CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Transitional phase from DWR to FDR systems in Thailand: Current situation and challenges

4.1.1 Biophysical settings

The key factor in term of production perspective to transform from DWR to FDR production system in the deepwater area is water management. Storage of excess water during the rainy season to supply for the FDR production in the dry season is a strategy for transforming production system in DWR area. In 2005, a policy is introduced to install an irrigation scheme through the construction of the Khun Dan Prakanchol Dam. Prior to constructing of the Khun Dan Prakanchol Dam, there is a few dam, e.g., Pra Prong Dam, and Kwae Rabom Siyat Dam constructed in the upper stream of Bang Pakong and Prachin Buri watershed. In addition, one more dam, entitled “Houry Sa Mong” dam, is under construction. This enables farmers to adopt a double cropping system of FDR production during the early rainy season (before flooding) and the dry season (after flooding). The main purpose of this policy is to provide security in the area in terms of water supply and, therefore, add more security to staple food production systems such as rice. Since FDR is a new cropping system for traditional DWR farmers, they currently have no specific management recommendations so untested technologies are their alternatives. Farmers use various sources of information to modify their rice cultural practices. However, more research and development of extension material is needed to obtain sustainable FDR production systems in this area.

4.1.2 Rice production in the study area

In 2009, the total area of DWR production in the study area is 36,165 ha. The three largest rice areas are Bang Phluang, Bang Decha, and Bang Yang, covering an area of 4,920; 3,662; and 3,369 ha, respectively. The smallest one is Bang Kham and it covers an area of 1,142 ha. The percentage rice area to the total area of each Tambons ranges from 42 to 78% with an average of 64% (Table 3 in Chapter 3). Traditionally this region has been cultivating DWR and is in the transitional period to a FDR production system. However, certain areas face constraints to transform such as flooding patterns, depth of flood water, and drainage in early rainy season and availability of water for irrigation in dry season. The entire region is expected to transform into a FDR rice production with the compilation of infrastructures for water management.

4.1.3 Sources of water in the study area

The main sources of irrigation water for rice cultivation are precipitation and local streams. The latter are the main sources of water for household consumption and for agriculture activity. The main stream in the area is the Bang Pakong river, while the two secondary streams are the Prachin Buri river and the Nakhon Nayok river (Figure 2). The third source for irrigation water is both the natural and man-made canals to supply water during dry season. These three sources of water are significant for FDR production system especially during the dry season. The Bang Pakong river flows directly from the North of the study area to Gulf of Thailand. Once fresh water of the streams is used during the dry season, there is a risk influx of sea water into the area. An increase in FDR production means that the system needs more fresh water for irrigation in both early rainy and dry seasons.

4.1.4 Soils in the study area

The soils of study area are classified into Vertisols soil order, sub order of Aquerts, and Dystraquerts great-group. There are seven soil series in the area, which are Bang-Pa in (Bin), Chachoengsao (Cc), Don rai (Dr), Mahaphote (Ma), Ratchaburi (Rb), Rangsit (Rs, Rs-a), and one unidentified soil. Rangsit (Rs + Rs-a) soil series covers an area of 18,652 ha (14,517+4,135 ha) or 52% of the total DWR rice production in the study area (Figure 10). The Rangsit soil series (Rs) is an acid sulfate soil, Rs-a soil series is also a Rangit soil series but it contains higher level of acidity than Rs soil series. It is classified into Sulfaqueptic subgroup. Soil family of Rs soil series is very-fine, mixed, isohyperthermics. The second, and the third rank of soil series in the study area, are Mahaphote (Ma), and Chachoengsao (Cc) covering the area of 12,109 and 4,371 ha, respectively (Table 6). Three major soil series (Rs+Rs-a, Ma and Cc) occupy the area of 35,132 ha, which is approximately 97% of rice area in the study site. Cc and Ma soil series are in Ustic subgroup. Cc and Rs soil series are in the same soil family of Fine, Mixed, Isohyperthermic, but Ma soil series is classified into Very-fine, Mixed, Isohyperthermic (Vijarnsorn and Eswaran, 2002).

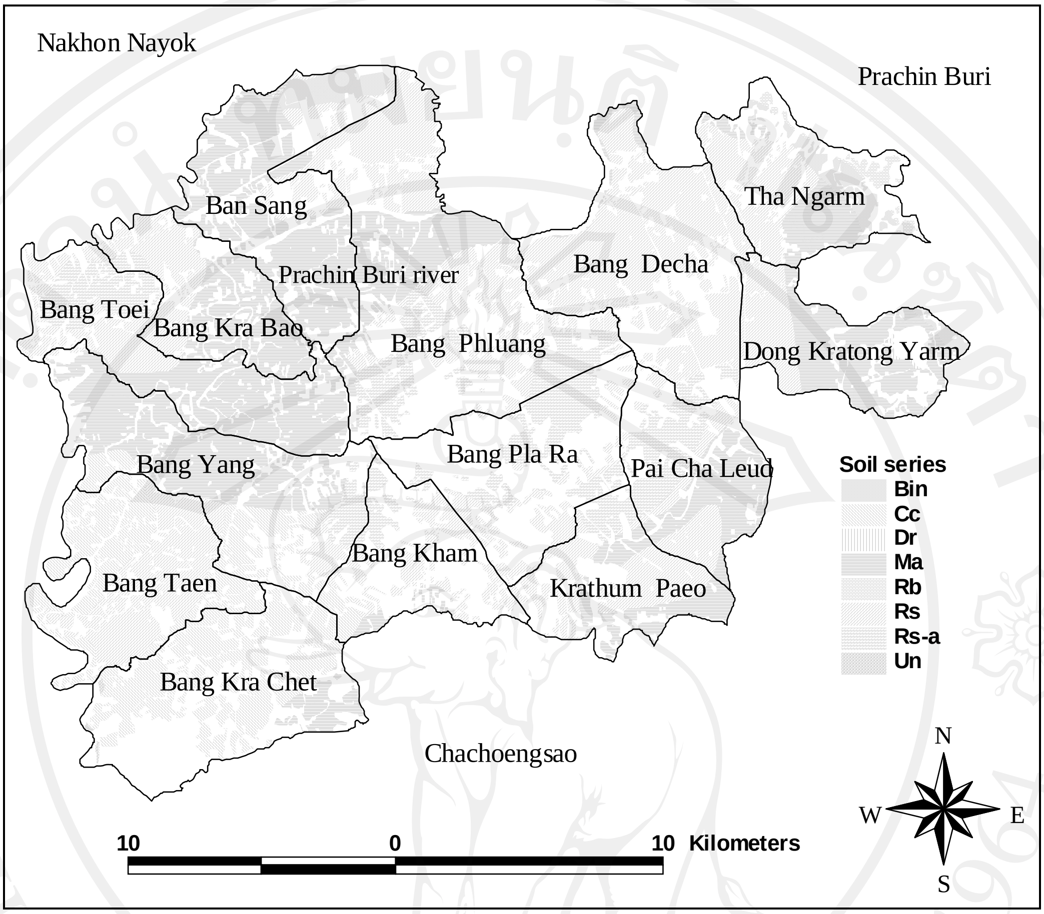

Figure 10 Soil series in rice field of 14 sub-districts of the study site (Land Development Department, Thailand).
Soil Series Name;
Bin: Bang-Pa in, Cc: Chachoengsao, Dr: Don rai, Ma: Mahaphote, Rb: Ratchaburi, Rs: Rangsit, Rs-a: Rangsit very acid, and Un: Unidentified soils

Table 6 Distribution of the soil series in each sub-district in the study site

Sub-district Name	*Soil Series*								*Total*
	Bin	Cc	Dr	Ma	Rb	Rs	Rs-a	Un	
	ha								
Ban Sang	374			2,151		409	13		2,947
Bang Kham		150		103		666	223		1,142
Bang Krabao				1,065		822	68		1,955
Bang Pla Ra				2		612	921		1,535
Bang Phluang				1,271		2,574	1,075		4,920
Bang Taen		1,337		3		1,530		1	2,871
Bang Toei				1,583		800	636		3,019
Bang Yang		749		2,081		303	236		3,369
Kra Thum Paeo				598		1,044	205		1,847
Bang Decha				101		3,461	100		3,662
Tha Ngam	346			625	176	900			2,047
Dong Kratong Yam	100		20	1,340		781			2,241
Phai Cha lued				895		615	658		2,168
Bang Kra Chet		2,135		291				16	2,442
Total	820	4,371	20	12,109	176	14,517	4,135	17	36,165

Source: Land Development Department, Thailand.
Soil Series Name:
Bin: Bang-Pa in, Cc: Chachoengsao, Dr: Don rai, Ma: Mahaphote, Rb: Ratchaburi, Rs: Rangsit, Rs-a: Rangsit very acid, and Un: Unidentified soils.

4.1.5 Farmer interviews

A total of 402 households in 14 sub-districts of Prachin Buri and Chachoengsao provinces are interviewed using a structured questionnaire. The averaged rice farm size per household is 7 (±4) ha. The number of parcels for rice production per household ranged from one to five fields. It is found that 50% of the interviewed households occupied one field per household, 30% of the households occupied two fields per household, 17% of the households occupied three fields per household, 2% of the households occupied four fields per household, and only 1% of the households occupied five fields per household. For land ownership, there is only 27% of household growing rice on their own land, 53% of household renting the land for rice growing. The rest of 20% percent is partial owner with additional rented land for rice production. The proportion of DWR and FDR in the area are 16 and 84%, respectively. The majority of the farmers used pre-germinated seed with 61 and 99% for DWR and FDR, respectively. The remainder of the farmers broadcasted with dry seeds.

For the FDR farmers, 80% transformed from DWR to FDR because of higher yield with short growth duration of FDR compared to DWR. The rest of 20% of FDR farmers converted because of suitability of the areas, suggestion of neighbor and market price. A significant criterion for the conversion is availability of water for FDR during the dry season. The remaining 16% of the households continue to grow DWR since their areas are not suitable for FDR and there is no water for irrigation during the dry season.

All interviewed household agreed that the three important cultural-practices that farmers considered before growing FDR include variety selection, appropriate planting date, and suitable fertilizer management. However, after planting there are also additional factors of concern such as disease, pest and disease management, the water supply, the costs of the inputs and price of rice. This research focused on the first three factors for further finding appropriate technologies to improve the system.

Rice Variety

Deepwater rice

The proportion of the farmers used the recommended and traditional rice varieties is 28% versus 72%. The recommended DWR varieties included Pli Ngam Prachin Buri and Lueng Yai 148, while the traditional varieties consisted of Ber Har, Khao Ta Cheu, Khao Ban Na, Khao Lourng, Roi Et, and Pourng Pet varieties. This indicated that the traditional rice varieties are still widely used for DWR production. The most popular rice varieties in the study area are Khao Lourng and Ber Har variety. The recommended variety is the rice variety which is registered and recommended by the Rice Department. The seed of the recommended variety is original multiplied and distributed by the rice department, while the traditional variety is a rice variety that is selected and multiplied by farmers. The selection is based on the suitability for their field and the quality of grain yield preference of the farmer.

Flooded rice

For the FDR system, the recommended rice varieties are grown by 76% of farm households, while 24% of the farmers grew the adopted rice varieties. The farmer adopted rice varieties apparently are those varieties tested by the Rice Department yield trial experiment project in farmer's fields, as a comparison between promising lines with a local rice variety before registration and recommendation. These promising varieties are selected by the farmers according to their own observations and preferences. Then they took an initiative to multiply for seed production and named the variety. The percentage of the farmers that use the recommended rice variety is higher for the FDR than for the DWR system. The most favorite varieties for FDR production in the area are the recommended rice varieties from "Suphan Buri Rice Research Center (SPR)" including SPR1, SPR60 and SPR90.

The farm households obtained their information from five sources for decision making on rice variety. Ranking from the most to the least significance this included 61% from a neighbor's suggestion, 14% from a neighbor's suggestion and trial and error, 8% from trial and error, 6% from a government agency, and 4% from a neighbor's suggestion and government agency (Figure 12). Farmers also obtained information from the community radio station and the local middle-man for selecting the most suitable rice variety for their field. Recommendations by a neighbor are similar to a farmer-to-farmer type of communication and knowledge exchange.

Planting date

Deepwater rice

The planting date for DWR started as early as April and ended as late as August, with 33% planted in April , 22% planted in May, 37% planted in June, 3% planted in July and 5% of farm household planted in August (Figure 11). Therefore, more than 90% of the households planted their DWR between April and June, during the beginning of the rainy season and the start of flooding. In addition, 61% of the households used pre-germinated seed and 39% of DWR households used dry seed for planting.

Flooded rice

For FDR production, there are two crops per year. The first crop is grown during the early rainy season (ERS) while the second crop is grown during the dry season (DS). The planting date for ERS crop ranged from March to July with 6% of household planted in March, 11% planted in April, 71% planted May, 9% planted in June and 3% of household planted in July. Planting for the DS crop ranged from August to December, with 1% planted in August, 1% planted in September, 5% planted in October, 90% planted in November and 3% of households planted in

December (Figure 11). For ERS, the majority of the rice is planted in May, while for DS the majority of the rice is planted in November. The planting method consisted of 99% pre-germinated seed and 1% dry seed.

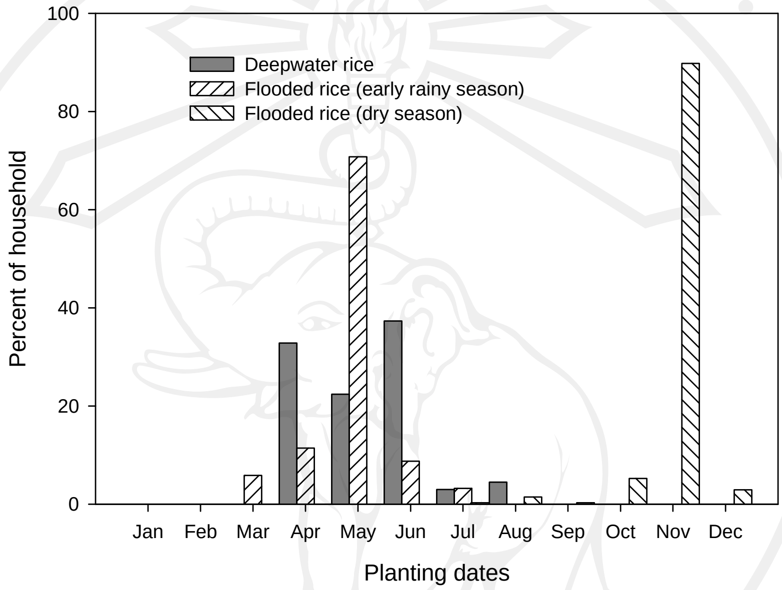

Figure 11 Percent of household and planting date of DWR and early rainy season and dry season of FDR production.

The farm households obtained their information from five sources for decision making on planting date. Ranking from the most to the least significance this included 56% from neighbor, 23% from neighbor and trial and error, 12% from trial and error, 5% from government agency and neighbor, and 2% from government agency (Figure 12). The other information sources include the community radio station and the local middle-man for selection a suitable planting date for their fields. It is also found that the main reason for the selection of the planting date is that the rice fields are adjacent to each other and, therefore, planting on the same date is necessary otherwise the tractor and land preparing equipment would not be able to access the field.

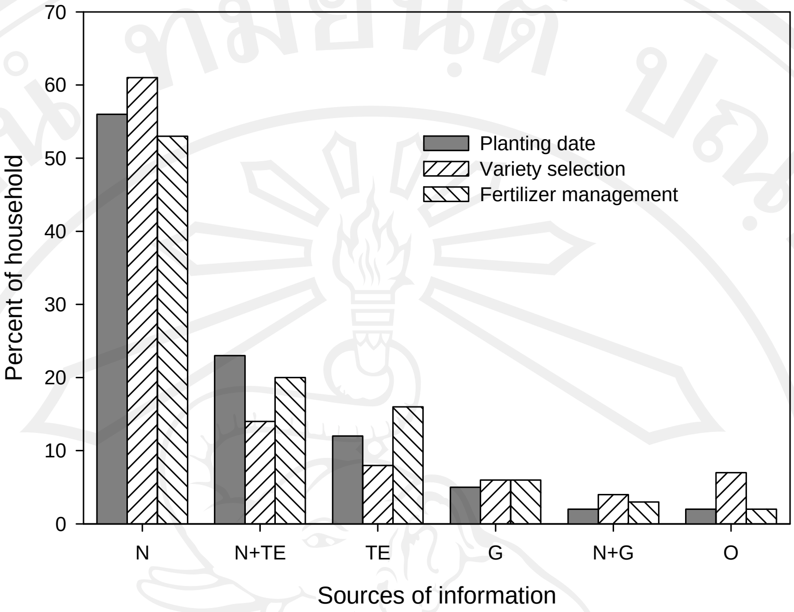

Figure 12 Percent of household to obtain the information from various sources to select appropriate planting date, variety selection, suitable fertilizer management, N = neighbor, TE = trial and error, G = government agency and O = others sources such as community radio and local merchant.

Chemical fertilizer application

Deepwater rice

For DWR, farmers normally applied chemical nitrogen fertilizer twice throughout the growing season. The total nitrogen (N) fertilizer (from urea and compound fertilizer) application rates ranged from 41 to 120 kg ha^{-1} (Figure 14). For the first application, more than 60% of the farmers applied N at a rate of 21 to 40 kg ha^{-1} which is similar to the amount applied during the second application (Figure 13a). The first application is made when the soil moisture content of the field is suitable or at the time of when flooding started, while the second application is made around the panicle initiation stage. The research found that 38% of household applied N fertilizer at a rate between 41 and 60 kg ha^{-1} while 31% of the farm households applied N fertilizer at a rate between 61 and 80 kg ha^{-1} for DWR production. The remaining 31% of farm households applied N fertilizer at a rate between 81 to 120 kg ha^{-1}, which is considered as a high rate for traditional DWR variety (Figure 14).

Flooded rice

Similar to the DWR households, chemical fertilizer is applied twice during the growing season. The total N fertilizer application rates ranged from 20 to 120 kg ha^{-1} (Figure 14). However, most of FDR farmer applied total N fertilizer at the rate higher than 41 kg ha^{-1}. For the first fertilizer application, more than 70% of the households applied N at a rate of 21 to 40 kg ha^{-1}, which is similar to rate of the second application (Figure 13b). The first application is normally made at 20 to 30 days after planting, while the second application is made at 45 to 60 days after planting. The research found that 52% of the farmers applied N fertilizer at a rate between 41 and to 60 kg ha^{-1} for FRD production throughout growing season, while the rest of farm households applied nitrogen fertilizer at a rate ranged between 61 and 120 kg ha^{-1} (Figure 14).

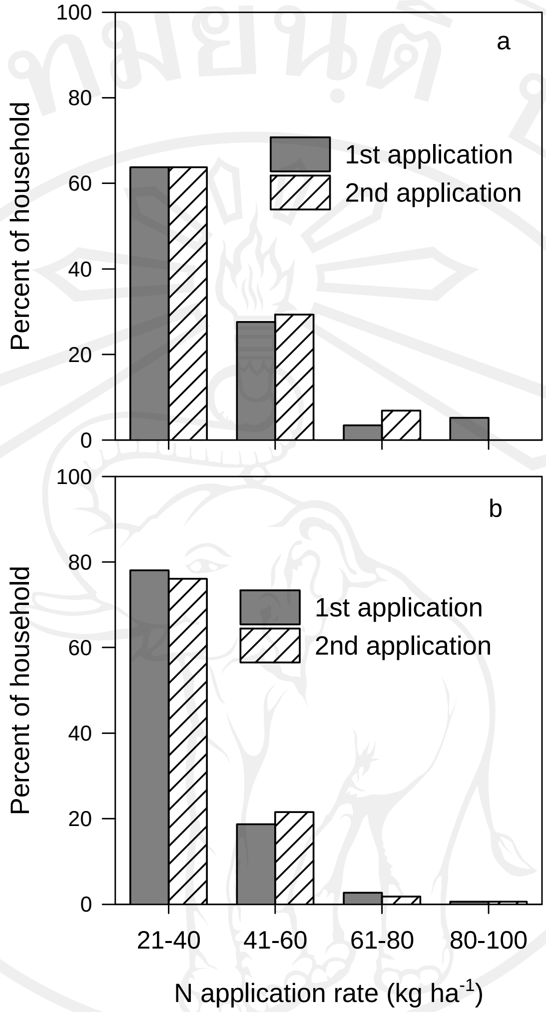

Figure 13 Percentage of household and the first and second N application rates for deepwater rice (a), flooded rice (b)

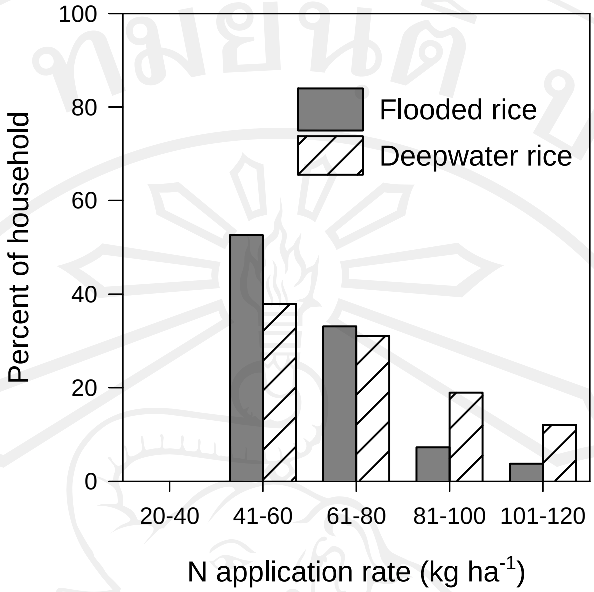

Figure 14 Percentage of household and total N fertilizer application rate for deepwater rice and flooded rice production

The farm households obtained their information from five sources for decision making to select appropriate chemical fertilizer management. Ranking from the most to the least significance this included 54% from neighbor, 20% from trial and error, 16% from neighbor and trial and error, 6% from government agency and neighbor, and 3% from government agency (Figure 12). Again, some information is obtained from the community radio and the local middle-man.

Yield

Deepwater rice

Yield for DWR ranged from two to five ton ha^{-1} with an average of 3.7 (±0.7) t ha^{-1}. Forty-seven percent of the farm households had a yield that ranged from 3 to 4 t ha^{-1}, and 40% of the farm households had a yield that ranged from 4 to 5 t ha^{-1}. The remaining households of thirteen percent of farm household could produce only 2 to 3 t ha^{-1}. One of the main disadvantages of DWR is that it can only produce one single crop per year compared to two crops under FDR.

Flooded rice

The yield of FDR ranged from 2 to 7 t ha^{-1} with an average of 4.7 (±0.5) t ha^{-1}. Eighty seven percent of the farmers produced rice yield that ranged from 4 to 5 t ha^{-1}, while 6% had a yield that is less than 4 t ha^{-1} and 7% had a yield over 5 t ha^{-1}. However, this yield had relatively high moisture content because rice grains are weighted and sold immediately after harvesting without drying. Therefore, the average gain yield will be less than 4.7 t ha^{-1} after drying and converted to the 14% moisture content standard.

4.1.6 Discussions

Based on the survey, FDR farmers continually face a range of production risks and associated low yield levels. This is due to a shortage of water supply, a limited availability of high yielding rice varieties, and limited access to chemical fertilizer in the area. The research finds that farmers exchange knowledge or acquire information from other sources to convert their fields from DWR to FDR.

Unfortunately, there is currently insufficient information available for the farmers reaching to appropriate management practices. It is, therefore, important for the Rice Department of the Thai Government and other research and development organizations to obtain a better understanding of the situation of these DWR farmers and to prioritize their research strategies and agenda for the timely development of alternatives for the transition from DWR to FDR. Studies also show that the development of appropriate technologies for variety selection, suitable planting date and for sustainable fertilizer management of rice production is needed.

4.2 Effect of planting date and variety on FDR production in the deepwater area

4.2.1 Effect of planting date and variety on development

Planting date

The average and SD of the duration that rice varieties stay in their vegetative phase for the early rainy season (ERS) for the four planting dates over three varieties is 64 (±4), 63 (±2), 52 (±3) and 56 (±3) days for PD1, PD2, PD3 and PD4, respectively. The average and SD of the duration of the reproductive phase for ERS for the four planting dates over three varieties is 32 (±1), 30 (±2), 31 (±1) and 32 (±1) days for PD1, PD2, PD3 and PD4. The average and SD of the duration of the ripening phase for ERS is 31 (±1), 25 (±2), 31 (±0) and 27 (±1) days for PD1, PD2, PD3 and PD4, respectively (Figure 15b). There is no significant difference of the planting date of ERS on the duration of the developmental phases of FDR production in the deepwater area. However, the vegetative phase tended to be shorter when the planting date is delayed (PD3 and PD4) and consequently affected the overall harvest date. The overall growth duration for PD1 is 123 (±3) days which is not significant difference with PD2 and is longer than the growth duration for PD3 (114 ±4) and PD4 (115 ±3) (Figure 15f).

The average and SD of the vegetative phase duration for the dry season (DS) over four planting dates of three rice varieties is 67 (±3), 67 (±2), 66 (±4) and 66 (±3) days after germination for PD1, PD2, PD3 and PD4, respectively. The average and SD duration of the reproductive phase over planting dates of three rice varieties is 22 (±0), 22 (±1), 25 (±2) and 28 (±1) days for PD1, PD2, PD3 and PD4, respectively. The average duration of ripening phase is 23 (±1), 17 (±2), 20 (±0) and 22 (±1) days of PD1, PD2, PD3 and PD4, respectively (Figure 15d). The overall growth durations are not statistically different, but harvest date of DS tended to be shorter than ERS (Figure 15f).

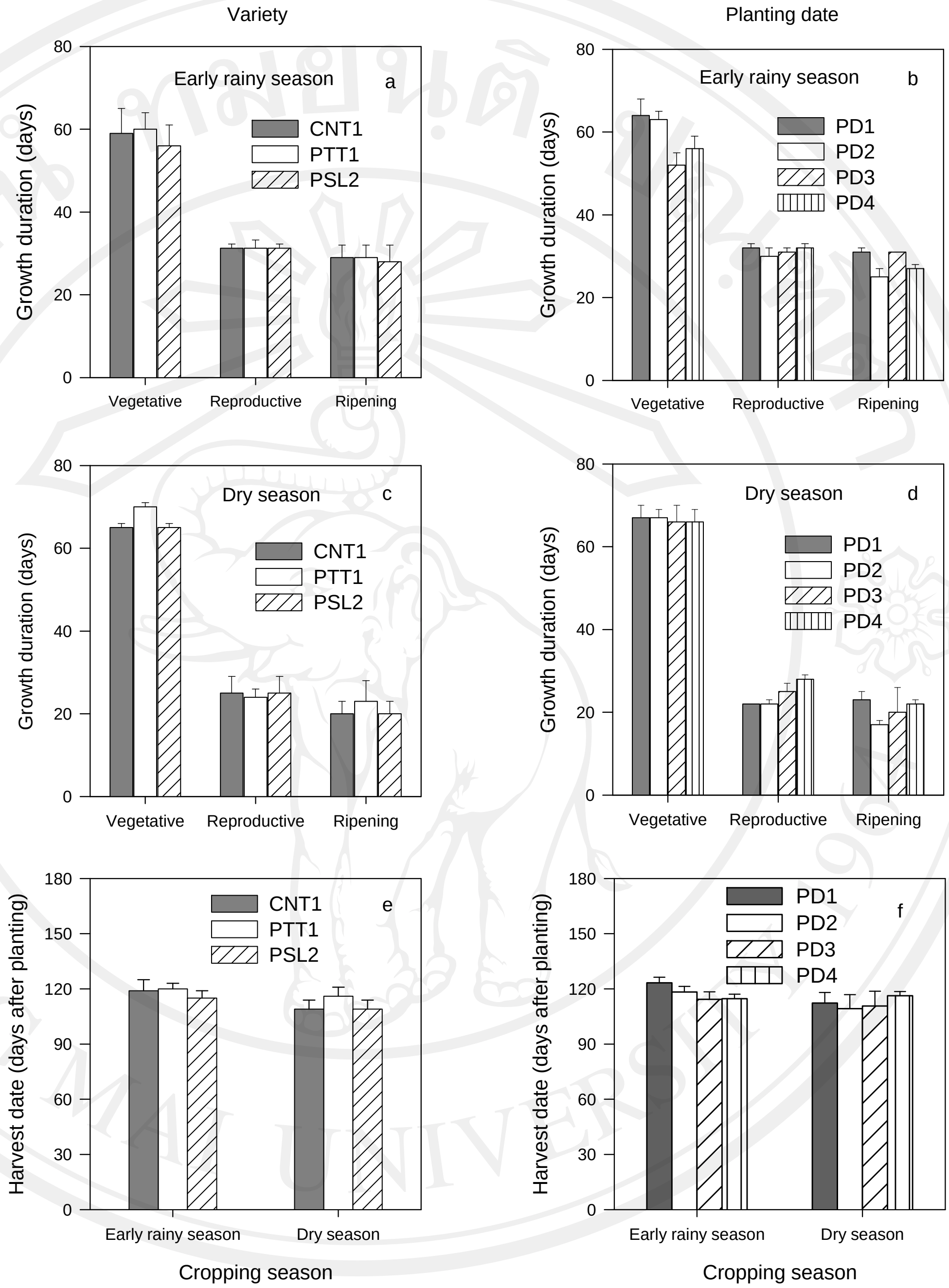

Figure 15 Development phase and growth duration for three varieties under four planting dates for the early rainy season (ERS) and dry season crop (DS).average growth duration for three varieties for ERS (a) and DS(c); average growth duration for four planting dates for ERS (b) and DS (d) average harvest date for three varieties (e) and four planting dates (f).

Variety

The average and SD of the vegetative phase duration for the ERS crop for the three varieties over four planting dates is 56 (±5), 59 (±6) and 60 (±4) days after germination for PSL2, CNT1 and PTT1, respectively (Figure 15a). The average and SD of the reproductive phase duration for ERS for the three varieties over four planting dates is 31 (±1), 31 (±1) and 31 (±2) days for PSL2, CNT1 and PTT1, respectively. The average and SD of the ripening phase duration is 28 (±4), 29 (±3), and 29 (±3) for PSL2, CNT1 and PTT1, respectively (Figure 15a). The overall average period of development phase from germination to harvest among three FDR varieties under different planting dates is 118 (±5) days after planting. The average harvest date of three varieties over four planting dates is 115 (±4), 119 (±6) and 120 (±3) of PSL2, CNT1 and PTT1, respectively (Figure 15e). The average duration of the vegetative phase (germination to panicle initiation: PI), the reproductive phase (from PI to flowering stage: FD) and the ripening phase (from FD to harvesting: HD) (Department of Agriculture, 2004b) are not significantly different among the development phases of three varieties (Figure 15a).

The average and SD the vegetative phase duration for the DS for the three varieties dates over four planting dates is 65 (±1), 65 (±1) and 70 (±1) days after germination for PSL2, CNT1 and PTT1, respectively (Figure 15c). The average and SD of the reproductive phase duration for DS of the three varieties over four planting dates is 25 (±4), 25 (±4) and 24 (±2) days for PSL2, CNT1, and PTT1, respectively. The average and SD of the ripening phase duration is 20 (±3), 20 (±3), and 23 (±5), respectively (Figure 15c). The overall average harvest date of the three varieties over four planting dates of FDR production after flooding is 111 (±6) days after planting.

The average and SD of the total growing duration among three rice varieties over four planting dates is 109 (±5), 109 (±5) and 116 (±5) days after planting for PSL2, CNT1 and PTT1, respectively (Figure 15e).

4.2.2 Effect of planting date and variety on growth and biomass

Planting date

For the first sampling at panicle initiation stage (S1) of the early rainy season crop there is a significant effect ($P < 0.05$) of the planting date on leaf and stem dried biomass and consequently total above ground biomass. For the growth analysis samples taken at flowering (S2), milky (S3) and harvesting stages (S4), leaf biomass, stem and above ground biomass are not significant difference ($P > 0.05$: Table 8). Above ground biomass is very similar (Table 9) across planting dates of FDR from May 20 to July 1. At final harvest the P value for above ground biomass is 0.4465 indicating that there is no significant difference among planting date (Table 7).

For the growth analysis of the dry season, stem biomass is significant different for all four growth analysis samples. Leaf biomass is significantly different for the first sampling at panicle initiation stage (S1) ($P < 0.05$) but there is no effect on the other three stages ($P > 0.05$). The total above ground biomass is significantly different ($P < 0.05$) for S2, S3, and S4 growth analysis samples, while the above ground biomass at S1 stage is not significantly different ($P = 0.5001$) (Table 7).

Table 7 Analysis of variance (*P*-value) for biomass, yield and harvest index (HI) for the early rainy season and dry season crop

Treatment factor	*Leaf biomass*				*Stem biomass*				*Above ground biomass*				*Yield*	*HI*
	S1	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*		
Early rainy season crop														
Planting date (PD)	0.0000	0.1117	0.0377	0.0713	0.000	0.1699	0.0262	0.3321	0.0000	0.2553	0.0306	0.4465	0.0942	0.1670
Variety (V)	0.2450	0.0000	0.0331	0.0000	0.6292	0.0389	0.3630	0.0000	0.9672	0.6731	0.0338	0.0000	0.0055	0.0000
PD x V	0.1738	0.0003	0.0004	0.0088	0.6890	0.0370	0.3957	0.0190	0.4427	0.3574	0.2347	0.0103	0.2214	0.2618
%CV	11.11	10.55	13.74	8.15	11.94	13.69	16.86	13.86	12.39	12.42	14.66	5.46	7.84	8.82
Dry season crop														
Planting date (PD)	0.0049	0.1711	0.0511	0.1089	0.0000	0.0005	0.0007	0.0000	0.5001	0.0038	0.0004	0.0000	0.0000	0.0000
Variety (V)	0.2946	0.0857	0.0020	0.1492	0.2719	0.2058	0.4027	0.1217	0.2988	0.4440	0.6985	0.4408	0.0070	0.0000
PD x V	0.6611	0.2521	0.0001	0.1287	0.3806	0.0248	0.9178	0.1581	0.4358	0.2031	0.8495	0.0063	0.0031	0.0004
%CV	17.48	14.99	9.78	11.16	17.30	17.61	21.61	15.40	16.01	15.30	17.55	9.81	14.57	11.17

Note: 1. S1-Panicle initiation stage, S2-Flowering stage, S3-Milky stage and S4-Harvesting (Ripening stage)
2. Above ground biomass = Leaf biomass + Stem biomass + Grain yield

Variety

Leaf biomass of FDR during the early rainy season is significantly different ($P < 0.05$) at the S2, S3 and S4 development stage but it is not significantly different at S1 ($P = 0.2450$). The stem biomass sample at S2 and S4 and above ground biomass at S3 and S4 are also significantly different ($P < 0.05$). At final harvest, leaf, stem and above ground biomass are all significantly different ($P < 0.05$; Table 7). This indicated that the three rice varieties are significantly different in term of growth for the early rainy season crop. The PTT1 variety gave the highest above ground biomass, with an average of 9,022 kg ha^{-1} followed by CNT1 with 8,509 kg ha^{-1} and PSL2 with 8,004 kg ha^{-1}, respectively (Table 8).

Leaf biomass FDR during the dry season at the S1, S2 and S4 development stage, and stem and above ground biomasses at all stages are not significantly different ($P > 0.05$). Leaf biomass at the S3 development stage is only significantly different (P = 0.0020) (Table 7). Overall biomass analysis indicates that there is no effect of rice varieties on above ground biomass of FDR production during the dry season in the deepwater area.

Table 8 Effect of variety on yield, above ground biomass and harvest index (HI) of the early rainy season and dry season crop in the deepwater area, Prachin Buri, Thailand, 2009-2010

Variety	*Yield*	*Biomass*			*HI*
		Above ground	*Stem*	*Leaf*	
	--------------------------- *kg ha^{-1}* ---------------------------				
<u>Early rainy season crop</u>					
Pitsanulok 2	3,898a	8,004c	2,520c	1,354b	0.49a
Pathum Thani 1	3,759a	9,022a	3,136b	1,573a	0.42b
Chai Nat 1	3,529b	8,509b	3,455a	1,635a	0.42b
<u>Dry season crop</u>					
Chai Nat1	1,796a	5,625a	2,456ab	1,233a	0.27a
Pitsanulok2	1,564b	5,378a	2,304b	1,314a	0.23b
Pathum Thani 1	1,524b	5,477a	2,590a	1,222a	0.20c

Note: Means with a column followed by the same letter are not significantly different according to LSD test at P < 0.05

4.2.3 Effect of planting date and variety on final yield

Planting date

The planting dates during the ERS crop did not affect on yield. The average yields over four planting dates, i.e. 3,932 kg ha^{-1} for PD1; 3,671 kg ha^{-1} for PD2; 3,565 kg ha^{-1} for PD3; and 3,746 kg ha^{-1}for PD4 are not significantly different (P = 0.0942). However, there is an effect of planting dates on flooded yield during the DS crop. The average yields for the four planting dates are 3,441 kg ha^{-1} for PD1: 2,536 kg ha^{-1} for PD2: 465 kg ha^{-1} for PD3: and 70 kg ha^{-1} for PD4. They are significantly different with P = 0.0000.

Variety

Rice variety affects yield for both ERS and DS crop with a *P* value of 0.0055 and 0.0070, respectively. The highest yield at 14% moisture content of ERS crop production over four planting dates is PSL2 rice variety with an average yield of 3,898 kg ha^{-1}. However, it is not significantly different from PTT1, with an average yield of 3,786 kg ha^{-1}. The harvest index (HI) for PSL2 and PTT1 are 0.49 and 0.42, respectively. The lowest yield is CNT1 with an average yield of 3,529 kg ha^{-1} with a harvest index of 0.42 (Table 8). For the DS crop, the highest yield over four planting dates at 14% moisture content is CNT1 rice variety with an average yield of 1,796 kg ha^{-1}. It is significantly different with an average yield of 1,564 kg ha^{-1} for PSL2 and of 1,524 kg ha^{-1} for PTT1 variety. The harvest index (HI) for CNT1, PSL2 and PTT1 are 0.27, 0.23 and 0.20, respectively (Table 8).

Table 9 Effect of interaction between planting dates (PD) and varieties (V) on yield, above ground biomass at harvesting, and harvest index under dry season crop of flooded rice production in deepwater area, Prachin Buri, Thailand.

Rank	*Yield*		*Above ground biomass*[a]		*Harvest Index*	
	PD x V	*Mean*[b]	*PD x V*	*Mean*[b]	*PD x V*	*Mean*[b]
		kg ha^{-1}		kg ha^{-1}		
1	PD1 x PTT1	3,661a	PD1 x PTT1	8,898a	PD1 x CNT1	0.43a
2	PD1 x CNT1	3,446ab	PD1 x CNT1	8,001b	PD1 x PTT1	0.41ab
3	PD1 x PSL2	3,217b	PD1 x PSL2	7,951bc	PD1 x PSL2	0.41ab
4	PD2 x CNT1	2,805c	PD2 x CNT1	6,970cd	PD2 x CNT1	0.40ab
5	PD2 x PSL2	2,557cd	PD2 x PSL2	6,907d	PD2 x PSL2	0.37b
6	PD2 x PTT1	2,246d	PD2 x PTT1	6,803d	PD2 x PTT1	0.33c
7	PD3 x CNT1	884e	PD3 x CNT1	4,949e	PD3 x CNT1	0.17d
8	PD3 x PSL2	397f	PD3 x PSL2	4,030f	PD3 x PSL2	0.10e
9	PD3 x PTT1	113f	PD3 x PTT1	3,371fg	PD3 x PTT1	0.04f
10	PD4 x PSL2	82f	PD4 x CNT1	2,835g	PD4 x PSL2	0.03f
11	PD4 x PTT1	75f	PD4 x PSL2	2,625g	PD4 x PTT1	0.02f
12	PD4 x CNT1	49f	PD4 x PTT1	2,578g	PD4 x CNT1	0.02f

Note: [a] Above ground biomass includes leaf biomass, stem biomass and grain yield.
[b] Means with a column followed by the same letter are not significantly different according to LSD test at $P < 0.05$

There is also an interaction between planting date and variety ($P < 0.01$) on FDR yield production during the DS crop (Table 7). The first three ranks of interactions are PD1 × PTT1, PD1 × CNT1 and PD1 × PSL2 with an average yield of 3,661, 3,446, and 3,217 kg ha^{-1}, respectively (Table 9). This indicated that PD1 and PD2 resulted in the higher yields than PD3 and PD4 (Table 9). Planting of PTT1 at November 9 resulted in the highest yield but it is not significantly different with CNT1 planted on the same date. Planting of FDR in the dry season should be done as soon as possible after receding of flooded water to ensure that there is a sufficient water supply for the rice crop throughout the growing season.

4.2.4 Discussion

A comparison between early rainy season and dry season crop

There are both advantages and disadvantage for lowland rice production in ERS and in DS. There is wider range of planting date in ERS than DS crop. The planting date in ERS ranges from March to early August. However, late plating date of ERS may risk to be flooded in late development phase of rice plant especially in reproductive phase, Another disadvantage is lodging of some FDR varieties e.g. PPT1 and SPR1 (from farmer interview and field survey). On the other hand, the planting in DS ranges from late October to December. Late planting date tends to be insufficient of water supply in the late part of growing season. In addition, low temperature in November and December might affect on growth and development of susceptible variety, e.g., PSL2 rice variety.

Temperature and day length

The field experiments are located at 13^{o} 52$^{/}$ N, and 101^{o} 09$^{/}$ E. The day lengths during the ERS and DS is not much different and ranged from 11 hrs 41 minutes to 12 hrs 34 minutes for the ERS crop and from 11 hrs 32 minutes to 12 hrs 15 minutes for the DS crop. The natural day length or photoperiod affecting rice development consists of the length of day light and the duration of the civil twilight (De Detta, 1981). For this location, the day length is longest on June 21 and shortest on December 21, with 12 hrs 50 minutes and 11 hrs 10 minutes, respectively (Ahrens, 2008). The optimum of temperature for rice is 27^{o}C (George, 2007). The average maximum and minimum air temperature is 34^{o}C (±1.7) and 25^{o}C (±0.9), respectively, for the ERS and 35^{o}C (±2.5) and 24^{o}C (±2.3), respectively for DS. There is, therefore, no significant difference in air temperature between the ERS and DS production period. However, it should be noted that the maximum air temperature is significantly higher than the optimum temperature of 25 to 30^{o}C for rice (Matthews, 1995; Paul, 1994; Singh, 2009; Sparks, 2009).

Planting date

The range of potential planting dates for FDR production in the deepwater area in Prachin Buri, Thailand is defined by flooding period during the rainy season, the limited water supply during the dry season and the salinity concentration of water in the river. There is not much impact of planting date during the ERS on growth and yield. However, there is a risk of flooding or too much water during the harvest in September and in October for the later planting dates (Catling, 1992). It is, therefore, recommended to plant as early as possible when water is available. In addition, an increase in the production of FDR in the area also means needed more water supply for the system.

Variety

There are currently more than 500 recommended modern rice varieties for FDR production across the world (Qi *et al*., 2009). However, since 1959 only 29 modern rice varieties have been recommended for FDR production in Thailand. The growth duration from germination to harvest ranges from 90 to 140 days (Department of Agriculture, 2002). Most of which are no longer planted in farmers' fields. Three widely adopted recommended varieties for FDR production are used in the research consisting of CNT1, PTT1 and PSL2 rice varieties. They have similar characteristics with respect to growth duration and yield but there are both advantages and disadvantages among those varieties. For example, PSL2 is suitable for early rainy season production because it is resistant to lodging. The CNT1 and PTT1 varieties are better than PSL2 in term of cold tolerance. This information is based on observations and discussions with farmers. Rice varieties that have shorter growth duration with a higher growth rate are preferred for planting both in ERS and in DS, due to the constraints of the flooding period during the rainy season and shortage of water supply during the dry season. There are other recommended early rice varieties, e.g., RD25 (growth duration 100 days), but they could not compete with these three varieties in terms of yield (Department of Agriculture, 2002 and 2004b).

Salinity

There is an issue of saline water due to an influx of sea water into the study area as a result of the drought. Amount and distribution of rainfall and amount of water supply from the dam relates to the salinity concentration of water in the river. Research by De Datta (1981); Fageria (1992) and Jaiwal *et al*. (1997) showed that salinity could injury rice growth at a high salt concentration. The demand for water for irrigation has increased with the expansion of FDR production area. However, the water supply for FDR production is limited especially during the dry season. The main channel that provides the irrigation water in the study area flows directly to the Gulf of Thailand. There is, therefore, a direct correlation between fresh water in the main channel and the sea water in the gulf of Thailand. The water supply for FDR production during the ERS is sufficient due to high volume of the upstream water inflow through the area to the gulf. However, during the DS the volume of water from upstream is less than the water used for irrigation. As a result, due to the increased pumpage for irrigation, water that is not replaced by the inflow from upstream will be replaced with seawater, causing an increase in salinity in the stream. Several salinity monitoring stations have been installed for measuring the salinity of Bang Pakong river along the study area. This includes the Bang Taen His Majesty Private Development Project, which is the location of these field experiments. Salinity could be detected as early as January at the downstream station and salinity continued to increase until April 7, 2010 (Figure 16). Most crops including rice are sensitive to salinity. The critical salinity threshold for rice cultivation is 2.0 dS m^{-1} (De Datta, 1981; Fageria, 1992; Jaiwal *et al*., 1997). The salinity at the experimental site is first detected in late January. The salinity level of the water is higher than the critical level for rice as early as mid February and continued to increase until the highest level is reached in early April. However, there is no exceeding salinity threshold level detected at the upper stream stations. This means that the potential planting date in the upper stream has a wider range than in the downstream area.

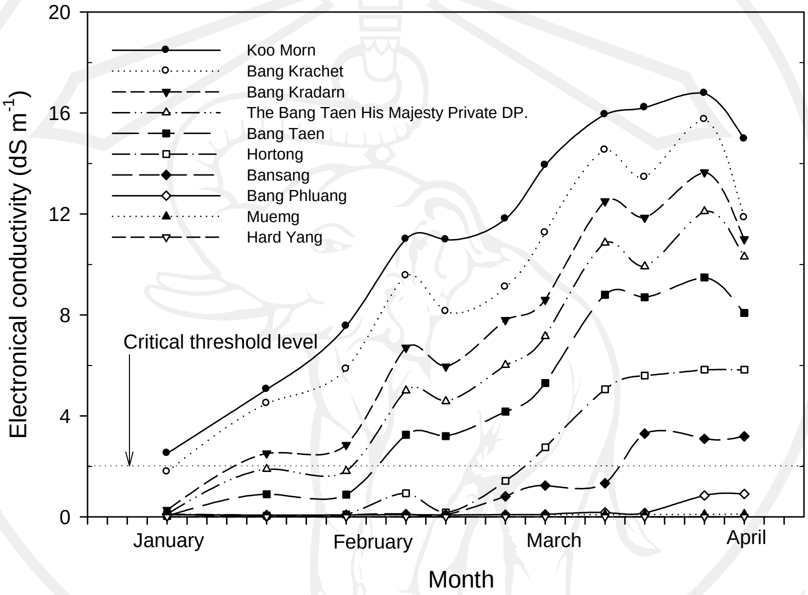

Figure 16 Salinity of water at 10 measurement stations along Bang Pakong River from downstream (Koo Morn station) to upper stream (Hard Yang station) of study area during 2010. (The experimental field is located in the vicinity of the monitoring station at the Bang Taen His Majesty Private Development Project).

4.3 Effect of chemical nitrogen fertilizer management and variety on FDR production in the deepwater area

4.3.1 Effect of chemical nitrogen fertilizer and variety on development

In this research, there is no effect of chemical nitrogen fertilizer on developmental phase of FDR rice varieties; therefore there is no variation of FDR rice development phase among fertilizer managements. However, the duration of each developmental phase of rice varieties are differed. The average values of the vegetative phase duration for the ERS of three rice varieties under four chemical nitrogen application rates are 66, 69, and 63 days after planting for CNT1, PTT1, and PSL2 variety, respectively. The average values of the reproductive phase duration of three varieties under four chemical nitrogen fertilizer application rates is 55 days after planting for CNT1, 56 days after planting for PPT1, and 55 days after planting for PSL2. Therefore, the duration of the vegetative and the reproductive phases of ERS crop are 124, 122, and 118 days after planting for CNT1, PTT1, and PSL2, respectively (Table 10).

The average values of the vegetative phase duration for the DS of the three varieties under four chemical nitrogen fertilizer application rates are 54, 61, and 54 days after planting for CNT1, PTT1, and PSL2 variety, respectively. The average duration of the reproductive phase of the three varieties over four fertilizer application rates are 54 days after planting for CNT1, 57 days after planting for PPT1, and 54 days after planting for PSL2 variety. Therefore, the total of vegetative phase and reproductive phase is 108, 118, and 108 days after planting for CNT1, PTT1, and PSL2 variety, respectively (Table 10). The total growing season of DS rice crop is 16, 6, and 10 days shorter than it ERS crop counterpart, due mainly to higher minimum temperature towards the end of growing season.

Table 10 Developmental stages and growth duration of three rice varieties in early rainy season and dry season of FDR production in DWR area, Prachin Buri, Thailand, 2009 – 2010

Development Stage	*CNT1*		*PTT1*		*PSL2*	
	ERS	*DS*	*ERS*	*DS*	*ERS*	*DS*
	-------------------------------		---*days*---		------------------------------	
Total growth duration	124	108	122	118	118	108
Vegetative	69	54	66	61	63	54
Reproductive	55	54	56	57	55	54

Note: 1. CNT1 = Chai Nat 1, PTT1 = Pathum Thani 1, and PSL2 = Pitsanulok 2

2. ERS = Early Rainy Season (before flooding), DS = Dry Season (after flooding)

4.3.2 Effect of fertilizer management and varieties on growth and biomass and yield

The analysis of variance (*P*-value) shows that there is no interaction between fertilizer management and FDR rice variety on both biomass and grain yield of early rainy season crop and dry season crop (Table 11). The effects of fertilizer management factor and variety factor on growth and yield are explained in the following paragraph. Explanation starts with the effect of fertilizer management on growth and yield, followed by the effect on varieties.

Effect of fertilizer management on biomass and yield

Fertilizer management affects leaf, stem, and above ground biomass (P < 0.05), at harvesting stage (S4) of the early rainy season crop (Table 11). LCC with deep placement produces the highest above ground biomass, with an average of 10,054 kg ha^{-1}, however it is not significantly different from farmer management with an average of 9,611 kg ha^{-1}. The lowest biomass is obtained from the no fertilizer application treatment with the average of 8,098 kg ha^{-1} (Table 12). The average rice yield of FDR under LCC with deep placement, farmer practicing and LCC with broadcasting are 4,579; 4,419; and 4,352 kg ha^{-1}, respectively, which are not significant difference. However they are higher than the average yield of 3,847 kg ha^{-1} obtained from the no fertilizer treatment.

Fertilizer managements also affect leaf biomass at all stages, harvesting stage of stem biomass and all stages of above ground biomass of FDR in dry season crop (P < 0.05) (Table 11). The biomass of FDR under three fertilizer managements are not statistically significant, however they are higher than the no fertilizer application treatment (Table 12). The average yield of FDR under LCC with deep placement, farmer practicing and LCC with broadcasting are 4,304; 4,029; and 4,060 kg ha^{-1}, respectively, and not statistically significant among these three fertilizer management treatments. However they are higher than the average yield of 3,421 kg ha^{-1} obtained from the no fertilizer treatment (Table 12).

Table 11 Analysis of variance (*P*-value) for biomass, yield and harvest index (HI) of the effect of fertilizer application and varieties on FDR production in early rainy season and dry season, Prachin Buri, Thailand, 2009-2010.

Treatment factor	*Leaf biomass*				*Stem biomass*				*Above ground biomass*				*Yield*	*HI*
	S1	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*		
Early rainy season crop														
Fertilizer (F)	0.0061	0.7171	0.7025	0.0022	0.1421	0.5543	0.2334	0.0021	0.0306	0.7819	0.4087	0.0007	0.0087	0.3137
Variety (V)	0.0037	0.0047	0.0036	0.0011	0.0251	0.0000	0.0000	0.0343	0.0143	0.0001	0.0271	0.7105	0.0849	0.0017
F x V	0.5869	0.4940	0.6080	0.9697	0.8069	0.6634	0.1402	0.9326	0.7711	0.6746	0.9707	0.9713	0.8029	0.7273
%CV	11.20	10.40	20.14	12.04	12.25	20.15	11.80	9.80	10.71	14.89	10.72	8.68	10.15	6.08
Dry season crop														
Fertilizer (F)	0.0034	0.0002	0.0059	0.0053	0.6378	0.0587	0.0936	0.0356	0.0437	0.0082	0.0330	0.0184	0.0452	0.4534
Variety (V)	0.1569	0.0634	0.0002	0.9034	0.1341	0.0000	0.0226	0.0007	0.1532	0.0000	0.0627	0.0013	0.0013	0.4621
F x V	0.7948	0.5909	0.9123	0.6560	0.9763	0.1812	0.7168	0.8861	0.9236	0.1913	0.7033	0.7070	0.3104	0.5904
% CV	11.00	16.01	11.31	12.78	10.79	13.48	18.43	11.77	10.18	12.62	15.09	6.48	8.61	7.56

Note: 1. S1-Panicle initiation stage, S2-Flowering stage, S3-Milky stage and S4-Harvesting (Ripening stage)
2. Above ground biomass = Leaf biomass + Stem biomass + Grain yield

Table 12 Effect of fertilizer management on biomass and yield of FDR production in deepwater area, Prachin Buri, Thailand, 2009-2010

Fertilizer Management	*Early rainy season*		*Dry season*	
	Biomass	*Yield*	*Biomass*	*Yield*
	------------------------------ *kg ha^{-1}*	------------------------------		
LCC N Deep placement	10,054a	4,579a	9,509a	4,304a
Farmer practice	9,611ab	4,419a	9,388a	4,029ab
LCC N Broadcasting	9,142b	4,352a	9,239a	4,060ab
No application	8,098c	3,847b	7,872b	3,421b
% CV	8.02	9.42	12.29	18.88

Note: 1. LCC rate: 59 kg N, 36 kg P_2O_5 ha^{-1}
2. Current fertilizer application rate used by interviewed farmer: 78 kg N, 44 kg P_2O_5 ha^{-1}
3. Means with a column followed by the same letter are not significantly different according to LSD test at P < 0.05

Effect of varieties on biomass and yield

For ERS crop, rice variety influences significantly (P < 0.05) on leaf, stem, and above ground biomass at all developmental stages except at harvesting stage (S4). (Table 11). There is significant different among rice varieties in term of harvest index (HI) in early rainy season production (P < 0.05) (Table 11). The best harvest index is PSL2 (0.49) which is relatively close to PTT1 (0.47), but their HIs are higher than CNT1 (0.45). The average biomass of three rice varieties over four fertilizer management under early rainy season are 9,353; 9,205; and 9,121 kg ha^{-1} for PTT1, CNT1 and PSL2 rice variety, respectively, which is not significantly different among rice varieties. The average yield of three rice varieties over four fertilizer management are 4,446; 4,354; and 4,098 and kg ha^{-1} for PSL2, PTT1, and CNT1 rice variety. The average yield of PSL2 is not significant different from PTT1, however they are higher than CNT1 variety.

For DS crop, rice variety significantly influence leaf biomass at Milky stage (S3), due mainly to difference of leaf deterioration rate. Rice variety significantly affects stem biomass at all development stages, except at panicle initiation (S1). Above ground biomass responses differently to rice variety at all developmental stages, but statistically significant difference at flowering and harvesting stages (P < 0.05) (Table 11). There is no significant difference among rice varieties in terms of harvest index (HI) in the DS rice production (P = 0.4621). The average biomass of three rice varieties over four fertilizer management under the dry season are 9,346; 9,148; and 8,512 kg ha^{-1} for PTT1, CNT1 and PSL2 rice variety, respectively. There is not significantly different among PTT1 and CNT1 rice varieties, but they are higher biomass than PSL2. The average yield of three rice varieties over four fertilizer management are 4,141; 4,053; and 3,666 and kg ha^{-1} for PTT1, CNT1, and PSL2 rice variety. The average yield of PTT1 is not significant difference from CNT1. However they are higher than PSL2 variety (Table 13).

Table 13 Effect of rice variety on biomass and yield of FDR production in deepwater area, Prachin Buri, Thailand, 2009-2010

Varieties	*Early rainy season*		*Dry season*	
	Biomass	*Yield*	*Biomass*	*Yield*
	---------- kg ha^{-1} ----------			
Pathum Thani1	9,353a	4,354a	9,346a	4,141a
Chai nat1	9,205a	4,098a	9,148a	4,053a
Pitsanulok2	9,121a	4,446a	8,512b	3,666b
% CV	8.68	10.15	6.48	8.61

4.3.3 Partial Factor Productivity (PFP) under different fertilizer management

Percent of nitrogen in rice plant biomass is analyzed to evaluate efficiency of nitrogen fertilizer application using PFP index (Table 14). The results of PFP calculation indicates that N efficiency of LCC with deep placement (DP) is 84.9 kilogram of grain yield per kilogram N applied, while LCC with broadcasting (BC) and farmer practice are 81.3 and 54.2 kilogram of grain yield per kilogram N applied, respectively (Table 14). Likewise, Agronomic Efficiency (AE) of LCC with DP is 13.7 kilogram of grain yield per kilogram N applied, where as AE are 9.7 and 7.6 kilogram of grain yield per kilogram of N applied for LCC with BC and farmer practice, respectively. The LCC with DP treatment is the best chemical fertilizer application based on PFP and AE indexes (Table 14). However, the analysis of variance (ANOVA) indicates that there is not statistically significant among three fertilizer application managements in term of rice grain yield. These finding reflects the fact that, in DWR area, rice varieties have similar or narrow genetic pool and potential.

Table 14 Efficiency of different nitrogen fertilizer management for FDR production (averaged across ERS and DS crops) in DWR area, Prachin Buri, Thailand. 2009-2010.

Items	***Fertilizer managements***			
	F1	F2	F3	F4
1. N applied (kg ha^{-1})	-	78	59	59
2.Yield (kg ha^{-1})	3,634	4,224	4,206	4,442
3. Yield difference from F1 (kg ha^{-1})	-	590	572	808
4. Agronomic efficiency (AE)	-	7.6	9.7	13.7
5. Partial Factor Production (PFP)	-	54	81	85
6. Fertilizer cost (Baht ha^{-1})	-	4,752	3,821	3,821
7. Fertilizer application cost (Baht ha^{-1})	-	312	250	4,375
8. Increment income (Baht ha^{-1})	-	5,900	5,720	8,080
9. Fertilizer management profit 8-(6+7)	-	836	1,649	-116

Note: F1 = 0 kg N ha^{-1} application, F2 = 78 kg N ha^{-1} application by broadcasting, F3 = 59 kg N ha^{-1} by broadcasting and F4 = 59 kg N ha^{-1} by deep placement, Currency 30 Baht = 1US dollar, Fertilizer cost: 16-20-0 = 15.4 Baht kg^{-1}, 46-0-0 = 14.8 Baht kg^{-1}, Rice price 10 Baht kg^{-1}

4.3.4 Discussion

Variety and Growth duration

The observed data of rice development phase indicates that rice growth duration in dry season is slightly shorter than in early rainy season by 10%, 5% and 10% for CNT1, PPT1, and PSL12 rice variety, respectively. Rice growth duration primarily depends on genetic and environmental condition (Gao *et al.*, 1987). Optimum photoperiod for rice growing is 10 – 12 hr d^{-1} and optimum temperature for rice ranges from 25 – 30^{o}C (Matthews, 1995; Paul, 1994; Singh, 2009; Sparks, 2009). During ERS and DS crop in 2009-2010, the averaged photoperiod are 11.61 and 12.14 hr, respectively. ERS crop in this research experiences a more optimum photoperiod that DS crop, which is reflected in their final yield. In term of average temperature for ERS and DS crops, it is not significantly different of average temperatures during ERS and DS with the number of 29.4 (±1.0) and 29.3 (±2.2)^{o}C, respectively. However, standard deviation of the average temperature in DS is greater than in ERS.

It indicates that the range of temperature in the DS is greater than in the ERS. The minimum and maximum temperatures during the DS are 24.0 and 33.4^{o}C compared to 24.9 and 31.4^{o}C during the ERS crop. Therefore, temperature during the ERS crop is more suitable for the FDR production as compared to the FDR production during the DS. The estimation of PAR use efficiency and aboveground biomass of rice plant range from 0.75 to 2.46 g MJ^{-1} depending on variety and development phase (Brigitte *et al.*, 1991). The differences of growth duration of the same variety in the ERS and the DS are absolutely affected by environmental factors. The recorded maximum and minimum temperature, precipitation and calculated solar radiation (based on maximum and minimum temperature) indicate that there is a slightly higher maximum temperature and solar radiation of the DS than of the ERS. Matsui *et al.* (1997) reported that high temperature during flowering stage resulted in increased pollen sterility and thereby reduced grain yield. In addition, there is much higher precipitation of the ERS (1,272 mm.) than of the DS (106 mm.). It means that there is more cloud affecting on solar radiation in the ERS (2,507 MJ m^{-2}) production than in the DS (2,825 MJ m^{-2}) (Frouin and Pinker, 1995).

Fertilizer management

The research reveals that there is no interaction between fertilizer managements and rice varieties; therefore they independently affect growth and yield of FDR production in DWR area. For transition from DWR to FDR production, farmers may apply 59 kg N ha^{-1}, with broadcasting for PSL2 and PTT1 rice variety in ERS and DS production, respectively. The farmer is able to attain the same yield level from the 59 kg N ha^{-1} application rate as compare to the 78 kg N ha^{-1} application rate of farmer practice. Comparison of fertilizer application cost and income increment from three fertilizer management treatments provides advantage in term of income as compared to no fertilizer application treatment. Incremental income from fertilizer application in Table 15 shows that farmer practice; LCC with BC and LCC with DP treatments give 5,900; 5,720; and 8,080 Baht ha^{-1} over no fertilizer application treatment, respectively. Fertilizer cost for farmer application treatment, and two LCC with BC and LCC with DP applications are 4,752 and 3,821 Baht ha^{-1}, respectively. Labor cost for fertilizer application is 312 Baht ha^{-1} for farmer treatment, 250 Bath ha^{-1} for LCC with BC treatment, and 4,375 Baht ha^{-1} for LCC with DP treatment. Consideration of cost increment for fertilizer and labor to make the best decision are, 1) the farmer application treatment applies higher fertilizer input than other two fertilizer treatments, 2) LCC with BC and LCC with DP is the same fertilizer application rate, and 3) DP application technique is higher labor cost than BC technique. Moreover LCC with BC could save 19 and 8 kg of N and P_2O_5 ha^{-1}, respectively, without affecting on yield compared to farmer practicing. The LCC with DP treatment is much higher cost of labor to insert chemical nitrogen mud balls into rice root zone than traditional broadcasting method. However, higher fertilizer efficiency of LCC with DP technique is challenge to develop a machine for this high efficiency of N fertilizer application. The research indicates that three to four times of traditional broadcasting cost for fertilizer DP is acceptable for FDR production system in DWR area. This is a challenge for technician to develop machine designed to insert chemical fertilizer into rice root zone.

4.4 CSM-CERES-Rice model calibration using GENCALC and GLUE estimators for FDR production in the deepwater area

4.4.1 Genetic coefficients of FDR variety

Genetic coefficients of three FDR rice varieties calculated by GENCALC and GLUE estimators are Chai Nat 1, Pathum Thani 1 and Pitsanulok 2. Phenology and growth genetic coefficients are calculated using 2009 experimental data set. Rice phenology coefficients are P1, P2O, P2R and P5, while rice growth coefficients labeled G1, G2, G3 and G4 (Table 15). Genetic coefficients of the same rice variety calculated by GENCALC and GLUE estimators differ in both development and growth coefficients. P1 coefficient values calculated by GENCALC are higher than those calculated by GLUE; while P2R coefficients from GLUE are higher than GENCALC. Likewise, G3 coefficients from GENCALC are higher than GLUE, but G4 coefficient from GLUE are higher than GENCALC (Table 16). However, these two different coefficients for each rice variety give similar outputs of development and growth against the observed values of FDR in deepwater area. The main reason of different of phenology and growth genetic coefficients calculated by GENCALC and GLUE is that the two GC estimators use different algorithms, GENCALC uses a stepwise method and GLUE uses a random process.

Table 15 Rice cultivar coefficients in CSM-CERES-Rice model

Abbreviation	*Definition*	*Unit*
Phenology coefficients		
P1	Time period in ^{o}C above a base temperature of 9^{o}C from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.	GDD (Growing Degree Days)
P2R	Extent to which phasic development leading to panicle initiation is delayed for each hour increase in photoperiod above P2O.	GDD
P2O	Critical photoperiod or the longest day length at which the development occurs at a maximum rate. At values higher than P2O developmental rate is slowed, hence there is delay due to longer day length.	h (hour)
P5	Time period from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9^{o}C.	GDD
Growth coefficients		
G1	Potential spikelet number as estimated from the number of spikelets per g of the main culm dry weight (less lead blades and sheaths plus spikes) at anthesis. A typical value is 55.	Number of spikelets per g of main culm
G2	Single grain weight under ideal growing conditions, i.e. nonlimiting light, water, nutrients, and absence of pests and diseases.	g (gram)
G3	Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.	-
G4	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0.	-

Source: Hoogenboom *et al.*, 1999

Table 16 Genetic Coefficients (GC) of three FDR varieties calculated by using GENCALC and GLUE estimators under different planting dates of FDR production in DWR area, Prachin Buri, Thailand. 2009.

Estimator	*Variety*	*Phenology coefficient*				*Growth coefficient*			
		P1	P2R	P5	P2O	G1	G2	G3	G4
GENCALC	CNT1	742.6	25.0	445.5	11.74	37.06	0.0278	1.00	1.00
	PTT1	769.0	28.7	414.7	12.07	37.67	0.0266	1.00	1.00
	PSL2	712.2	23.5	422.8	11.90	40.38	0.0267	1.00	0.90
GLUE	CNT1	465.5	161.2	400.6	12.67	64.67	0.0270	0.346	1.25
	PTT1	561.2	41.16	374.3	11.80	74.83	0.0250	0.510	1.25
	PSL2	320.3	187.4	426.4	12.33	55.33	0.0260	0.425	1.25

4.4.2 Phenology, growth and yield simulation

Phenology simulation

Two critical developmental phases of FDR to compare with observed data are anthesis day and maturity day after transplanting. Anthesis date or flowering date in the CSM-CERES-Rice model is defined as the timing when 50% of spikelets of the rice crop are fully opened. The overall average observations of developmental phase across varieties and planting dates are 63 and 93 days after transplanting for anthesis day and maturity day, respectively. The simulated outputs for anthesis and maturity day are 64 and 93 days after planting by GENCALC and 63 and 93 days after planting by GLUE GC estimator, respectively. RMSEn values are 3.97 and 3.67 for anthesis and maturity dates by GENCALC, 3.67 and 2.50 for anthesis and maturity dates by GLUE GC estimator, respectively. Both simulation results are considered satisfactory (RMSEn < 10) compared to the observed data (Table 17). Growth durations from transplanting to harvest are all the same at 93 days for simulation by using GENCALC and GLUE GC estimators.

Table 17 GENCALC and GLUE comparison against observation values of flooding rice production in deepwater area, Prachin Buri, Thailand 2009

Variables	*Observation*	*Mean*		*RMSE*		*RMSEn*		*d-Stat*	
		GENCALC	GLUE	GENCALC	GLUE	GENCALC	GLUE	GENCALC	GLUE
Anthesis (day)	63	64	63	2.50	2.31	3.97	3.67	0.74	0.79
Maturity (day)	93	93	93	3.42	3.33	3.67	2.50	0.50	0.66
Grain weight (g)	0.027	0.027	0.027	0.001	0.001	3.68	3.68	0.71	0.81
Grain number m^{-2}	13,743	13,957	12,954	1,139.22	1,426.58	8.29	10.38	0.63	0.47
Yield (kg ha^{-1})	3,729	3,769	3,532	320.00	372.05	8.57	9.98	0.47	0.33
Top weight (kg ha^{-1})	8,512	11,727	11,544	3,264.15	3,084.68	38.35	36.24	0.22	0.22
Leaf N (%)	1.56	1.69	1.67	0.56	0.47	35.87	29.95	0.94	0.96

Yield components and gain yield simulation

Three yield component variables are used to make comparison between the two GC estimators against observed data, namely; grain weight, grain number per square meter and top weight or above ground biomass. The grain weights are precisely simulated as compared with the observed values. The overall average single grain weight is 0.027 gram per grain (RMSEn = 3.68) for both GENCALC and GLUE which is the same as observed value. Rice single grain weight is known to be a constant value for a majority of rice, especially indica type (Gravois, 1992).

Observed grain number per square meter is 13,743 while GENCALC and GLUE GC outputs are 13,957 and 12,945, with RMSEn of 8.29 and 10.38, respectively (Table 17). GENCALC give a better estimate of grain number per square meter than GLUE due to its stepwise method as mentioned earlier. The observed grain yield is 3,729 kg ha^{-1} compared to 3,769 and 3,532 kg ha^{-1} from GENCALC GC and GLUE GC, respectively. GENCALC GC seems to be better than GLUE in term of grain yield simulation. In addition, leaf N (%) is simulated with a high agreement index (d-Stat), high correlation value (r^2) and high RMSEn values (Table 17 and Figure 18). However, there are more than 3 tons of above ground biomass overestimated by both GENCALC and GLUE GC (Table 18).

Comparison of anthesis day, maturity day, grain number grain weight, grain yield and above ground biomass, using genetic coefficients estimated by GENCALC and GLUE GC estimators, indicate that there are not significantly different between the two simulations outputs. However, simulated grain number and simulated grain yield by using GLUE GC are lower than observed and simulated values by using

GENCALC GC. Simulated above ground biomass of all three varieties is overestimated and significantly different with observed values (Figure 17).

4.4.3 Discussions

Rice genetic coefficients are separated into two groups, namely; phenology coefficients and growth coefficients. The most important rice GC affecting both phenology and growth coefficient is G4 coefficient. The procedure in GENCALC GC calculation did not calibrate for G4 coefficient (Figure 8). This is difficult for GLUE GC estimation to obtain a proper set of rice coefficients due to it run automatically by random process within defined range (He *et al.* 2008; Jing *et al.* 2010) for all phenology and growth genetic coefficients. A solution to this problem is that one has to provide the Maximum, Minimum and Flag values of G4 coefficient in the "Parameter Property" file in DSSAT45\Tools\GLUE\ directory, which is set to 1, 1 and 0, respectively. Then run GLUE estimator and change the G4 coefficient value manually in the RICER045.CUL cultivar file in DSSAT45\Genotype\ directory, until getting the best G4 coefficient value (the best fit between observed and simulated values). Finally GLUE program can be used to run normally to estimate the best set of GC.

The advantage of GENCALC estimator is less time consuming compare to GLUE estimator. The disadvantage is that the user's skill is needed and the calculation of GC based on manual operation, step-by-step from P1 to G3 coefficient, until obtaining the best GC with the minimum error comparing with observed the values. The GLUE estimator run automatically with time consuming depending on the number of experiments and treatments input and G4 has to be defined manually and fixed for obtaining the best GC.

Simulated above ground biomass (including stem and leaf biomass) and tiller number per area (372-675 tillers per square meter) outputs by both GCs are overestimated (Figure 17). User has to be very careful for interpretation of this simulation output. However anthesis date, maturity date, grain weight, grain yield (Figure 18) and leaf N (%) simulation outputs using GENCALC GC are not significant different and produce good agreement when compared with observed values (Figure 19).

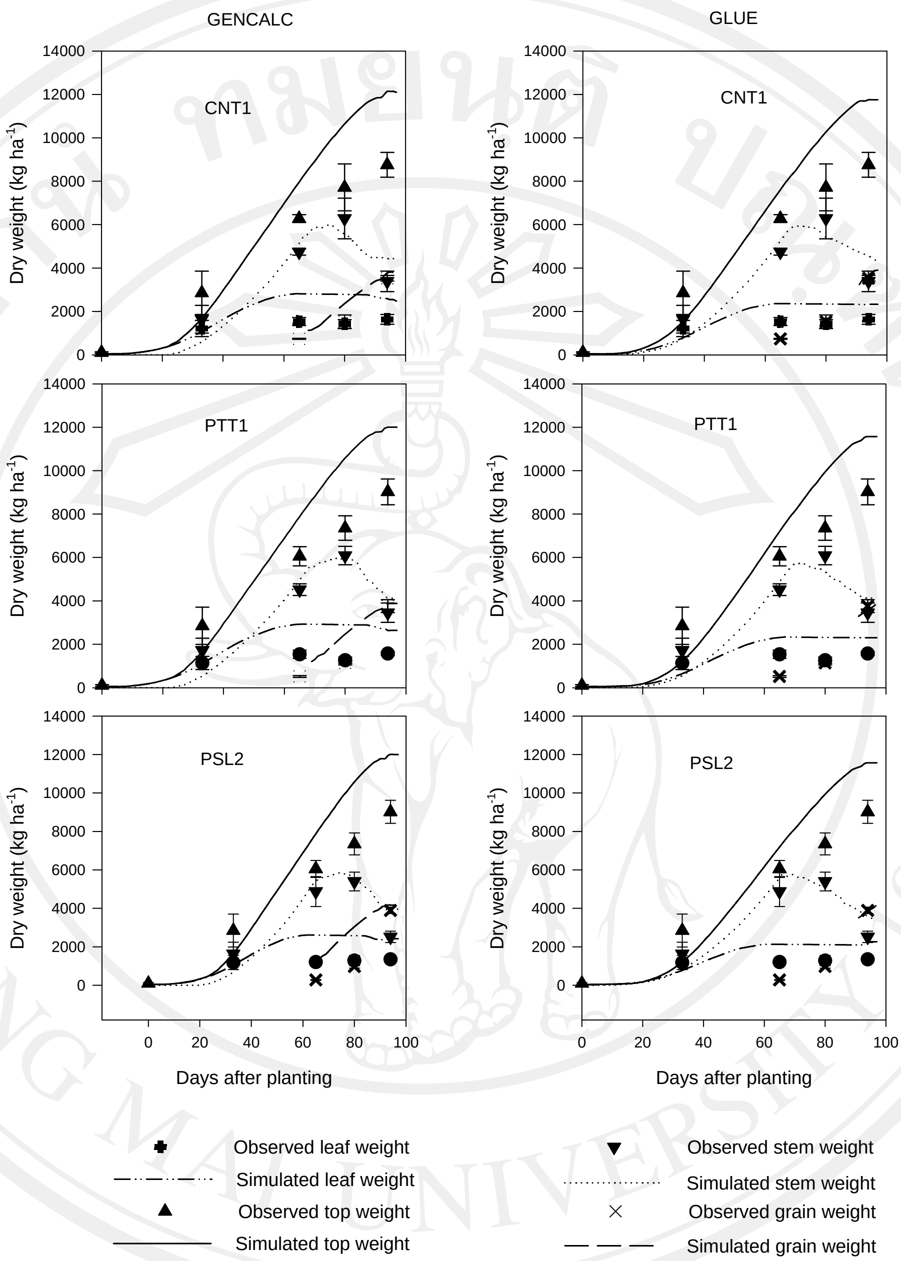

Figure 17. Observed and simulated stem weight, leaf weight, above ground biomass, and grain weight of Chai Nat 1 (CNT1), Pathum Thani 1 (PTT1) and Pitsanulok 2 (PSL2) from four planting dates (PD1:Jun 19, PD2: Jul 2, PD3:Jul 16 and PD4: Jul 23) using genetic coefficients estimated by GENCALC and GLUE estimators, Prachin Buri Thailand. 2009.

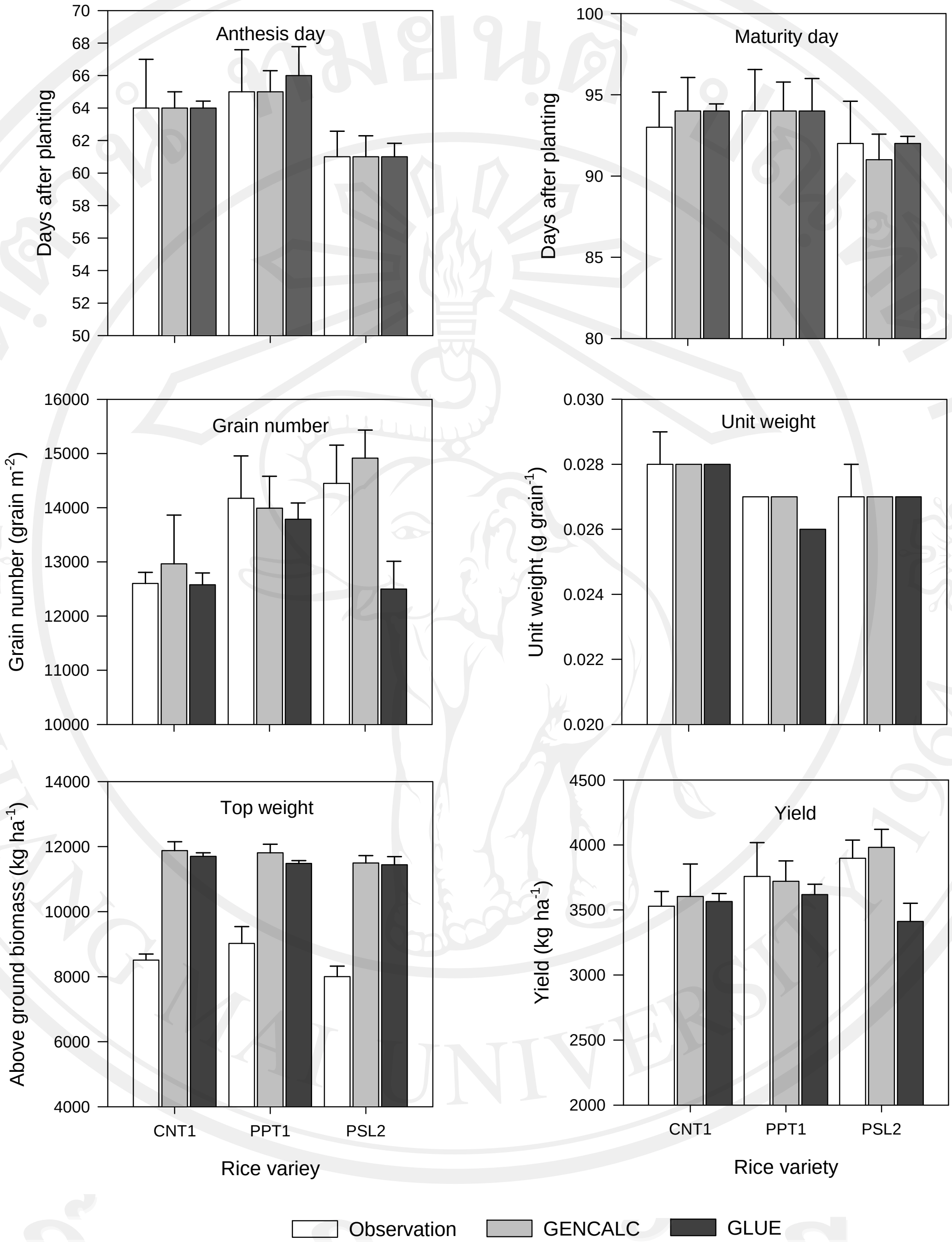

Figure 18 Observed and simulated anthesis day, maturity day, grain number, unit weight (grain weight: gram/grain), top weight and yield of Chai Nat 1 (CNT1), Pathum Thani 1 (PTT1) and Pitsanulok 2 (PSL2) from four planting dates (PD1:Jun 19, PD2: Jul 2, PD3:Jul 16 and PD4: Jul 23) using genetic coefficients estimated by GENCALC and GLUE estimators, Prachin Buri Thailand. 2009.

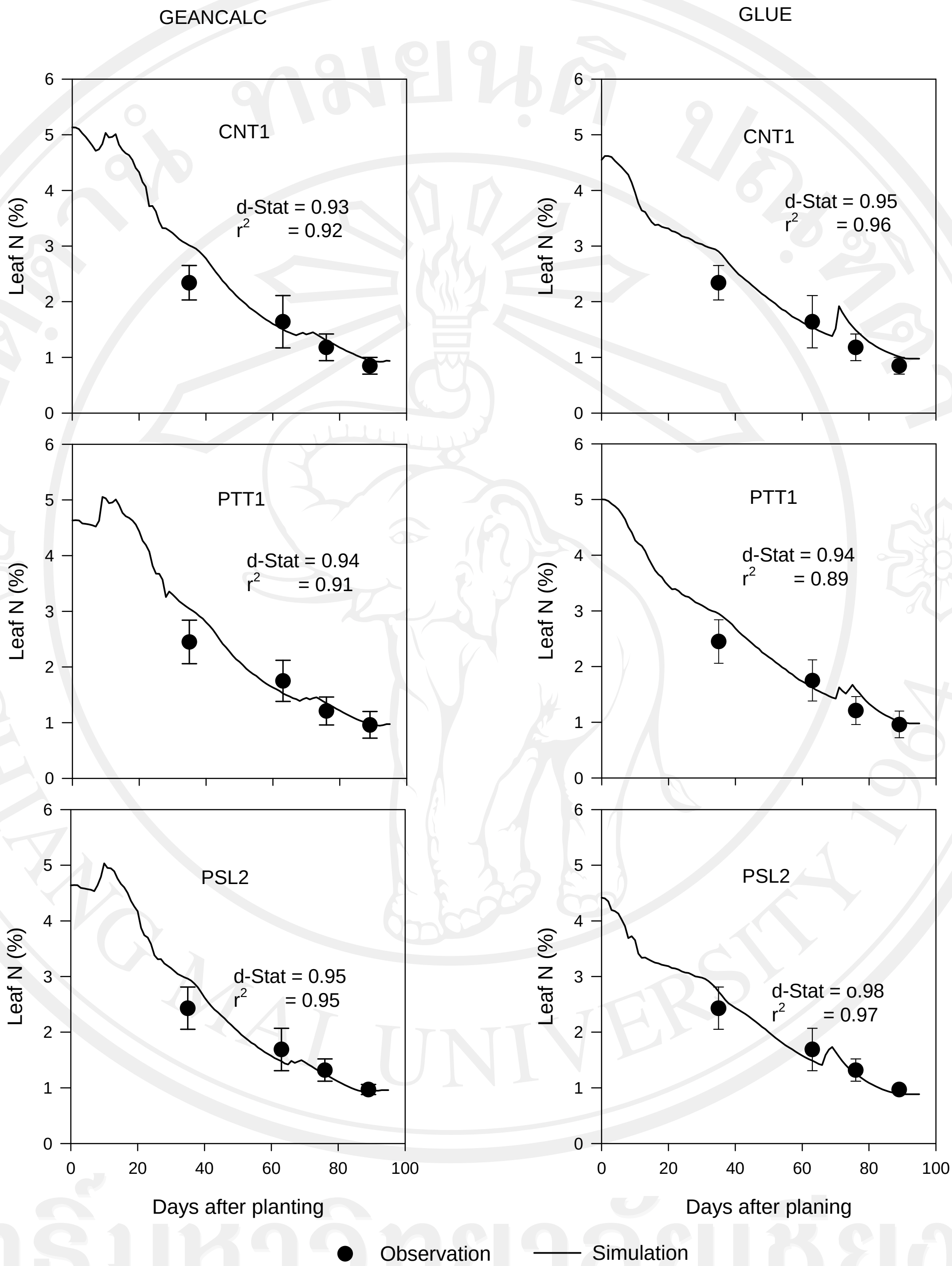

Figure 19 Observed and simulated leaf nitrogen (%) of Chai Nat 1 (CNT1), Pathum Thani 1 (PTT1) and Pitsanulok 2 (PSL2) from four planting dates (PD1:Jun 19, PD2: Jul 2, PD3:Jul 16 and PD4: Jul 23) using genetic coefficients estimated by GENCALC and GLUE estimators, Prachin Buri Thailand. 2009.

4.5 The evaluation of CSM-CERES-Rice model

This section provides results of the evaluation of the CSM-CERES-Rice model under DSSAT version 4.5 package. The evaluation use a set of genetic coefficients estimated by GENCALC GC estimator since they provide satisfactory results when compared with the observed values of FDR production systems in deepwater area in Prachin Buri province, Thailand. The evaluation results present in this section are rice developmental phase, yield components, grain yield, and percent leaf nitrogen.

4.5.1 Development phases

The average and SD of the observed anthesis day after planting of three FDR varieties is 59 (±5) days while the simulated value is 63 (±2) days, which is not significantly different. The RMSE and RMSEn for anthesis day comparison are 7 and 13, respectively, and a d-Stat value is 0.40. Likewise, the average of observed maturity day after planting is 84 (±5) days compared with the simulated value of 91 (±3) days, which is also not significantly different. The RMSE and RMSEn for maturity day comparison are 8.79 and 10.37, respectively, and a d-Stat value is 0.41 (Table 18). The precision of the model in predicting of the anthesis and maturity dates for FDR production in DWR area is satisfactory.

4.5.2 Growth of rice plant

Grain weight and grain number per square meter simulation outputs are evaluated. Simulation of grain weight is the same as observed data. The average and SD of grain weight is 0.027 (±0) g per grain. The RMSE and RMSEn for grain weight comparison is 0.001 and 3.89, respectively, and a d-Stat is 0.61. The average and SD of observed grain number per square meter is 14,472 (±1,487) while simulated grain numbers per square meter is 13,666 (±1,869). The RMSE and RMSEn for grain number per square meter comparison is 2,045 and 1,413, respectively, with a d-Stat of 0.56 (Table 18). The precision between simulations and observations of grain weight is good, while the precision between simulations and observations of grain number per square meter of FDR production in DWR area is satisfactory.

Table 18 Statistics of model evaluation by using coefficients from GENCALC GC estimator application on FDR production in deepwater area, Prachin Buri, Thailand 2009 – 2010

Variables	*Observation*		*Simulation*		*RMSE*	*RMSEn*	*d-Stat*	*n*
	Mean	SD	Mean	SD				
Anthesis day	59	5	63	2	7.39	12.55	0.40	24
Maturity day	84	5	91	3	8.79	10.37	0.41	24
Grain weight (g)	0.027	0	0.027	0	0.001	3.89	0.61	24
Grain number m^{-2}	14,472	1,487	13,666	1,869	2,045	14.13	0.56	15
Top weight (kg ha^{-1})	8,617	764	11,195	1,337	2,714	31.50	0.38	15
Yield (kg ha^{-1})	3,871	451	3,658	530	571	14.75	0.59	15
Leaf N (%)	1.54	0.81	1.66	0.79	0.19	12.54	0.98	12

The averaged of observed and simulated top weight biomass are also compared to evaluate the CSM-CERES-Rice model. Top weight biomasses are sampled from five developmental stages, including seedling stage, panicle initiation, flowering, milky, and harvesting stage of FDR. The average observed of top weight biomass of FDR production under deepwater area is 8,617 (±764) kg ha^{-1}, while the average simulated top weight biomass output is 11,195 (±1,337) kg ha^{-1}. The simulated top weight biomass is higher than the observed values, particularly leaf biomass (Figure 20). The standard deviations of observed and simulated values of top weight biomass revealed that there is no significant between observed leaf N and simulated leaf N value. However, simulated values top weight biomass of three FDR varieties is higher than observed values. The RMSE and RMSEn for FDR top weight biomass comparison is 2,714 and 31.50, respectively, with a d-Stat of 0.38 (Table 18). The precision between simulations and observations of top weight biomass under FDR production in DWR area is poor. The lost of decay leaf before taking sample at each developmental stage is a source of error which widen the gap between observed and simulated values.

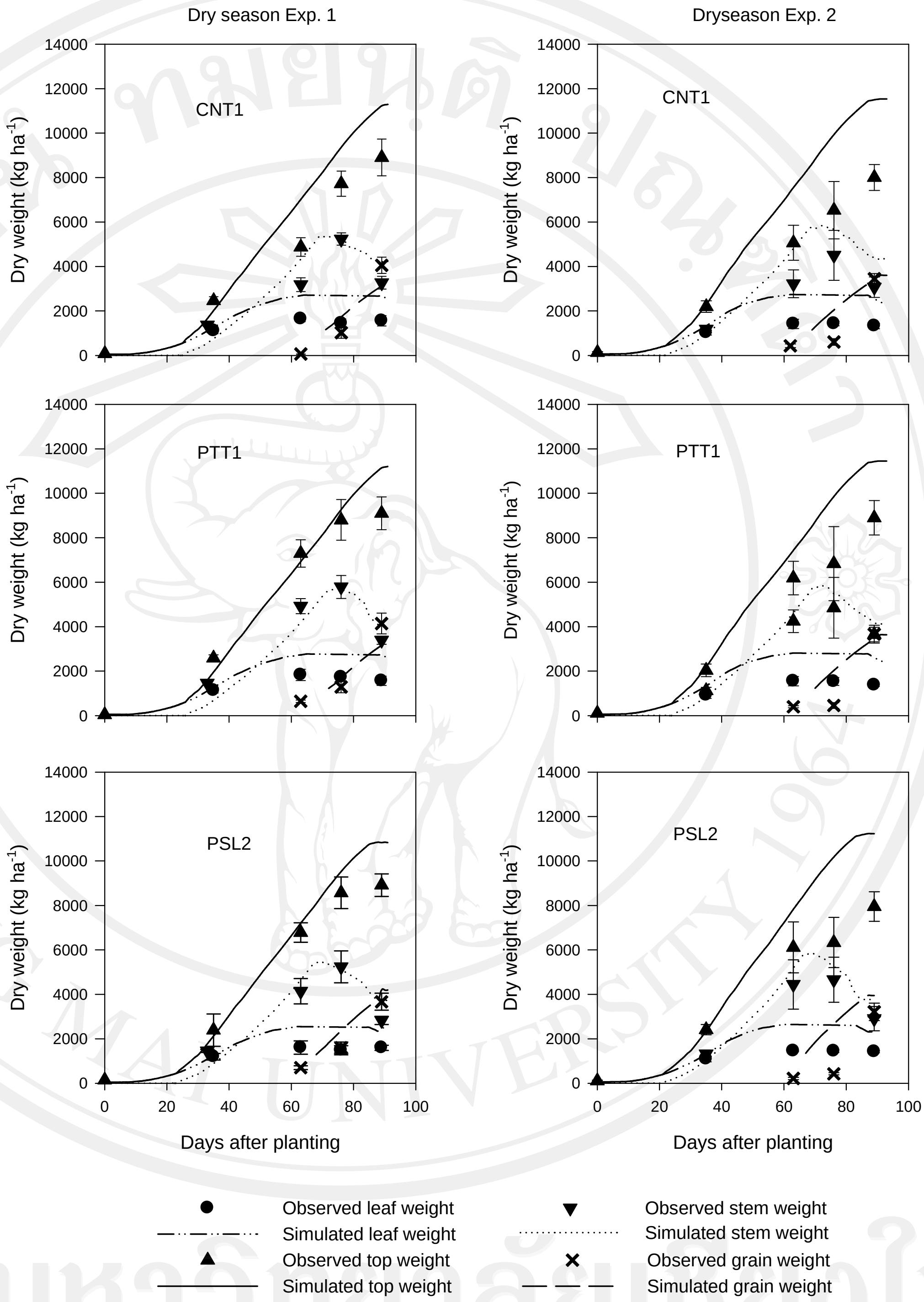

Figure 20 Comparison between observed and simulated biomass of three rice varieties under planting date and fertilizer management experiment, Prachin Buri, Thailand, 2010.

4.5.3 Grain yield

Rice grain yield is the ultimate output of rice production systems. The average and SD of observed yield of the FDR production in the deepwater area is 3,871 (±451) kg ha^{-1}, while the average simulated yield output is 3,658 (±530) kg ha^{-1}. The standard deviations of observed and simulated value revealed that there is no significant between observed yield and simulated grain yield values. The RMSE and RMSEn for FDR yield comparison is 571 and 14.75, respectively, with a d-Stat of 0.59 (Table 18). The precision between simulations and observations of grain yield under FDR production in DWR area is satisfactory.

4.5.4 Leaf N

The averaged and SD of observed and simulated leaf N values are compared to evaluate the CERES-Rice model. Four rice development stages including panicle initiation, flowering, milky, and harvest stage of FDR leaves are sampled and analyzed. The average observed leaf N of FDR production under deepwater area is 1.58% (±0.81), while the average simulated leaf N output is 1.66% (±0.79). The standards deviations of observed and simulated value revealed that there is no significant between observed leaf N and simulated leaf N value. The RMSE and RMSEn for FDR leaf N comparison is 0.19 and 12.54, respectively with d-Stat of 0.98 (Table 18). The precision between simulations and observations of leaf N under FDR production in DWR area is good. In addition, there are high correlation (r^2) and high agreement index (d-Stat) between observed and simulated of leaf N data of three FDR varieties (Figure 21)

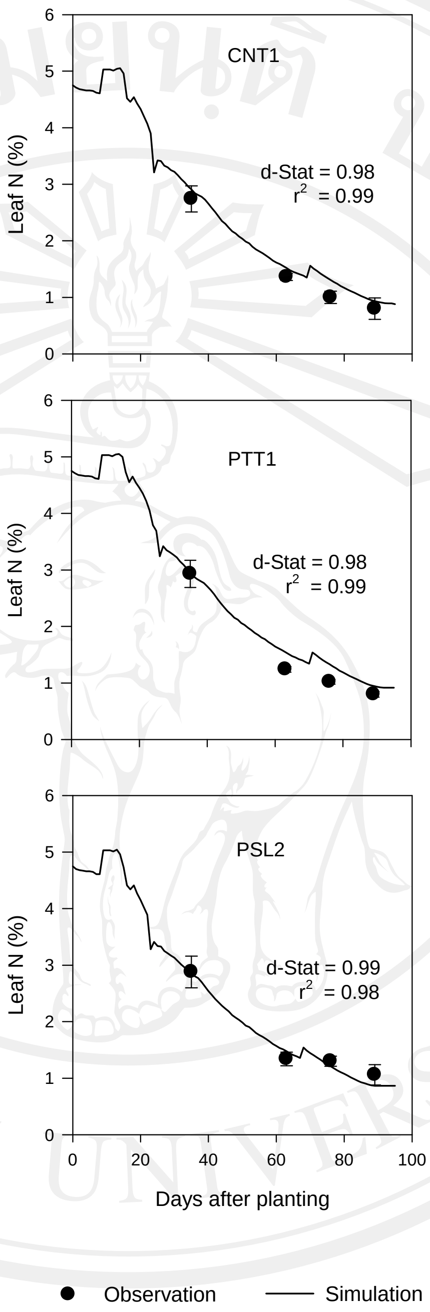

Figure 21 Comparison of observed and simulated leaf nitrogen (% Nitrogen in leaf) of Chai Nat 1 (CNT1), Pathum Thani 1 (PTT1) and Pitsanulok 2 (PSL2) rice varieties under FDR production in DWR, Prachin Buri, Thailand. 2009

4.5.5 Discussion

Evaluation of CSM-CERES-Rice model under FDR production system in deepwater area reveals that RMSEn values range from 3.98% to 31.50% for all evaluated parameters. The RMSEn of anthesis and maturity dates are 12.55% and 10.37%, respectively. Timsina and Humphreys (2006) reported that RMSEn of anthesis and maturity dates are 4-7% and 2-5%, respectively. However, a research conducted in Thailand concluded that the number of days from planting to physiological maturity is overestimated by 9–12 days (Tongyai, 1994). The maturity day of FDR in this research is overestimated by 7 days. The RMSEn of top weight biomass from previous report ranged from 13 to 33% (Bouman and Laar, 2006; Jing *et al*., 2010; Timsina and Humphreys, 2006) compared to 31.5% of top weight biomass simulation in this research. The d-Stat ranges from 0.38 to 0.98. It indicates that the agreement between observed top weight biomass and simulated top weight biomass is not satisfied, while the agreement between observed percentage of leaf N concentration and simulated percentage of leaf N concentration is satisfied. One reason of over-estimated top weight biomass is due to the fact that there is the decay of the old leaves in the field condition occurring before biomass sampling date on each developmental stage. The grain yield's RMSEn of FDR simulation evaluation in deepwater area is 14.75% which is acceptable and is in range of the previous report of 3 to 37% (Jiang and Zhi-qing, 2009; Timsina and Humphreys, 2006). The CSM-CERES-Rice model provides good estimates of leaf N concentration in FDR production systems. The RMSEn of leaf N concentration is 12.54% compared to 26% of N uptake in the previous study (Jing *et al*., 2010). Overall evaluations indicate that CSM-CERES-Rice model can be used to simulate FDR production systems in deepwater areas. Simulated output of development, growth, grain yield and leaf N concentration is acceptable compared to field recorded values. However, simulated top weight biomass is overestimated compared to observed data.

The results of model evaluation are the witnesses that the CSM-CERES-Rice model can be use to estimate FDR production system in the DWR area. The effects of environmental factors e.g. soil fertility, weather and the management practicing can be assessed before making decision. The model can be used to assess the effects of heterogenesis both chemical and physical of soil property on FDR yield. The amount and distribution of rainfall including air temperature pattern during the growing season in any specific location of deepwater area can also be defined their effects. Therefore anywhere of DWR area can be evaluated in term of environmental effects before transformed into FDR. The management practices for FDR production e.g. fertilizer application in term of amount and mode of application can be formulated prior to application. Another factor is flooded rice variety. There is a few GC of Thai rice included in the CSM-CERES-Rice model, RD7 and RD23 (calibrated by Jintrawet, 1985). Calibration of rice GC might be needed prior to application the model for difference rice characteristics, e.g., growth duration and grain weight. In term of FDR production, the model can be used to evaluate the effect of soil, weather, variety and management practices on yield and formulating the appropriate alternatives management base on specific set of input prior to making decision.

In addition, limitation of CSM-CERES-Rice Model application is daily weather data for specific site of simulation. The distance from simulation site to weather station and quality of weather data may affects on the precision of simulation. Solar radiation data is one of limitation. Most of weather stations in Thailand have no sensor to record solar radiation data. It has to be calculated based on minimum and maximum temperature. For the best quality of input data for model simulation, collaboration of modeler, agronomist, soil expert and meteorologist is an important factor.

4.6 The alternative management practices for FDR production and adoption possibility of farmer

There are three recommended managements for FDR production formulated by this research. The first recommendation is suggested FDR variety for ERS and DS, the second recommendation is suitable planting date and the third recommendation is appropriate chemical fertilizer management. There are three selected FDR variety to evaluate the suitability in the area. The research recommended that PSL2 is appropriate for growing in ERS, while PTT1 is suitable for growing in both ERS and DS. For the second recommendation, the farmer should start to grow ERS and DS crop of FDR production in early May and early November, respectively. The last recommendation is fertilizer management. The usage of LCC technique to estimate N requirement of FDR with application mode of broadcasting is the best alternative for FDR production. The average yield is not significant difference from the over dose fertilizer application of farmers' practicing.

In addition, these recommendations are tested to evaluate the possibility of implement in the area. A group of seventeen farm households from five Tambons is interviewed including farmers from Tambon Bansang, Bang Krabao, Bang Teoi, of Bansang district, Dong Kratong Yarm of Muang district, Prachin Buri province and farmers from Tambon Sri Jula of Muang district, Nakorn Nayok province. The average of their farm size is six ha per household. The results of interview are as follows;

4.6.1 Variety

The farmers tend to eject PTT1 and CNT1 rice varieties by 56% and 64%, respectively. Disadvantage of these two varieties are lodging, long growth duration (from farmers' point of view), and susceptible to diseases. However, 55% of the interviewed farmers tend to adopt PSL2 rice variety, due to shorter stem and resistant to lodging as compared to the other two varieties. The farmers who tend to eject this variety indicate that it is not resistant to cold weather especially in dry season production period (November to February or to March). The expected characteristics of FDR variety for planting in the deepwater area are short growth duration, resistant to insect pests and diseases, resistant to lodging and certainty giving a high yield.

4.6.2 Planting date

Most of the interviewed farmers (63%) agree with planting date of ERS with the range from May to July. The main reasons are ample supply of irrigation water and rice can be harvested before flooding. All interviewed farmers tende to adopt the planting date of DS in November for FDR production. They said that they started to grow FDR as soon as possible after receding of flood water in the field.

4.6.3 Fertilizer application

The best alternative as a result from this research for fertilizer management is to split applications, one at the vegetative phase (30 kg N ha^{-1}) and at the PI stage (29 kg N ha^{-1}), with the total nitrogen rate of 59 kg ha^{-1}. The suitable application mode is broadcasting. The group interview shows that 80% of farmers agree with this recommendation. They mention that it makes rice plant strive well throughout the growing season. Some of farmers are interested in this fertilizer management technique and intend to conduct a trial-and-error experiment in their own field.