CHAPTER 2

LITERATURE REVIEWS

2.1 Rice ecosystems

Several attempts had been made to classify the environments in which rice was grown, and relate them to the different terminologies to describe rice production systems (International Rice Research Institute, 1984; 1985b; 1993). Water regime was the criteria for the system classification. There were four simple rice production systems classified by International Rice Research Institute (IRRI), including upland, irrigated, rainfed lowland, and flood-prone rice ecosystems (Figure 1). The possible subdivisions within each of the four major mentioned categories might be classified. For example, flood-prone rice ecosystem was classified into deepwater rice and floating rice (Greenland, 1997). The rice production system was the major crop of Thailand covering the area of 9.2 million ha. The proportion of each major category were 1, 19, 75, and 5% for upland rice, irrigated rice, rainfed rice and flood-prone rice, respectively (Rice department, unpublished). Flood-prone area was a flat plane to slightly sloping or depressed fields; more than 10 consecutive days of medium to very deep flooding (50 to more than 300 cm) during crop growth. Planting method was direct seeded on plowed dry soil; aerobic to anaerobic soil; soil salinity or toxicity in tidal areas. Both deepwater rice and floating rice were grown on the area (Greenland, 1997).

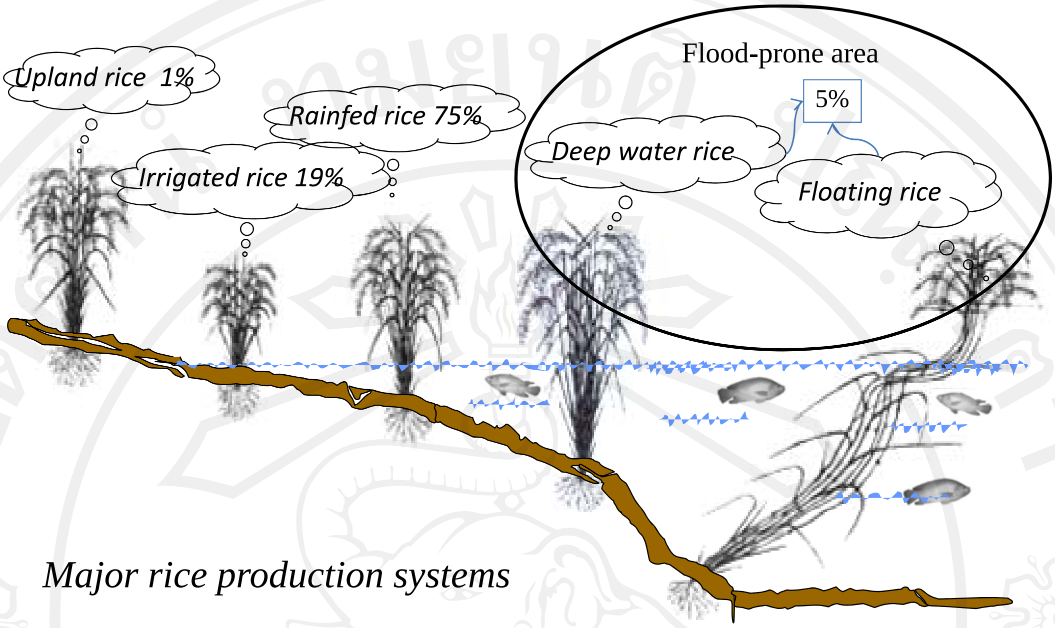

Figure 1 Rice production systems classification base on water regime (International Rice Research Center, 1984; Greenland, 1997; Rice Department, unpublished)

2.2 Deepwater rice area

The DWR area was a flood-prone rainfed-based rice production system (International Rice Research Institute, 1985a). The total acreage of DWR was approximately 6% of the total area in the world that was commonly used for rice production (Catling, 1992). The area was scattered around South and Southeast Asia and West Africa (Catling, 1992; Shepard *et al.*, 2004). Approximately 95% of the total DWR acreage was located in eleven countries in Asia (Khush and Toenniessen, 1991), i.e., India, Bangladesh, Myanmar, Thailand, Vietnam, Cambodia, Indonesia, Nepal, Philippines, China, and Sri Lanka. The top five countries growing DWR covered the area of 2.47, 2.40, 1.28, 0.76, and 0.56 million ha, respectively (Table 1) (Catling, 1992). Only 5% of DWR was grown in West Africa, mainly in areas where water was not controlled (Brian, 1994; Mather and That, 1984). The total acreage

West Africa was approximately 0.46 million ha, located in Mali, Guinea, Nigeria, Sierra Leone, Niger, Burkina Faso, Togo, Benin, Senegal and Gambia. Ninety percent of Africa's deepwater areas can be found in the first three countries (Table 1) (Catling, 1992). Although it was not a significant crop in Africa, appropriate crop management practices were needed in order to optimize crop production as it was mainly grown by subsistence farmers.

The area for DWR could be categorized into three groups depending upon the depth of water and duration of the high water level (Catling *et al.*, 1988).

1. Deepwater area: the depth of the flood water was between 150-400 cm and the flood duration was about 3-4 months. Bangladesh and Thailand were two of the main countries where DWR was grown under these conditions.
2. Flooded area: this was an area where the maximum water level was less than 150 cm and the flood duration was for several months varying from June to November. It normally could be found in low-lying areas and included tidal swamps. The common areas for this group can be found in Thailand, India, Bangladesh and Cambodia.
3. Submerged area: the water level in this area was variable. The rice plants were usually completely submerged for several days to one week or more. In some areas submergence occurs almost every year during typhoons and heavy continuous rain such as some areas in Bangladesh and Thailand.

Table 1 DWR area in Asia and Africa, percent of region, and percent of the total DWR area of the world

Asia

Country	Area (1,000 ha)	Percent of Asia	Percent of total
India	2,470	30	28
Bangladesh	2,402	29	28
Myanmar	1,281	16	15
Thailand	763	9	9
Vietnam	567	7	7
Cambodia	405	5	5
Indonesia	128	2	2
Nepal	118	1	1
Philippines	76	1	<1
China	30	<1	<1
Sri Lanka	4	<1	<1
Total of Asia	8,244	100	95

Africa

Country	Area (1,000 ha)	Percent of Africa	Percent of total
Mali	161	35	2
Guinea	152	33	2
Nigeria	105	23	1
Sierra Leone	20	4	<1
Niger	10	2	<1
Burkina Faso	6	1	<1
Togo	6	1	<1
Benin,Senegal, Gambia	3	<1	<1
Total of Africa	463	100	5
Total of the world	8,707		100

Source: (Catling, 1992).

Five million ha of DWR land within the three groups was a conservative estimate of the total area that was subject to an annual flood. The depth of the water, duration of the flood, the rate of the increase in water level, water temperature and turbidity vary for different locations (Nesbitt, 1997). The main countries that were exposed to this annual flood include Bangladesh, Thailand, Vietnam, Myanmar, Cambodia, Mali and India. Unfortunately very little research has been done to improve rice production and increase grain yield for these regions (International Rice Research Institute, 1976).

2.3 Deepwater rice yield

The yield of DWR was relative low due to the unavailable of suitable high yielding varieties and the lack of appropriate technologies (Nesbitt, 1997; Maclean *et al.,* 2002; Mather and That, 1984; Molle and Kaewkulaya, 1998; Puckridge *et al.,* 1989). This was one of the main reasons that the smallholder farmers using these management practices were condemned to a life of hunger and poverty, despite their hard work to increase and improve yield. There was an urgent need to increase the total production level in this region and to improve standard of living for millions of farmer families (International Rice Research Institute, 1988).

In addition to the variable flood water level, deepwater areas may be constrained by severe soil problems, such as salinity, peatness, acid sulfate condition, iron toxicity, and a deficiency of phosphorous and other micro elements (International Rice Research Institute, 1989). Acid sulfate soils were especially common in Thailand, Indonesia, Vietnam, and Bangladesh. However, scientific research on DWR area started in 1917 in Dhaka, Bangladesh. In 1934, research started at the DWR Station in Habiganj in Bangladesh (International Rice Research Center, 1988). DWR research increased from 1970 to 1990, but then decreased. Most of the research had concentrated on varietal improvement. Yield of DWR had increased, but it was still low at a level of 2 t ha^{-1} compared to yield from other rice production systems, especially from FDR production system that could reach up to 6 t ha^{-1} (Catling, 1992; Mannan, 1987; Molle and Kaewkulaya, 1998). This was, therefore, a need for further research for the regions where DWR was being grown in order to improve this production system and increase rice yield.

The Köppen Climatic Classification classified the world DWR production area into a group A climate, which was a Tropical Moist climate (Catling, 1992). Under this climate group, all months' average temperature was higher than 18^{o}C and annual rainfall was greater than 1,000 mm. The temperature contrasted between the warmest and the coolest month was typically less than 10^{o}C (Moran and Morgan, 1994). It consisted of a short dry season with heavy monsoonal rain in other months. Most of rainfall occurs during the 7 to 9 hottest months, while there was little rainfall during the dry season. The climate of the DWR production area in Thailand was also classified as a tropical monsoon climate (Am). The temperature ranged from 20-38^{o}C and relative humidity ranges from 41-100% (based on an 18 years averaged) (Khedari *et al.*, 2002).

2.4 Trend of deepwater rice production

The total area of DWR across the globe, including Thailand, tended to decrease continuously (Mahabub *et al.*, 1994; Molle and Kaewkulaya, 1998; Sombilla *et al.*, 2002). The first survey of DWR area in Thailand was conducted from 1986 to 1988. This survey found that the total DWR area was about 763,000 ha or equal to 8% of the total rice grown in Thailand (Catling, 1992; Khush and Toenniessen, 1991). Five years later, from 1992 to 1993, another survey was conducted to determine the situation of floating rice cultivation in Thailand. Normally floating rice was considered to be part of DWR. DWR means the rice which could be grown in flooding area with 50 to 100 cm of water depth, while floating rice means the rice could be grown in flooded areas with more than 100 cm of water depth during the tillering to flowering stage (Hirunyupakorn *et al.*, 1988). This survey covered an area with 50 cm or more of water depth. The survey found a reduction in acreage of DWR area from 763,000 ha in 1988 to 504,169 ha in 1993 (Chareontham *et al.,* 1994; Sommut, 2003). Another survey was conducted for 2000/2001 crop season by a group of researchers from the Prachin Buri Rice Research Center. This survey indicated a reduction in DWR acreage and also showed the introduction of the FDR to replace the DWR (Sommut and DungSoongnern, 2002; Sommut, 2003).

2.5 Rice production system and fertilizer management in deepwater area

In the eastern plain of Thailand, DWR production was the main season of rice system in rainy season. It was grown in the lowest terrace and flooded to at least one meter depth or more during the growing period (Catling, 1992). The planting season of DWR starts in April through May followed by flooding in August until a maximum flooding depth was reached in November. The DWR harvesting ranged from late November to January (Kupkanchanakul *et al.*, 1986; Puckridge *et al.*, 1994). Traditional photosensitive rice varieties with appropriate harvesting date had been selected by farmers as they were suitable for management practice and result in a relatively high productivity (Department of Agriculture, 2004b). However, potential yield of DWR was relatively low compared to other rice production systems such as the FDR production system (Catling, 1992; Mahabub *et al.,* 1994; Puckridge *et al.*, 1989). DWR was not only common rice production system to eastern Thailand but also in other flood prone rice regions across the world. Many DWR farmers in Thailand and Vietnam were converting their fields to FDR production system in order to increase rice yield resulting in a higher economic return (Denning and Xuân, 1994; Sommut, 2003). The characteristics of a FDR plant were a dwarf erect plant type, with 80 to 120 cm of plant height that was insensitive to photoperiod and could be grown during all seasons of the year. Rice growth duration varies from 90 to 140 days after planting, depending on varieties (Table 2). The significant FDR's character were high yield and short growth duration compared to DWR (Department of Agriculture, 2002).

Table 2 Comparison of deepwater rice and flooded rice production systems

Items	*Deepwater rice*	*Flooded rice*	*Remarks*
Recommended Varieties*	11	29	Since 1959
Photoperiod sensitivity	Sensitive	Non-sensitive	Except RD17 for deepwater rice
Planting date	April-May	Any	
Harvesting date	December-January	90-140 days	Depending on variety
Growth duration (days)	>210	90-140	Depending on variety
N application rate (kg ha^{-1})	54	88	
Field water level (cm)	> 50	< 50	During tillering to flowering stage
Elongation ability	Yes	No	
Planting method	Dry seed broadcasting	Pregermination broadcasting or transplanting	
Yield	Low	High	

* Source: Rice Department, 2009

However, the constraints of FDR production in the deepwater area were the onset and receding of flood water during the rainy season and the water supply during the dry season.

Differences in planting dates were not just differences in time but also differences in many other factors such as temperature, solar radiation, rainfall, and soil conditions (Schafera and Kirchhof, 2000; Shunji and Kimuraa, 2007). Late planting dates could delay panicle initiation, heading and maturity (Halder *et al.*, 2004). It was, therefore, important to identify the optimum planting dates and varieties so that farmers could make the appropriate decision when changing from DWR to a FDR production system.

Transition of traditional DWR production system to intensive FDR production in deepwater area was the change of a low input system to a high input system, especially chemical fertilizer input (Mahabub *et al.*, 1994; Mazaredo *et al.*, 1996). The increment of rice production during the Green Revolution era of the past 30 years had been based on increased irrigation and chemical fertilizer used. Technologies and policies to enhance fertilizer-use efficiency would be needed in the intensive rice production areas for the coming decades (Pingali *et al.*, 1998). The Department of Agriculture, reported that Thailand imported chemical fertilizer at amount of 4.2 million tonnes of chemical fertilizer during the first ten months of the year of 2009, and most of which was nitrogen fertilizer (Department of Agriculture, 2010). Certainty it was used for cereal production especially in rice production system. Fertilizer application for rice production in Thailand recommended by the Rice Department (RD), Ministry of Agriculture and Cooperative (2009) was categorized into two broad groups: rain-fed and irrigated rice production systems. In clay soil area, rainfed rice production was recommended to apply chemical fertilizer at the rate of 54 kg N ha^{-1} and 31 kg P_2O_5 ha^{-1}, while FDR production was recommended to apply chemical fertilizer at the rate of 88 kg N ha^{-1} and 38 kg P_2O_5 ha^{-1} (Department of Agriculture, 2004a).

Urea (46-0-0) chemical fertilizer was the primary source of nitrogen (N) fertilizer available to apply in rice production system. It was first introduced in 1935, and it had been widely used, due to high N content and ease of handling (Jones *et al.*, 2007). Many researchers conducted experiments to find out the efficiency of fertilizer application in paddy field (Cassman *et al.*, 1998). The researches on N application in rice fields found that the recovery of applied nitrogen by rice ranged from 20 to 61% depending on soil property, fertilizer form, rate of application, mode and timing of application (Aulukh and Bijay-Singh, 1997; De Datta, 1978; De Datta *et al.*, 1978; Eriksen and Nelsen, 1982; Mohanty *et al.*, 2009; Pasandaran *et al.*, 1999).

Research and extension work to improve nitrogen management of irrigated rice had received considerable investment because yield levels presently achieved by Asian farmers depend on large amounts of N fertilizer. Most work had focused on placement, form, and timing of applied N to reduce losses from volatilization and denitrification. In contrast, less emphasis had been given to development of methods to adjust N rates in relation to the amount of N supplied by indigenous soil resources. As a result, N fertilizer recommendations were typically made for districts or regions with the implicit assumption that soil N supply was relatively uniform within these domains. Recent studies, however, document large variation in soil N supply among flooded rice fields with similar soil types or in the same field over time. Despite these differences, rice farmers do not adjust applied N rates to account for the wide range in soil N supply, and the resulting imbalance contributes to low N-use efficiency. A model for calculating N-use efficiency was proposed that explicitly accounts for contributions from both indigenous and applied N to plant uptake and yield. It could be argued that increased N-use efficiency would depend on field-specific N management tactics that were responsive to soil N supply and plant N status. N fertilizer losses were thus considered a symptom of incongruence between N supply and crop demand rather than a driving force of N efficiency. Recent knowledge of process controls on N cycling, microbial populations, and soil organic matter (SOM) formation and decomposition in flooded soils were discussed in relation to N-use efficiency. The research concluded that the natural capacity of wetland rice systems to conserve N and the rapid N uptake potential of the rice plant provide opportunities for significant increase in N efficiency by improved management and monitoring of indigenous N resources, straw residues, plant N status, and N fertilizer (Cassman *et al.*, 1998).

An alternative technique to increase the N use efficiency was deep placement of N fertilizer (International Fertilizer Development Center, 2007). Urea Deep Placement (UDP) technique was developed to increase N application efficiency by insertion of large urea briquettes into the rice root zone after transplanting. It cut nitrogen losses significantly. Farmers who use UDP could increase yields by 25% while using less than 50% as much urea as before (International Fertilizer Development Center, 2007). The fertilizer was most efficient when the highest concentration was placed in the soil at a depth of 5.0 cm. This fertilizer application method increased the grain yield by 20% as compared with the soil surface application (Eriksen and Nelsen, 1982). UDP was recommended and widely adopted in Bangladesh, Cambodia, and Vietnam to increase N use efficiency and increase yield per unit area at the same time (International Fertilizer Development Center, 2008). The UDP technique increased rice yield by 900 to 1,100 kg ha^{-1}, decreased urea application rate by 78 to 150 kg ha^{-1} and subsequently increased profits by 116 to 137 US$ ha^{-1} (International Fertilizer Development Institute, 2008).

Another technique to manage N fertilizer application in rice production was application base on rice leaf color (Furuya, 1987; Takebe and Yoneyama, 1989) by using Leaf Color Chart (LCC) (Buresh, 2007). The LCC was a plastic ruler-shaped strip containing four panels that range in color from yellowish green to dark green. It was an easy-to-use and inexpensive diagnostic tool for monitoring the relative greenness of a rice leaf as an indicator of the plant N status (Dobermann *et al.,* 2004; Furuya, 1987; Takebe and Yoneyama, 1989). Leaf N status of rice was closely related to photosynthetic rate and biomass production, and it was a sensitive indicator of changes in crop N demand within a growing season. The LCC can be used to rapidly assess leaf N status and thereby guide the application of fertilizer N to maintain an optimal leaf N content, which can be vital for achieving high rice yield with effective N management (Buresh, 2007). There were two strategies of LCC technique in recommending application of N fertilizer for rice production 1) a fixed time and adjustable-dose N management strategy and 2) a real time N management strategy (Buresh, 2007). The decision on which strategy to use could be based on preferences of the farmers and location-specific factors.

DWR and FDR varieties were different in terms of growing ecosystems, plant morphology, growth duration, photosensitivity, and fertilizer response (Kunnoot, 2006). Transition from DWR to FDR required that farmers to appropriately select a rice cultivar for a given ecosystem (Mahabub *et al*., 1994). Many non-photosensitivity rice varieties had been released and recommended for FDR production during the past four decades (Rice Department, 2009). Transition from DWR to FDR production also requires appropriate fertilizer management practices. The significant point was that there has been no specific fertilizer application and variety recommendation for such an area.

2.6 Crop simulation model

Crop simulation model (CSM) was mathematical, computer-based representations of crop growth and interaction with the environment. The CSM had been developed based on the theory of crop physiological ecology (Grave *et al.,* 2002). It was a dynamics in crop and soil processes, comprehensiveness and applicability, and could be used to dynamically simulate the effects of climate, soil, genetic type, crop management, and the impact of carbon dioxide concentration on the crop growth and yield (Jones *et al*., 2003; Min and Zhi-qing, 2009). The concept of crop development mainly involved the processes of crop phenology, leaf age increment and appearances of various morphological organs such as leaf blades, leaf sheaths, tillers, roots, stem internodes, and panicles (Gao *et al*., 1992; Ritchie *et al.,* 1987).

The CSM had been used widely to describe systems and processes at various levels of agricultural systems from the genotype level, the crop, the farming system, the region, and the global environment (Matthews *et al.,* 2002). There were various used of CSM-CERES-Rice model in Asia for gap and yield trend analysis to improve overall crop management by making appropriate planting decision, devising improved cultural practices, developing fertilizer use efficiency, and water and pest management. The models were also used to predict the impact of climate change on crop productivity to assist the policy maker in the strategic decision making and planning (Timsina and Humphreya, 2006; Yao *et al.*, 2007). However, ultimate of using crop model would be beneficial for poor people who were depended upon crop production. Therefore, there was an urgent need to make the use of models in research more relevant to problems in the real world and to find effective alternative technology to overcome existing problems for those beneficiaries. It meant that researchers must think of the real problems faced by farmer in the areas and construct model and apply their models to contribute to solving those problems (Matthews *et al.,* 2002). The advantage CSM tool was that these tools could reduce the need for expensive and time-consuming field experimentation and it could be used to analyze yield gaps in various crops including rice (Timsina *et al.,* 2004). However, proper calibration and evaluation in the environment of interest before applying them to evaluate management options should be done. This was especially important in the absence of reports on evaluation of model processes as reflected in the models' relative inabilities to predict a range of crop, soil and water parameters (Timsina and Humphreys, 2006).

The CSM-CERES-Rice model (version 4.0.2.0) was calibrated and validated using the data from a field experiment carried out during the rainy season of 2004 and 2005 at Shalimar, Srinagar 1,587 m above the mean sea level, India. The experiment included six rice cultivars each transplanted on 25 May, 10 June, and 25 June. Data of 25 May transplanting was used for model calibration and development of the genetic coefficients of the rice cultivars (Singh *et al.,* 2007). The quantitative assessment of potential monsoon-season aman rice for four transplanting dates: 1 June, 1 July, 15 July, and 15 August was conducted. A crop-growth simulation model, the CSM-CERES-Rice, was applied to sixteen locations representing major rice-growing regions of Bangladesh to determine baseline yield estimates for four transplanting dates (Mahmood *et al.,* 2003). Moreover, testing of CSM-CERES-Rice model by statistical analysis and application confirmed that this model could be acceptable for use as a research tool for choosing the most appropriate strategy prior to conducting field experiments (Cheyglinted *et al.*, 2001).

There were four input data sets to be used for running the CSM-CERES-Rice model including soil data, weather data, management data and crop characteristics data or crop genetic coefficient (GC) (Hoogenboom *et al.,* 1999). In the past, crop modelers used two techniques to calculate GC of a rice variety under observed weather data and known crop development and growth data sets. The first method was by trial-and-error and the second was calculation technique such as the Genetic Coefficient Calculator (GENCALC), which used a deterministic stepwise procedure to automatically adjust the coefficients with values within the plant's realistic physiological ranges (Hunt *et al.*, 1993; Pabico, 2008).

Another program to estimate genotype-specific coefficient for the CSM-CERES-Rice model was GLUE (Generalized Likelihood Uncertainty Estimation) program (He *et al.*, 2008; He *et al.*, 2010). It was a Bayesian estimation method that uses Monte Carlo sampling from prior distributions of the coefficients and a Gaussian likelihood function to determine the best coefficients based on the data that were used in the estimation process. Both of GENCALC and GLUE were included in DSSAT v4.5 package. There were advantages and disadvantages of using these estimators. Disadvantages of the GLUE technique was that it may require a lot of time for the computations, depending on the number of treatments selected for the estimation process (He *et al.*, 2008). On the other hand GENCALC needs more manual operation than GLUE.

Transition production system from DWR production to modern FDR production system was challenge for farmer who getting familiar with low input of traditional DWR production system. There were not only planting date and variety but also fertilizer management was another significant factor to improve rice yield. The combination of appropriate application techniques in tern of mode, time and rate of N application was challenge task for the farmers. Integration of field experiment and crop model simulation was powerful strategy to formulate alternative management practices for farmer to select under specific environment and constraints of their field.

Crop yields were influenced by many interacting and often co varying environmental and biological factors, with the result that it was usually difficult to disentangle the effects of any one factor in field experiments. With irrigated and well fertilized crops in the tropics, however, fluctuations in nutrient and water supply and seasonal changed in day length and temperature were minimized, whereas exposure to different sequences of irradiance during crop development was maximized by the ability to plant and harvest crops in all months of the year (Evans and De Datta, 1979).

However, the CSM-CERES-Rice model could be an alternative tool to test the strategies at both research and farm levels. Recent advances of analysis through simulation using microcomputers enabled alternative strategies to be tested over several years and this allowed the researchers to select optimum strategies for field testing. Hence, this was a study to evaluate the CSM-CERES-Rice model in Decision Support System for Agrotechnology Transfer version 3.5 (DSSAT v3.5) (Kerdsuk, 2002; Mankeb, 1993) with the field data from selected rice research stations in Thailand, for its applicability in determining appropriate technologies and their levels for rice production in this region (Cheyglinted *et al.*, 2001). The CSM-CERES-Rice a sub model in DSSAT v3.5 was used to simulate growth and yield of four common rice varieties in Thailand with the attention on rate and timing of N application, a factor that most limits crop yield. The model predicted slightly higher grain yield than that observed for all varieties at N input of 75 kg ha^{-1}, but the differences between observed and simulated yields were not significant, except for varieties HSP and SPR90 (Cheyglinted *et al*., 2001). The precision between simulation and observation data could be defined. The smaller the RMSEn value was the higher the precision, when RMSEn<10%, the simulation results were good; when 10%<RMSEn<20%, the simulation results were fairly good; when 20%<RMSEn<30%, the simulation results were moderate; and when RMSEn>30%, the simulation results were poor (Michele *et al*., 2003).

This research started with the problem situation of transition from DWR to FDR production system in deepwater area. Then field experiments were conducted for finding appropriate technologies for FDR production, e.g. planting date, variety and fertilizer management. However, field experiment was time and budget consuming. Another weak point was that it could only be representative of the production under the environment of the experimental site. Crop modeling could be used as a tool to overcome this weak point of field experiment. Calibration of crop modeling (CSM-CERES-Rice in DSSAT v4.5) was done to calibrate rice coefficients for the best simulation output base on observation data comparison. Then the best coefficient was used the simulate rice growth and phenology under different set of environment for model evaluation.