the study area. Pre-germinated direct seeding, which requires less intensive labor than seedling transplanting, was popular planting method in the study area. Most of irrigated farms (70 percent) planted modern rice varieties, while half of rain-fed farms in rain-fed area planted modern rice varieties. All rice farmers applied chemical fertilizers during production process. Two types of chemical fertilizers were applied: diammonium phosphate (DAP) and urea. Forty percent of rice farmers applied chemical pesticides during production process.

Rice farm performances, the results showed statistically significance differences between two agro-ecosystems in land productivity or rice yield per ha. Most of the farmers sold their green paddy after harvesting at farm-gate. The important cost compositions of rice production were variable costs: labors, seed, and chemical fertilizers, which shared 50, 12, and 30 percent of total variable costs, respectively. Gross margin and profit of rice production were 2.31 and 1.32 THB per kg of paddy, respectively. In addition, the average annual household income of irrigated farms was higher than rain-fed farms because irrigated farms could produce rice two crops in a year.

Farmers' opinion on problems and obstacles of rice production, the results showed that the most severe and severe problems were high cost of chemical inputs (chemical fertilizer and pesticide), water shortage, low output price, and low land productivity. In addition, farmers' perception on negative environmental effects of rice farming, the results showed that the farmers have got information about the negative effect of chemical inputs on the environment, but lack of information about the negative effect of rice farming conditions on the environment.

7.1.2 Main findings of technical efficiency analysis

The input-output data of the individual farm were used to analyze the technical efficiency. The combination of inputs: labor, machine, seed, and fertilizers were allocated to produce a single desirable output. Two models of technical efficiency were constructed, which differed in terms of fertilizer forms. In Model I, fertilizers were treated in commercial formulas (DAP, Urea), while commercial formulas were converted into nutrient compositions (nitrogen fertilizer, phosphorus fertilizer) in Model II.

The results showed that the average levels of technical efficiency of Model I was slightly higher than Model II. The average levels of technical inefficiency were approximately 14 percent for all sample farms, and 10 percent and 8 percent for irrigated and rain-fed farms, respectively. Thus, the farmers of inefficient farms can improve their technical efficiency by learning from the technical best practice farms (TBPFs) and adjusting the combination of inputs close to these TBPFs.

The technical best practice farms applied 17-22 kg N-fertilizer to produce one ton of paddy rice, whereas the average of southern region farms applied 22.93 kg N-fertilizer to produce one ton of paddy rice. In other words, the TBPFs applied N-fertilizer in range of 66-72 kg per ha. In addition, the technical best practice farms used 35-42 kg of seed to produce one ton of paddy rice, while the average of southern region farms used 44.38 kg of seed. In other words, the TBPFs used seed rate ranging between 135-149 kg per ha. The direct consequences of this technical efficiency improvement are all inputs reduction and the farmers gain financial benefit from these cost savings.

FARM SIZE and PROVINCE had statistically significant positive effects on technical efficiency of all farms. Due to the fact that most of the farmers were small farm holders, the results suggested that an increase in rice farm size would lead to an increase in the technical efficiency. In addition, the results indicated that rice farming in the Songkhla province would lead to attain higher level of technical efficiency. This may be due to the differences in soil types between the two provinces.

In contrast, RICE VARIETY, SHRIMP EFFECT, and SEED REPLACEMENT had statistically significant negative effects on technical efficiency of all farms. These results suggested that the use of modern rice varieties, shrimp farming external effect on rice farms, and an increase in the number of paddy crops before new seed replacement would lead to a decrease in the level of technical efficiency. This may be because of the unsuitable modern varieties (Chainat 1, Suphanburi 60) for the environment of southern Thailand, effects of negative externality from shrimp farms on rice yield and grain quality, and a genetic erosion of seed or decrease seed quality when increasing in the number of paddy crops without new seed replacement.

The common factors affecting the technical efficiency of all farms, irrigated and rain-fed farms of Model I were similar to the results of Model II. RICE VARIETY had statistically significant negative effect, while PROVINCE had statistically significant positive effect on technical efficiency.

7.1.3 Main findings of economic efficiency analysis

Rice farmers were assumed to produce rice at cost minimization level. The results showed that only 2 percent of all sample farms were on the cost (Meta) frontier. The average levels of economic (cost) inefficiency were approximately 32 percent for whole sample farms, 29 percent for irrigated farms, and 30 percent for rain-fed farms. Hence, the farmers of inefficient farms can improve their economic efficiency by learning information from the economic best practice farms (EBPFs).

The economic best practice farms used all combination of inputs less amounts than the average except the labor input. This may imply that the EBPFs used their labors as substitution input with others, especially machine. In addition, the EBPFs paid the unit price for rice seed higher than the average. This may imply that the EBPFs concern on high seed quality, which may reflect in high seed price, but can produce more output than low quality. The EBPFs applied 16-19 kg N-fertilizer and used 36-48 kg of seed to produce one ton of paddy rice. In other words, the EBPFs applied 59-62 kg N-fertilizer and used 132-156 kg of seed per ha. The farmers' direct benefits of economic efficiency improvement can be considered in terms of cost savings or gross margin increasing.

PROVINCE had statistically significant positive effect on economic efficiency of all farms, while EXPERIENCE, RICE VARIETY, and SEED REPLACEMENT had statistically significant negative effects on economic efficiency. The results suggested that rice farming in the Songkhla province would lead to gain higher level of economic efficiency. However, an increase in the rice farming experience, the use of modern rice varieties and an increase in the

number of paddy crops before new seed replacement would lead to a decrease in the level of economic efficiency.

The common factors affecting the economic efficiency of all farms, irrigated and rain-fed farms was similar to the results of factors affecting the technical efficiency. RICE VARIETY had statistically significant negative effect, while PROVINCE had statistically significant positive effect on economic efficiency.

7.1.4   Main findings of environmental efficiency analysis

Environmental efficiency model of this study is focused on input-oriented in order to minimize pollution from N-fertilizer application and still attain the same level of output. The results showed that the average levels of environmental inefficiency were approximately 46 percent for all sample farms, 45 percent for irrigated farms, and 42 percent for rain-fed farms.

The environmental best practice farms (ENEBPs) applied 12-16 kg of N-fertilizer to produce one ton of paddy rice. In other words, the ENEBPs applied 45-56 kg N-fertilizer per ha, which is lower than N- fertilizer rate of the TBPFs and EBPFs. The efficient use of the chemical fertilizer particularly N-fertilizer can be beneficial to both rice farmers and the environment. If the environmental inefficient farmers can scale down the amounts of N-fertilizer, they will financially benefit from cost saving. Then it will automatically reduce the gaseous emission and nitrate leaching and this pollution reduction will be social benefit for the society.

EXPERIENCE had statistically significant positive effect on environmental efficiency, while LAND TENURE, and RICE VARIETY had statistically significant negative effects on environmental efficiency. The results suggested that an increase in the rice farming experience would lead to an increase in the level of environmental efficiency. However, the farmers' ownership on their land and the use of modern rice varieties would cause a decrease in the level of environmental efficiency. There is no common factor affecting the environmental efficiency of all farms, irrigated and rain-fed farms.

7.2 Suggestions and policy recommendations

In order to sustain and improve efficiency of rice production systems in southern Thailand, suggestions and policy recommendations are drawn from the study results. In general, our findings lead to support the restructure of rice-related agencies in 2006, which has been established as Rice Department under Ministry of Agriculture and Cooperatives. The responsibility of Rice Department focuses on rice policy and strategy planning, rice research and development, rice seed production, rice production extension services, and rice product development (RD, 2007). This government institution and its activities are necessary and very important to improve the efficiency of rice farming in southern Thailand. However, our findings lead to suggest the differences in implementation of the efficiency improvement policies for the farmers in different provinces and agro-ecosystems.

To be more specific, our findings lead to suggest advisory measures for short-term implementations, which focus on the farm efficiency improvement under existing technology. In addition, in long-term, research and development of new technologies for improvement of rice farms efficiency are necessary, and economic instruments for efficiency use of N-fertilizer may be needed.

7.2.1 Short-term suggestions and policy measures

Paddy soil quality tested

Due to the findings from field study, most of paddy farms have been never tested. Moreover, the findings from Tobit regression analysis showed that farms in Songkhla province had positive effect on efficiency. This may be due to the differences in soil types between the two provinces. Therefore, the Rice Department under the Ministry of Agriculture and Agricultural Cooperatives should set up the mobile unit of paddy soil testing and give advises to the farmers after having the soil tested results that how to improve the soil quality and recommend how to use the proper combination of inputs especially chemical fertilizers and organic fertilizers. For example, crop rotation practices and split N-fertilizer applications may help to improve soil quality and efficiency use of chemical fertilizers.

Set up benchmarking of the southern rice production

The findings of the best practice farms can be used to set up the benchmarking of rice production in southern Thailand especially chemical fertilizers. The technical best practice farms applied 66-72 kg N-fertilizer per ha (17-22 kg N-fertilizer per ton of paddy), while the average chemical N-fertilizer use of the sample farms was 78-81 kg N-fertilizer per ha (22-25 kg N-fertilizer per ton of paddy). In addition, the environmental best practice farms applied 45-

56 kg N-fertilizer per ha (12-17 kg N-fertilizer per ton of paddy). Therefore, the benchmarking of chemical N-fertilizer of rice production southern Thailand should be in the range of 45-72 kg N-fertilizer per ha (12-22 kg N-fertilizer per ton of paddy), though it is relatively higher than recommendation rate of Agricultural Extension Department. The optimum rate of total N-fertilizer for rice production in clayey soil and non-photoperiod sensitive variety is 55 kg N-fertilizer per ha (DOAE, 2002).

The technical best practice farms applied seed 135-149 kg per ha (35-42 kg seed per ton of paddy), while the average seed rate of the sample farms was 150-153 kg per ha (42-49 kg seed per ton of paddy). Therefore, the benchmarking of seed rate of rice production southern Thailand should be in range of 135-149 kg per ha (35-42 kg seed per ton of paddy), although it is relatively higher than recommendation of seed rate of Rice Research Institution and FAO. The optimum seed rate for direct seeding is ranging between 94-125 kg per ha (RRI and FAO, 2003).

Increasing rice income by improving inputs use efficiency

The findings from the field study, chemical fertilizer cost and seed cost shared 30 percent and 12 percent of total variable costs. These costs are cash expenses of the rice farms. The inefficiency farms should be considered on reduction of these cash costs by learning from the best practice farms, and then they would increase income or gross margin from rice farming. In addition, rice farmers as professional farm managers, the planning and evaluation of farm performances are necessary. Thus the farmers need to be trained on records keeping systems. Then this information can again be used for farm improvement.

Dissemination of rice production information via agricultural extension services

Rice Department is the main government agency who works closely to the rice farmers. The officers of Rice Department should provide and disseminate information of the best practice farms or benchmark farms to all rice farmers in the region. The officers should stimulate the farmers of the inefficiency farms to alert to improve rice production efficiency.

Moreover, the field study findings suggest that the rice farmers need more information or training on how to collect and produce good seed quality and the farmers must be briefed upon the negative effects from rice farming and suggested ways to mitigate these negative effects especially by using N-fertilizers at optimum level.

7.2.2   Long-term suggestions and policy measures

7.2.2.1 New technology

Nutrient management practices

According to IRRI (2006) recommended to use site-specific nutrient management (SSNM) to eliminate excess use of fertilizer and increase farmers' income. The SSNM or precision rice farming (KYUMA, 2004) aims to apply fertilizer at optimum rate and time then it would increase efficiency in nutrient use and reduce environmental effects. In practice, this needs to do the specific research on rice farming in southern Thailand, which would be related to the soil types and rice varieties.

New fertilizer products

The pollution abatement technologies on fertilizer products are coated form of N-fertilizer, especially coated urea (KYUMA, 2004), controlled-release or slow-release, and nitrification inhibitors (CHOUDHURY and KENNEDY, 2005). These would help to reduce the pollution from excessive use of N-fertilizer because it releases nitrogen nutrient gradually during the production period and is possible to reduce N-fertilizer by 30-40 percent of the ordinary dose. However, due to high cost of these types of fertilizer, it may be compensated by savings in labor and fertilizer use (KYUMA, 2004). Therefore, according to Thai situation, which the import values of chemical fertilizers for rice farming are 17 billion THB per annum, these new fertilizer products are needed to research that it can be substituted by domestically produced or it is financial feasible for rice farmers to use these low pollution technologies.

New rice variety

The findings from Tobit regression analysis showed that the modern rice variety had statistically significant negative effect on efficiency of rice farms in southern Thailand. This may be because of the unsuitable modern varieties (Chainat 1, Suphanburi 60) for the environment of the region. Therefore, research and development of new rice varieties are needed. The new rice varieties should be improved from the traditional varieties, which suitable for the south, but non-photosensitive qualification of the new varieties are needed. The Phatthalung Rice Research Center is one of the main government agencies responsible for selecting and improving the rice varieties of the southern region.

Dissemination of new technology information via agricultural extension services

In long-term, the officers of Rice Department again should provide and disseminate new technology information and study on adoption of rice farmers to the new technologies.

7.2.2.2 Economic instruments for improvement of efficiency use of chemical fertilizers

According to PRETTY *et al.* (2001) and WEERSINK and WOSSINK (2005), fertilizer taxes and/or subsidy and incentives would be possible economic instruments to implement in the long-term in order to improve efficiency use of chemical fertilizers. However, due to the fact that rice farmers are poorer than other farmers, fertilizer taxes would lead to increase in fertilizer prices and decrease in rice farmers' gross margin and profit. Thus fertilizer taxes measure should be the last choice for the policy makers to consider. The subsidy and incentives to the farmers who adopt to the best practice or low polluting technologies would be the practical measure to improve efficiency use of chemical fertilizers in rice farming.

7.3   Limitations of the study and recommendations for further study

7.3.1   Limitations of the study

One year cross section data

In this study, one year cross section data were used for efficiency analysis. The recommendation of improvement of rice farms efficiency would be more precise in case of panel data of rice farms are available.

Nitrogen emission and nitrate leaching information

In environmental efficiency analysis, nitrogen emission and nitrate leaching information were assumed from the experimental study, which conducted in the central region. In case of there are the study results of nitrogen balance of rice fields in the southern region, it would give more specific results.

One environmental detrimental input (chemical N-fertilizer)

In environmental efficiency analysis, chemical N-fertilizers were considered as the main source of potential environmental effects because all farmers applied chemical fertilizers on the rice fields. However, if the environmental effects from chemical pesticides and herbicides use are known, it will help to calculate the environmental efficiency of all environmental detrimental inputs of rice production systems.

7.3.2 Recommendations for further study

Efficiency analysis tools and data set: comparison the efficiency analysis results between data envelopment analysis (DEA) and stochastic frontier analysis (SFA) by using observed one year cross section data and/or panel data

Environmental efficiency in DEA model: alternatives DEA model to treat nitrogen emission and nitrate leaching as outputs

Multi-functionality of rice farming: economic valuations of positive externality of rice production systems

Farmers' Attitudes: Attitudes of rice farmers or adoption of rice farmers to the new technologies particularly to the new rice varieties.

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Appendix

A.1   Rice standards

According to the rice standards of the Thai Ministry of Commerce (MOC, 1997), the standards for White rice 100% Grade B, White rice 5%, and White broken rice A1 are specified as follows:

A.1.1   White rice 100% Grade B

White rice 100% Grade B shall have Grain classification, Grain composition and Milling degree as follows:

A.1.1.1   Grain classification, comprising of:

- Long grain Class 1 not less than 40.0 %, the rest shall be Long grain Class 2and or Class 3.

(Long grain Class 1 is whole kernel having the length exceeding 7.0 mm., Long grain Class 2 is whole kernel having the length exceeding 6.6 mm. up to 7.0 mm., and Long grain Class 3 is whole kernel having the length exceeding 6.2 mm. up to 6.6 mm.)

- Of all these there may be Short grain not exceeding 5.0 %

(Short grain is whole kernel having the length not exceeding 6.2 mm.)

A.1.1.2 Grain composition, comprising of:

- Whole kernels not less than 60.0 %

(Whole kernels mean rice kernels that are in whole condition without any broken part, including the kernels that have the length as from 9 parts onward.)

- Brokens having the length as from 5.0 parts onward but not reaching 8.0 parts not exceeding 4.5%. Of this there may be brokens having the length not reaching 5.0 parts and not passing through sieve No. 7 not exceeding 0.5 %, and Small white brokens C1 not exceeding 0.1 %

(Brokens mean broken kernels that have the length as from 2.5 parts but have not reached the length of Head rice. This includes split kernels that retain the area less than 80% of the whole kernel. Small brokens C1 mean small broken kernels that pass through round hole metal sieve No.7).

- The rest shall be Head rice having the length as from 8.0 parts onward.

(Head rice means broken kernels whose lengths are more than those of Brokens but have not reached the length of the whole kernel. This includes split kernels that retain the area as from 80% of the whole kernel.)

A.1.1.3 Rice and matter that may be present:

- Yellow kernels not exceeding 0.2 %

(Yellow kernels mean rice kernels that have some parts of the kernels turn yellow obviously.)

- Chalky kernels not exceeding 6.0 %

(Chalky kernels mean non-glutinous rice kernels that have an opaque area like chalk covering the kernels as from 50% onward.)

- Damaged kernels not exceeding 0.25 %

(Damaged kernels mean kernels that are obviously damaged as can be seen by the naked eyes due to moisture, heat, fungi, insects or other.)

- White glutinous rice not exceeding 1.5 %

- Paddy not exceeding 7 grains per 1 kg. of rice

(Paddy means rice that is not yet dehusked.)

- Undeveloped kernels, Immature kernels, Other seeds and Foreign matter either singly or combined not exceeding 0.2 %

(Undeveloped kernels mean kernels that do not develop normally as should be, and are flat without starch. Immature kernels mean rice kernels that are light green, obtained immature paddy. Other seeds mean seeds of other plants than rice kernels. Foreign matter means other matter than rice. This includes rice husk and bran detached from rice kernels.)

A.1.1.4 Milling degree: Extra well milled

(Extra well milled is the removal of bran entirely to the extent that the rice kernel has a specially beautiful appearance.)

A.1.2   White rice 5%

White rice 5%shall have Grain classification, Grain composition and Milling degree as follows:

A.1.2.1 Grain classification, comprising of:

- Long grain Class 1 not less than 20.0%, the rest shall be Long grain Class 2 and or Class 3.

- Of all these there may be Short grain not exceeding 10.0%

A.1.2.2 Grain composition, comprising of :

- Whole kernels not less than 60.0%

- Brokens having the length as from 3.5 parts onward but not reaching 7.5 parts not exceeding 7.0%. Of this there may be brokens having the length not reaching 3.5 parts and not passing through sieve No. 7 not exceeding 0.5%, and Small white brokens C1 not exceeding 0.1%

- The rest shall be Head rice having the length as from 7.5 parts onward.

A.1.2.3 Rice and matter that may be present:

- Red kernels and or Undermilled kernels not exceeding 2.0%

(Red kernels mean rice kernels that have red bran covering the kernels wholly or partly. Undermilled kernels mean milled rice kernels that have the milling degree below that specified for each grade of rice.)

- Yellow kernels not exceeding 0.5%

- Chalky kernels not exceeding 6.0%

- Damaged kernels not exceeding 0.25%

- White glutinous rice not exceeding 1.5%

- Paddy not exceeding 10 grains per 1 kg. of rice

- Undeveloped kernels, Immature kernels, Other seeds and Foreign matter either singly or combined not exceeding 0.3%

A.1.2.4 Milling degree: Well milled

(Well milled is the removal of bran entirely to the extent that the rice kernel has a beautiful appearance.)

A.1.3 White broken rice A1 Extra Super

White broken rice A1 Extra Super is obtained from the milling of White rice 100% and shall have Grain composition as follows:

A.1.3.1 Grain composition, comprising of:

- Brokens having the length not reaching 5.0 parts and not passing through sieve No. 7 not exceeding 10.0%

- The rest shall be brokens having the length as from 5.0 parts onward.

- Of all these there may be Whole kernels not exceeding 15.0%, and Small white brokens C1 not exceeding 1.0%

A.1.3.2 Rice and matter that may be present:

- White glutinous rice not exceeding 1.5%, of this there may be Small white glutinous brokens C1 not exceeding 0.5%

- Foreign matter not exceeding 0.5%

A.2 Numerical example of DEA technical efficiency score calculation

According to the model specification of technical efficiency in section 4.2.3.1, the numerical example is presented in this appendix. To illustrate the DEA approach, a simple numerical example involving 10 rice farms which produce a single output (paddy rice) using the combination of two inputs (Urea, DAP). The input and output information of these rice farms is presented below in Table A.1. The unit isoquant map can be plotted as shown in Figure A.1. In this simple case, there are 5 rice farms (farm No. 2,8,1,9,4) lie on this isoquant.

Table A.1: Input-output information of 10 rice farms

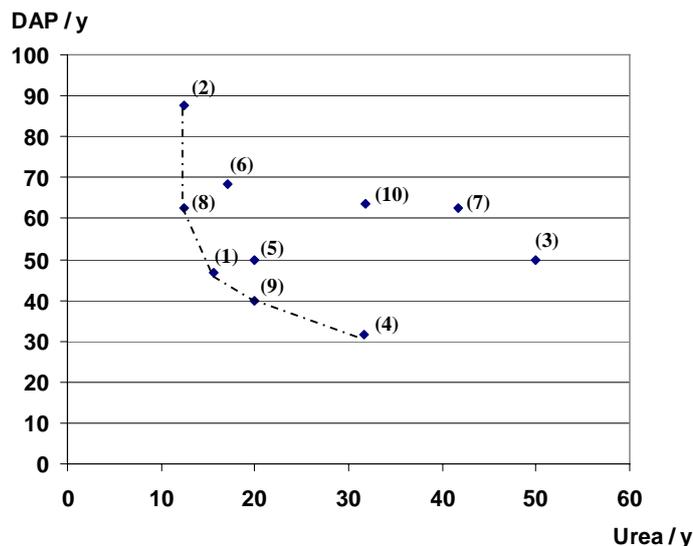| Farm No.	Paddy (Y) (kg)	Urea (X_1) (kg)	DAP (X_2) (kg)	X_1/Y	X_2/Y
1	3200	50	150	15.63	46.88
2	8000	100	700	12.50	87.50
3	15000	750	750	50.00	50.00
4	11050	350	350	31.67	31.67
5	5000	100	250	20.00	50.00
6	2920	50	200	17.12	68.49
7	4800	200	300	41.67	62.50
8	4000	50	250	12.50	62.50
9	2500	50	100	20.00	40.00
10	3150	100	200	31.75	63.49

Figure A.1: Unit isoquant of two inputs

The illustration of numerical example calculation begins with the linear programming problem. Again, linear programming framework of the model following (DE KOEIJER *et al.*, 2002) and its assumptions are shown below. DEAP software version 2.1 is used for data analysis.

- Farm *j* (j = 1, 2,…, 10) produces a single output (y_j) using a combination of inputs X_{ij} (i = Urea and DAP)

- Variable returns to scale (VRS) input oriented production frontier

$$\min_{\Delta,\lambda} \Delta j$$

subject to

$$\sum_{j=1}^{n} y_j \lambda_j - y_j \geq 0; \lambda_j \geq 0 \, for \forall_j$$

$$x_{ij}\Delta - \sum_{i=1}^{m} x_{ij}\lambda_j \geq 0;$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$0 \leq \Delta \leq 1$$

where Δj is a scalar which indicates the technical efficiency scores of the j-th farm;

y_j is a 1×n vector of single output produced by the 10 farms;

λ_j is a n×1 vector of weight value;

and x_{ij} is a m×n input matrix

In other words, the linear programming problem for 10 rice farms case can be written as below:

$$\min_{\Delta,\lambda} \Delta j$$

subject to

$$(Y_1 \lambda_1 + Y_2 \lambda_2 + ... + Y_{10} \lambda_{10}) - Y_j \geq 0$$

$$X_{1j}\Delta - (X_{11}\lambda_1 + X_{12}\lambda_2 + ... + X_{110}\lambda_{10})$$

$$X_{2j}\Delta - (X_{21}\lambda_1 + X_{22}\lambda_2 + ... + X_{210}\lambda_{10})$$

$$\lambda_1 + \lambda_2 + ... + \lambda_{10} = 1$$

$$\lambda_j \geq 0$$

$$0 \leq \Delta \leq 1$$

For example, consider input efficiency of farm No. 7. Then the linear programming problem of farm No. 7 can be written as

$$\min_{\Delta, \lambda} \Delta_7$$

subject to

$$(3200\lambda_1 + 8000\lambda_2 + 15000\lambda_3 + 11050\lambda_4 + 5000\lambda_5 + 2920\lambda_6 + 4800\lambda_7 + 4000\lambda_8 + 2500\lambda_9 + 3150\lambda_{10}) - 4800 \geq 0$$

$$200\Delta - (50\lambda_1 + 100\lambda_2 + 750\lambda_3 + 350\lambda_4 + 100\lambda_5 + 50\lambda_6 + 200\lambda_7 + 50\lambda_8 + 50\lambda_9 + 100\lambda_{10})$$

$$300\Delta - (150\lambda_1 + 700\lambda_2 + 750\lambda_3 + 350\lambda_4 + 250\lambda_5 + 200\lambda_6 + 300\lambda_7 + 250\lambda_8 + 100\lambda_9 + 200\lambda_{10})$$

$$\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9 + \lambda_{10} = 1$$

$$\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \lambda_8, \lambda_9, \lambda_{10} \geq 0$$

The results which obtained by using the DEAP software are presented in Table A.2. The technical efficiency score of farm No.7 is 0.600 which means farm No.7 could reduce both inputs by 40 percent and still produce the same output (4,800 kg of paddy). In other words, farm No.7 can produce 4,800 kg of paddy by using 180 kg of Urea and 120 kg of DAP.

Seven out of ten farms are technical efficient farms which their score equals to one. They are farm No. 1,2,3,4,6,8,9. The average score is 0.923 which means that farms has potentially reduce both inputs by 7.7 percent on the average without reducing their output. This technical efficiency score is relative score among these 10 rice farms then the technical efficient farms can refer as the benchmark or best practice farms.

The efficient frontier of these 10 rice farms is drawn on unit isoquant map is presented in Figure A.2. Due to the variable returns to scale assumption of this analysis, this frontier is piece-wise linear convex form.

Table A.2: VRS input-oriented DEA results

Farm No.	Δ	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}
1	1.000	1.000									
2	1.000		1.000								
3	1.000			1.000							
4	1.000				1.000						
5	0.990	0.189			0.163				0.648		
6	1.000	0.600								0.400	
7	0.600	0.434			0.233					0.333	
8	1.000								1.000		
9	1.000									1.000	
10	0.645	0.338			0.048					0.613	
Average	0.923										
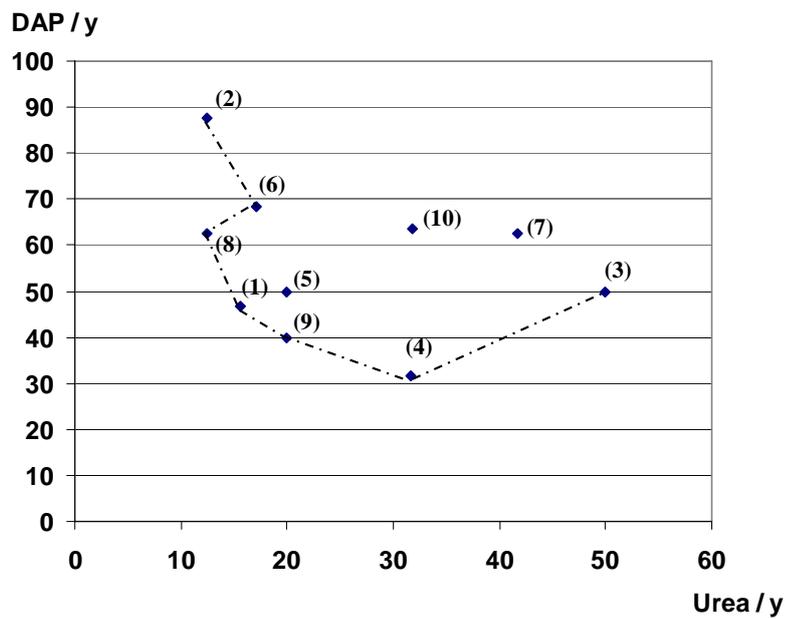
Figure A.2: The technical efficient frontier of sample farms