CHAPTER 5
PURPLE GLUTINOUS RICE MODEL

Abstract

The purple glutinous rice model was developed using ORYZA0 model as a base model. The model is simple mechanistic model based on physiological process. The model utilized solar radiation as a driven variable for determining rice growth rate which in turn estimates biomass accumulation and grain yield. Nitrogen sub model was built into the model thus allowed user to explore the effect of nitrogen management of growth and yield of rice. The model also includes phenology sub model which is used to estimate the flowering and maturity date. Simulation of dynamic of total phenolic content in leave, steam and grain was also integrated into the model.

Comparing simulated and observed biomass and yield of 5 varieties of purple glutinous rice planted on 9 August and 1 September 2008, the results display the ability of model to mimic behavior of growth reasonably. However, grain yield was underestimated for August planting and overestimated for September planting. Depending on variety, the difference between simulated and observed grain yield was between 118-1149 kg/ha. The model utilized quadratic function to simulate the dynamic of leave and stem total phenolic content and used 3rd order polynomial function to simulate the dynamic of rice grain total phenolic. Phenolic content was satisfactory simulated. However, the simulated phenolic content can be explained only as a function of growth period.

Even though the model is simple in which it used solar radiation as a driven variable and accumulation of growing degree days with day length to determine flowering and maturity dates but it has ability to simulate growth (biomass accumulation), grain yield, leave nitrogen and total nitrogen in rice plant. With available additional crop data, the model could be further improved so that it can

simulate yield of specific variety as well as simulate dynamic of total phenolic content as a function of related variables such as nitrogen.

5.1 Introduction

Purple glutinous rice is commonly known as "Kao Kum" or black sticky rice, generally grown in the North and North eastern part of Thailand. There are many purple glutinous rice varieties in which differences among varieties can be seen from their phenotype. Even though purple glutinous rice varieties are differ in their stem and leaf color. Their grain has similar color which is dark purple color. The dark purple color of brown rice is primarily due to its high in mixture of anthocyanins content which located in the aleurone layer (Hu *et al*., 2003). The purple glutinous rice is becoming popular among those who concern on healthy food product due to its sweet flavor and high in antioxidant content in grain. However the production area is decreasing. This is because grain yield per area of purple glutinous rice is quite low due to it contains characteristics of native rice and photo period sensitive. Thus rice growers prefer growing high yielding variety that could create higher income.

It was found that purple glutinous rice has potential of producing high yield under optimal management condition (Khempet, 2011). Among 24 varieties study their yield range between 1.4 – 4.7 t/ha. Normally crop growth and yield reflected genetic and environment (GxE) interaction. Some varieties could have great yield in certain growing area but produce low yield in the other area. Therefore the ability to predict growth and yield of purple glutinous rice could play an important role in providing information for better management for the rice grower i.e. varietal selection, optimum planting date, plant density and nitrogen management.

Crop simulation models are increasingly being used in agricultural research and development (Wisiol, 1987). A large number of rice model have been developed i.e. CERES-Rice (Singh *et al*., 1993), SIMRIW (Horie *et al*., 1992), ORYZA2000 (Bouman *et al*., 2001), RiceGrow (Tang *et al*., 2009), ORYZA1 (Kropff *et al*., 1994), TRYM (Williams *et al*., 1994), VSM (Kobayashi, 1994), RICAM (Yin and Qi, 1994), RIBHAB (Salam *et al*., 1994) and a rice-weed competition model (Graf *et al.*, 1990). Each of the model has been develop with specific objective and have its own set of underlying assumptions and complexity. The purple glutinous rice model in this study used ORYZA0 model as a core model. This is because the model was readily available and widely-used process model. ORYZA0 is the one of ORYZA models have been developed by the International Rice Research Institute (IRRI) as a part of the SARP program (System Analysis for Rice Production). The ORYZA0 is developed by Berge *et al*. (1996) and used for nitrogen optimization. The model originally constructed using FORTRAN source codes. Schaber (1996) has been translated ORYZA0 FORTRAN source codes to STELLA II 3.0.7 under his FARMSIM: A dynamic model for the simulation of yields, nutrient cycling and resource flows on Philippine small-scale farming systems. The purple glutinous rice model in this study is based on ORYZA0 model but modified the phenology part and used data set from field study in northern part of Thailand. The objectives of this study were to modified and test the performance of the ORYZA0 STELLA based model for purple glutinous rice for direct seeded under upland rainfed condition.

5.2 Material and method

5.2.1 Field experiment and data collection

Field experiment was performed at Multiple Cropping Center, Chiang Mai University. Design of this experiment was split plot with 3 replications. Main plot was two planting dates which were 9 August 2008 and 1 September 2008. Sub plot was five varieties of purple glutinous rice namely MHS1, Samoeng No.3, PGMHS 6, PGMHS 15 and PGMHS 17. Each variety was grown on seedling bed in 2.5 x 5 m. Plant spacing was 0.30 x 0.25 m. Two hills of rice were removed to determine dry matter at each growth stage i.e. seedling, early tillering, active tillering, maximum tillering, booting, heading and physiological maturity stage Yield and yield components were determined under 1 m^2 harvested area. Daily maximum, minimum temperature were recorded using automatic weather data recorder (HOBO Pro series). Daily solar radiation data were obtained from Multiple Cropping Center field experiment. Total phenolic content of leave and stem data obtained from Kuppatarat

(2010) and grain (brown rice) total phenolic content data obtained from Parirakwichit (2010) were used to construct empirical model used in the purple glutinous rice model to simulate the dynamic of phenolic in rice.

5.3 Model description

This study used ORYZA0 written in STELLA language (Schaber, 1996) as a based model structure. The model was modified using STELLA 9.1.4 version. The model utilized solar radiation, temperature and differences in varietal characteristics for phenological, morphological and physiological processes as main factors determining the growth rate of the crop on a specific day. The model simulates daily dry matter production of plant organs and the rate of phenological development. Dry matter production is simulated throughout the growing season by integrating growth rate overtime. Simulated total phenolic content of leave, stem and brown rice grain were used empirical model developed from data of PGMHS 15. Input requirements of the model are daily weather data (radiation, maximum and minimum temperature) planting date, phenological data and nitrogen input. Summary of model structure is shown in figure 5.1.

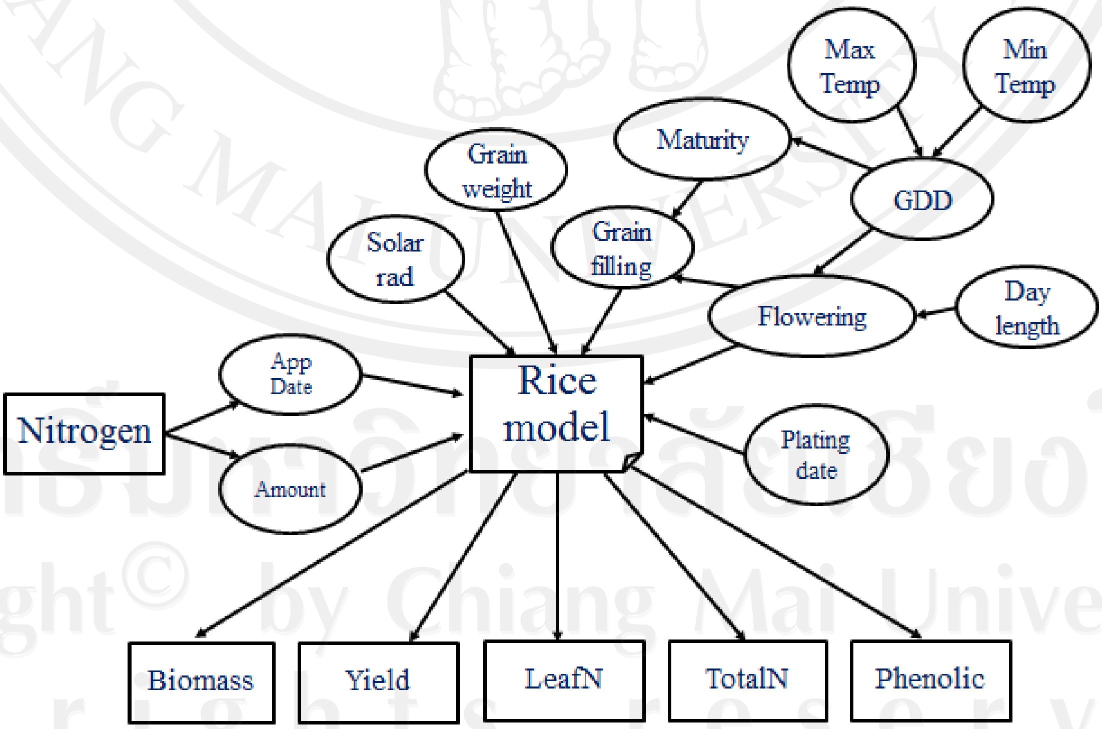


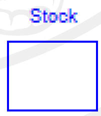
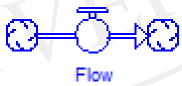
Figure 5.1 Structure of purple glutinous rice model.

STELLA version 9.1.4 was used to construct purple glutinous rice model. STELLA is a program designed to assist users in creating their own simulations using system dynamics. This program uses an iconographic interface to facilitate construction of dynamic system models.

The key features of STELLA consist of the following tools

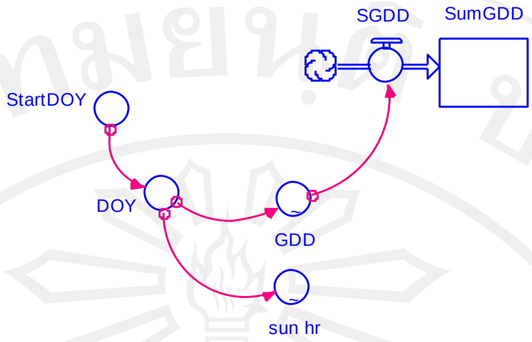
1. Stocks, which are the state variables for accumulations. They collect whatever flows into and out of them.
2. Flows, which are the exchange variables and control the rate of incoming and outgoing materials from state variables.
3. Converters, which are the auxiliary variables. These variable can be represented by constant values or by values depending on other variables, curves or functions of various categories.
4. Connectors, which are to connect among modeling features variables and elements. It show the direction of relationship in a system.

Stock, flow, converter and connector are represent by the following symbols.

Variable	Symbol
Stock	
Flow	
Converter	
Connector	

5.3.1 Planting date and phenology

The following flow diagram represents structure of management in terms of planting date and summation of growing degree days for determination phenological events i.e. flowering date and maturity date.



Planting date is determined by start day of year (StartDOY) set as Julian day. The model calculate duration of plant growth (DOY) using the following equation (1).

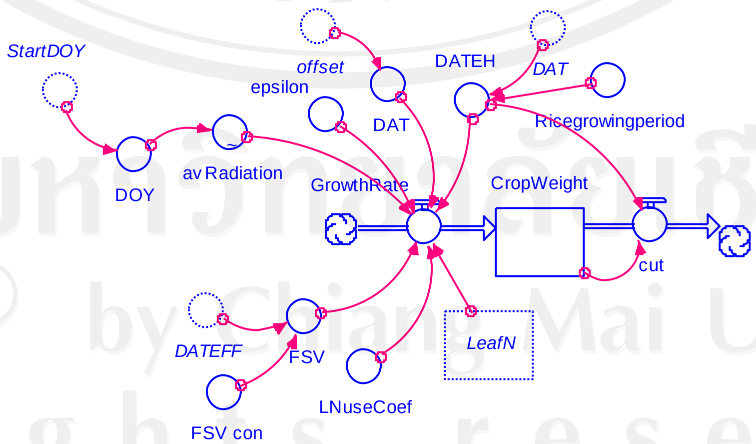
DOY = mod(StartDOY+time,365)+1 ……….(1)

Depending on rice varieties, flowering date (heading) are determined by both accumulated growing degree days (SumGDD) and day length (Sun hr). The maturity date is also determined by accumulated growing degree day imported as data table (Appendix table 2). Equation 2 describes flowering date as control by both accumulated growing degree days (SumGDD) and day length (Sun hr).

JDflower = if SumGDD>ObsGDDF and sun_hr<ObsSunhr then DOY else 0…….(2)

5.3.2 Rice growth

Model growth structure is shown as flow diagram below



Growth rate equation (3) is a function of rice growth calibration parameter (FSV), initial leaf nitrogen used coefficient (LNuseCoef), amount of nitrogen in the rice canopy (LeafN), initial global radiation use coefficient of rice (epsilon) and daily average incident radiation (avRadiation).

GrowthRate=IF(DAT<=0)or(DATEH=1)THEN0 ELSE FSV*LNuseCoef*LeafN*(1-exp(-(epsilon*avRadiation)/(LNuseCoef*LeafN*0.1))) ……….(3)

Growth rate equation starts functioning at planting (Day at transplant; DAT) is greater than 0. Similarly it stopped functioning when harvest (Date of rice harvest; DATEH) is activated (DATEH=1). Note that the model can run both direct seeded and transplanted rice. That is if DAT=0 the model assumed rice is direct seeded. In contrast if DAT is greater than 0, value of DAT refer to transplanting date.

Average incident global radiation data is a solar energy collected daily in MJ/m^2. Epsilon refers to the initial global radiation coefficient which is 2.5 g dry matter/MJ incident global radiation (SARP, 1994). FSV is rice growth calibration parameter in which it was pre-set at 1 prior to flowering. At flowering the FSV value is 0.83. It is site specific calibration factor. LeafN is amount of nitrogen in the rice canopy. Initial leaf nitrogen used coefficient (LNuseCoef) is set at 10 kg DM/kg leaf N. Radiation used in this simulation is the tabulated daily as observed by Multiple Cropping Center weather station in 2008 (Figure 5.2).

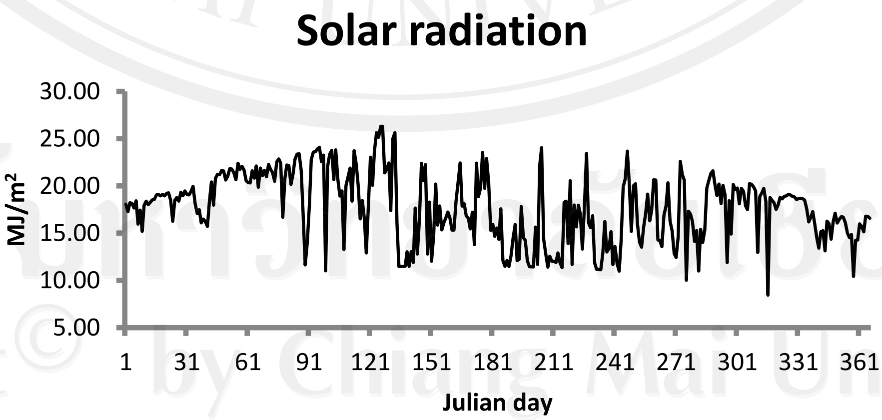


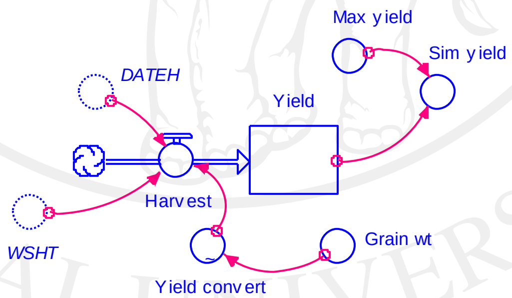
Figure 5.2 Observed solar radiation at Multiple Cropping Center weather station in 2008.

CropWeight (kg DM/ha) is the total crop dry matter weight represented as stock variable as shown in the above flow diagram. The simulated crop weight consists of shoot and root weight. The dynamic of crop weight is calculated by integration of the growth rate (GrowthRate, kg DM/(ha*d)) over time as shown in equation (4)

$$CropWeight(t) = CropWeight(t - dt) + (GrowthRate - cut) * dt \quad \text{.........(4)}$$

The initial value of crop weight is 0 for direct seeded rice but it can be set at seedling weight value if rice is transplanted. CropWeight is accumulated via GrowthRate. Total crop weight become 0 at harvest (CUT).

Grain yield (Yield, kg/ha) is represented by stock variable as shown in below diagram. Grain yield is calculated using yield converter which is a function of 1000-grain weight (Figure 5.3) times total dry matter or shoot weight (WSHT, kg/ha). Since total dry matter (CropWeight) include both root and shoot, shoot weight is calculated as a function of CropWeight and root-shoot ratio (RSR) as shown in equation (5)



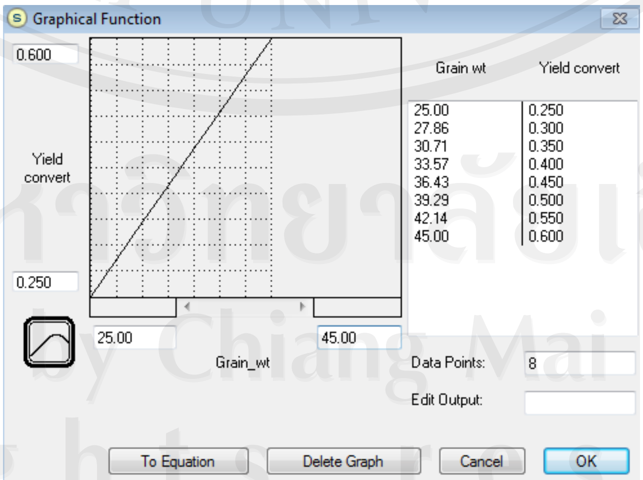


Figure 5.3 Yield converter as a function of 1000-grain weight.

WSHT = CropWeight/(1+RSR) ....(5)

RSR is dynamic during growing period of rice but assumes as constant after flowering. This mean that there was no further root development after flowering. The constant was set at 0.15 but can be changed according to rice variety. The RSR value before flowering is a function of DAT and flowering date as DAT/flowering. Figure 5.4 shown the dynamic of root-shoot ratio as assumed the flowering day is 73 days after planting.

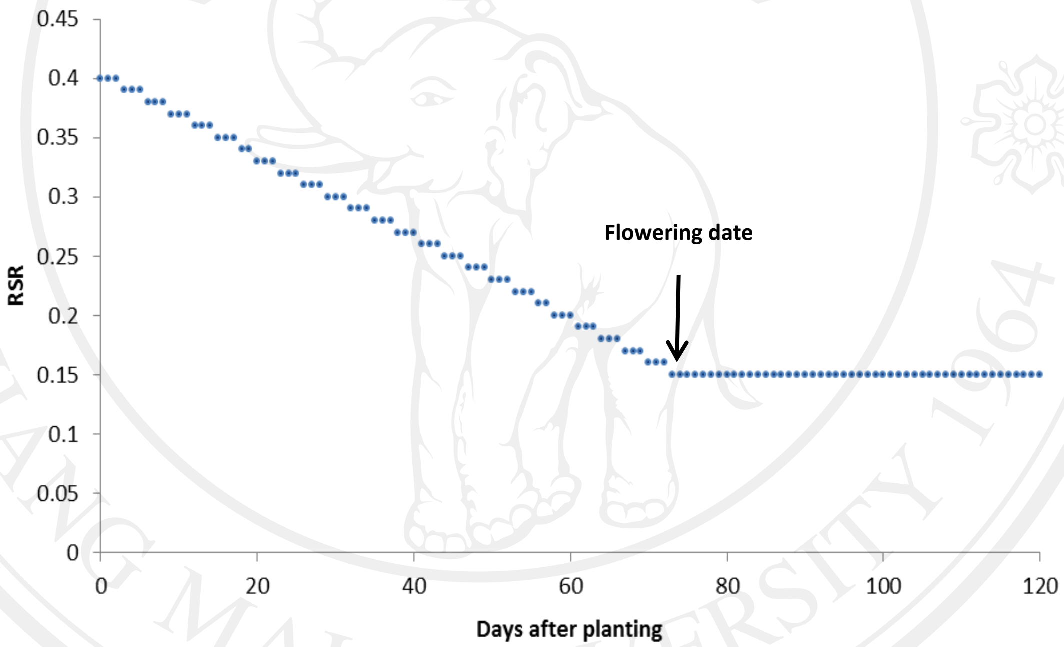
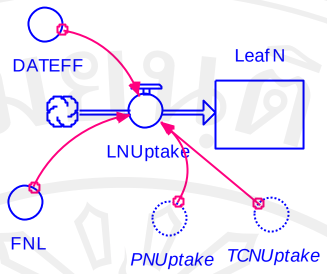


Figure 5.4 Root – shoot ratio (RSR) as a function of growing period.

5.3.3 Nitrogen sub model

The nitrogen sub model consists of leaf nitrogen, total crop nitrogen and panicle nitrogen.

Leaf nitrogen (LeafN, kg/ha) is a stock variable as a function of leaf nitrogen uptake rate (LNUptake, kg/ha*d) as shown in diagram below.



The LNUptake is determined by total crop nitrogen uptake (TCNUptake, kg/ha*d) and panicle nitrogen uptake (PNUptake, kg/ha*d). LNUptake is calculated as 50% of TCNUptake allocated to leaf starting from planting till 7 days prior to flowering. This is because the model assumes that leaf nitrogen is reallocated to panicles 1 week before flowering. Equation (6) describes LNUptake at planting till 7 days before flowering.

LNUptake = TCNUptake*FNL ………(6)

The FNL is a fraction of the total crop nitrogen uptake assumed to be 0.5.

At 7 days before flowering the LNUptake is a function of TCNUptake and PNUptake. LNUptake as calculated in the following equation (7).

LNUptake = FNL*(TCNUptake-PNUptake) ……….(7)

The above equation suggests that LNUptake at this stage is a remaining of TCNUptake when deduct PNUptake.

Total crop nitrogen uptake (TCNUptake) is a rate variable determines dynamic of total crop nitrogen (TotalCropN, kg/ha*d). TCNUptake is a function of nitrogen uptake from rice (NUptake, kgN/(ha*d)) which is determined by available soil nitrogen (NAvail, kgN/ha) and nitrogen demand of rice (NDemand, kgN/(ha*d)). NAvail (Equation 8) is determined by fertilization i.e. nitrogen application rate (NAppl, kgN/(ha*d)) and soil nitrogen supplied (SoilSupply, kgN/(ha*d)).

NAvail = NAppl*Recovery+SoilSupply ……..(8)

The model assumed that only fraction of fertilizer applied (Recovery, g/g) can be uptaken by roots. The maximum recovery fraction is reached around panicle initiation to flowering. The model assumed linear increase of recovery from 0.0 at planting to 0.4-0.7 at panicle initiation and can be reached 0.8 at first flowering stage (7 days prior to flowering). It was linearly decrease to 0.0-0.2 over time span of three weeks (SARP, 1994). Schaber (1996) stated that the dynamic of recovery (Figure 5.5) was an empirical tabulated function of the size of the root system.

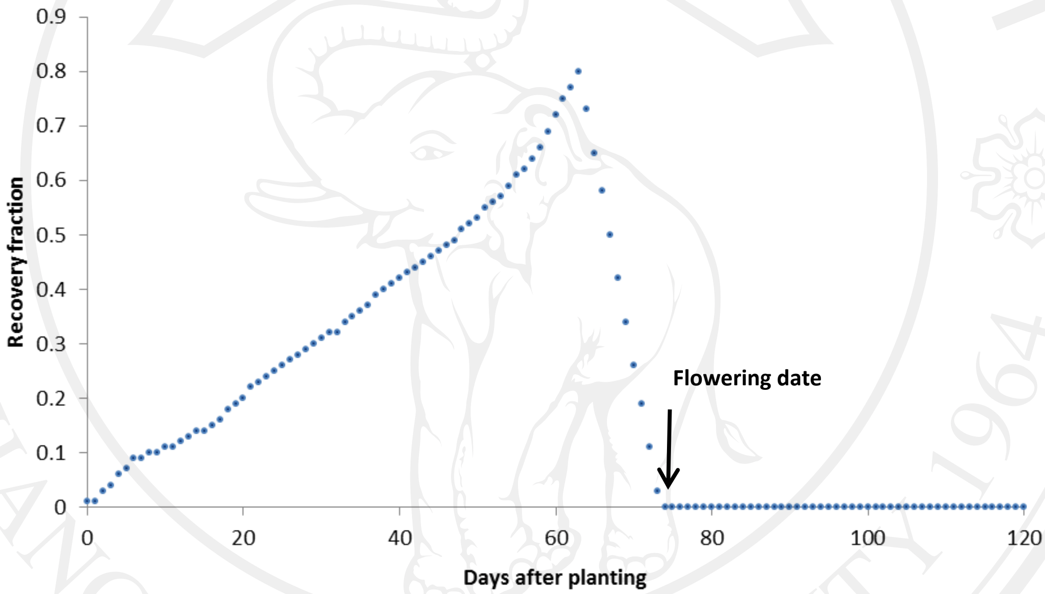
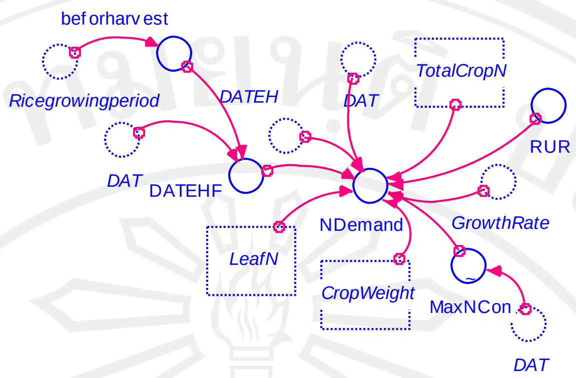


Figure 5.5 Recovery fraction (root nitrogen uptake). Maximum recovery fraction is assumed to be at panicle initiation.

From nitrogen uptake experiment (SARP, 1995), the soil nitrogen supply was estimated as 0.6 kgN/ha*d

Schaber (1996) has modified the nitrogen application rate from ORYZA0 to suit the actual practice of farmer in which nitrogen application rate (NAppl) is set for two time applications.

Nitrogen demand of rice (NDemand) is a empirical/logical function as propose by Schaber (1996) as shown in equation (9). Flow diagram of nitrogen demand of rice is shown as follow.



NDemand = IF(DATEH=1) THEN 0
ELSE (IF(DAT<=0) THEN 0
ELSE (IF(TotalCropN<35.0) AND (DAT<20) THEN (RUR*TotalCropN)
ELSE
MIN(5,0.035*GrowthRate,(MaxNCon*(CropWeight+GrowthRate*DT)-
TotalCropN)/DT,
IF(LeafN>=100) THEN 0 ELSE 9999.9,
IF(DATEHF=1) THEN 0 ELSE 9999.9))) ………..(9)

Schaber (1996) stated that the amount of nitrogen needed by the plant is calculated on the basis of several assumptions. Naturally, there is no demand of nitrogen after harvest (DATEF=1) and before planting (DAT<=0). During the first 20 DAT the demand is governed by the relative uptake coefficient (RUR, 0.2/d). This phase ends before completion of the 20 days period if the total crop nitrogen exceeds 35 kg/ha.

The nitrogen demand of rice equation set limitation after the exponential phase as:

1. The uptake rate cannot exceed a certain given value of 5.0 kg /(ha*d).
2. The ratio of daily nitrogen uptake and daily biomass production cannot exceed a certain value (0.035*GrowthRate).
3. The maximum overall nitrogen concentration (MaxNCon, g/g) depends on the developmental stage of the plant. Daily uptake cannot exceed the difference

between MaxNCon and the current ratio. MaxNCon is a tabulated function: it starts at 0.04 kg/kg, decreases linearly to 0.02 at flowering and 0.015 when the crop approaches maturity.

4. Uptake ceases when the total leaf nitrogen exceeds a certain value (100 kg N/ha).
5. Uptake stops 7 days before harvest.

5.3.4 Total phenolic content

The basic simulation of total phenolic content used empirical model in which the dynamic of total phenolic content of leave, stem and grain (brown rice) is a function of growing duration. Using Kuppatarat (2010) observed data, the dynamic of leave and stem total phenolic content can be described as following equation 10 and 11. Similarly, Parirakwichit (2010) observed data was used to construct the following equation 12-14 to describe dynamic of grain total phenolic content.

$$\text{LeafPhenolic} = -0.0108*(\text{DAT}^{\wedge}2)+1.1455*\text{DAT}+67.801 \quad \ldots\ldots\ldots 10$$

$$\text{StemPhenolic} = 0.0093*(\text{DAT}^{\wedge}2)-0.7755*\text{DAT}+33.832 \quad \ldots\ldots\ldots 11$$

$$\text{Upper\_Phe} = 0.0068*(\text{DAH}^{\wedge}3)-0.7337*(\text{DAH}^{\wedge}2)+13.397*\text{DAH}+3.3637 \ldots\ldots\ldots 12$$

$$\text{Middle\_Phe} = 0.0315*(\text{DAH}^{\wedge}3)-1.3896*(\text{DAH}^{\wedge}2)+15.399*\text{DAH}+5.2309 \ldots\ldots\ldots 13$$

$$\text{Lower\_Phe} = 0.0483*(\text{DAH}^{\wedge}3)-1.9148*(\text{DAH}^{\wedge}2)+18.291*\text{DAH}+13.349 \ldots\ldots\ldots 14$$

5.4 Model assumption

The model assumed that rice was grown under good management practices i.e. no pest infection, no water stress and no grain loss from bird and shattering. Thus biomass and yield were simulated under optimum conditions.

5.5 Model simulation

The following simulation was run using input data from the experiment conducted at Multiple Cropping Center, Chiang Mai University. Following data were used as an input to the model.

5.6 Model input

5.6.1 Planting date

Planting date set in the purple glutinous rice model is the same date of the experiment. It is converted to Julian day which is 222 of date 1 for date 1 planting (9 August) and 245 for date 2 planting (1 September).

Date	StartDOY
9 August 2008	222
1 September 2008	245

5.6.2 Fertilizer input

Field experiment was fertilized with nitrogen fertilizer twice application for the August planting date and one application for the September planting date. For August planting, all rice varieties were fertilized with 25 kgN/ha on 15 September (day 37) and 72 kgN/ha on 3 October (day 55). Rice plants were fertilized with 25 kgN/ha on 7 October (day 36) for the September planting date.

Planting date	Application date1	DAT1	Amount (KgN/ha)	Application date2	DAT2	Amount (KgN/ha)
9 August	15 September	37	25	3 October	55	72
1 September	7 October	36	25	n/a	n/a	n/a

5.6.3 Weather input

The model started simulates rice growth using weather data started on given StartDOY. The model used daily Tmax and Tmin for calculation of accumulated growing degree days. The accumulated growing degree days and day length were used to simulate flowering date. Daily solar radiation is a driven variable for biomass simulation with determine rice growth. Weather used in the model are shown below.

Date	Jday	Tmax (°C)	Tmin (°C)	Solar rad (MJ/m^2)	Day length (Hour)
1-Aug	214	33.6	25.0	11.87	12.9
2	215	32.5	23.3	11.35	12.8
3	216	33.6	24.0	18.26	12.8
4	217	33.1	23.4	18.38	12.8
5	218	32.7	23.6	13.89	12.8
6	219	28.7	23.6	20.55	12.8
7	220	32.6	25.0	11.69	12.8
8	221	32.0	25.0	17.97	12.8
9	222	29.0	23.2	15.65	12.7
10	223	30.0	22.5	17.95	12.7
11	224	30.5	23.1	17.04	12.7
12	225	29.0	23.0	13.31	12.7
13	226	29.5	24.0	17.92	12.7
14	227	28.5	23.0	23.44	12.7
15	228	32.4	23.5	16.10	12.7
16	229	33.5	23.0	15.57	12.6
17	230	33.5	23.8	16.85	12.6
18	231	32.1	23.2	11.82	12.6
19	232	31.6	22.6	11.16	12.6
20	233	34.0	23.1	11.15	12.6
21	234	32.6	23.8	11.13	12.6
22	235	32.2	23.5	12.92	12.6
23	236	35.3	23.6	16.24	12.5
24	237	34.5	24.0	13.01	12.5
25	238	33.7	23.5	13.38	12.5
26	239	32.5	23.5	15.16	12.5
27	240	31.5	23.5	11.67	12.5
28	241	31.0	23.7	13.58	12.5
29	242	33.9	23.2	11.76	12.4
30	243	34.1	23.5	10.97	12.4
31	244	34.3	24.0	14.15	12.4
1-Sep	245	33.5	22.5	19.89	12.4
2	246	32.8	23.5	20.76	12.4
3	247	34.0	23.4	23.67	12.4
4	248	33.8	24.0	20.32	12.3
5	249	34.0	23.2	15.18	12.3
6	250	30.5	23.9	20.00	12.3
7	251	29.3	23.2	20.23	12.3
8	252	32.4	22.5	15.99	12.3
9	253	33.0	24.3	14.05	12.2
10	254	33.0	23.1	13.51	12.2
11	255	32.8	22.5	15.64	12.2
12	256	34.0	22.0	17.01	12.2
13	257	32.6	24.5	19.13	12.2

Date	Jday	Tmax (°C)	Tmin (°C)	Solar rad (MJ/m^2)	Day length (Hour)
14	258	30.5	24.1	16.30	12.2
15	259	29.7	23.7	17.41	12.1
16	260	31.8	23.5	20.65	12.1
17	261	33.2	23.5	20.61	12.1
18	262	34.2	22.0	14.27	12.1
19	263	29.0	24.2	14.23	12.1
20	264	34.8	24.7	13.57	12.1
21	265	32.7	23.9	16.92	12.0
22	266	33.2	22.3	17.88	12.0
23	267	31.9	22.9	20.33	12.0
24	268	32.4	22.7	16.28	12.0
25	269	33.0	24.0	15.24	12.0
26	270	32.9	23.6	12.84	11.9
27	271	32.5	22.9	12.42	11.9
28	272	32.5	23.0	14.61	11.9
29	273	34.6	23.0	22.59	11.9
30	274	34.1	23.4	21.17	11.9
1-Oct	275	34.9	22.5	20.62	11.9
2	276	33.1	23.0	10.01	11.8
3	277	31.6	23.4	17.31	11.8
4	278	32.8	22.5	17.01	11.8
5	279	34.0	23.2	16.23	11.8
6	280	34.1	22.7	14.12	11.8
7	281	31.0	22.1	15.27	11.7
8	282	32.3	22.6	10.98	11.7
9	283	33.5	23.2	15.40	11.7
10	284	29.2	23.0	14.03	11.7
11	285	33.5	22.6	15.29	11.7
12	286	33.7	24.1	19.79	11.7
13	287	34.0	21.4	20.55	11.6
14	288	34.0	21.2	21.32	11.6
15	289	33.4	21.0	21.60	11.6
16	290	33.6	22.0	20.10	11.6
17	291	32.2	22.7	18.97	11.6
18	292	34.0	21.9	20.20	11.5
19	293	34.1	22.5	18.13	11.5
20	294	33.5	22.5	20.05	11.5
21	295	33.1	23.0	19.04	11.5
22	296	32.0	22.7	11.88	11.5
23	297	33.5	22.0	18.44	11.5
24	298	32.2	22.7	14.90	11.4
25	299	31.5	23.2	20.15	11.4
26	300	32.1	23.0	19.61	11.4
27	301	29.5	24.0	19.77	11.4

Date	Jday	Tmax (^oC)	Tmin (^oC)	Solar rad (MJ/m^2)	Day length (Hour)
28	302	29.9	22.0	18.10	11.4
29	303	31.0	22.0	19.74	11.4
30	304	32.0	22.0	19.44	11.3
31	305	33.0	22.1	17.90	11.3
1-Nov	306	31.0	23.6	17.49	11.3
2	307	30.3	23.2	20.24	11.3
3	308	32.3	23.5	20.16	11.3
4	309	32.1	21.0	19.87	11.3
5	310	32.2	22.0	19.46	11.3
6	311	32.3	22.6	12.95	11.2
7	312	31.1	21.5	18.88	11.2
8	313	32.8	22.3	19.25	11.2
9	314	33.0	20.4	19.74	11.2
10	315	31.0	15.5	18.35	11.2
11	316	29.4	13.6	8.43	11.2
12	317	31.0	14.4	18.77	11.2
13	318	28.5	15.5	18.49	11.1
14	319	28.4	13.6	18.21	11.1
15	320	29.0	14.5	17.50	11.1
16	321	29.0	15.5	17.99	11.1
17	322	32.0	18.0	18.79	11.1
18	323	33.3	19.9	18.62	11.1
19	324	33.7	20.1	18.89	11.1
20	325	31.0	21.5	18.94	11.1
21	326	29.5	21.9	19.10	11.0
22	327	29.5	20.0	19.04	11.0
23	328	31.0	19.1	18.89	11.0
24	329	32.6	20.8	18.83	11.0
25	330	32.6	20.0	18.57	11.0
26	331	32.5	19.1	18.63	11.0
27	332	30.7	16.4	18.69	11.0
28	333	28.5	17.0	18.65	11.0
29	334	28.6	13.6	18.50	11.0
30	335	27.6	12.5	17.60	11.0
1-Dec	336	26.5	9.5	16.18	11.0
2	337	27.5	6.8	16.64	10.9
3	338	26.8	8.5	17.28	10.9
4	339	28.2	10.6	15.93	10.9
5	340	30.0	11.6	14.45	10.9
6	341	30.1	12.5	13.41	10.9
7	342	29.5	16.0	15.15	10.9
8	343	28.5	15.3	15.26	10.9
9	344	29.5	15.0	13.12	10.9
10	345	28.0	15.0	16.27	10.9

Date	Jday	Tmax (°C)	Tmin (°C)	Solar rad (MJ/m^2)	Day length (Hour)
11	346	29.1	18.2	16.00	10.9
12	347	29.7	16.1	14.36	10.9
13	348	29.0	15.4	16.22	10.9
14	349	31.3	15.5	17.11	10.9
15	350	30.1	15.5	16.07	10.9
16	351	29.7	14.9	16.45	10.9
17	352	29.0	14.9	16.75	10.9
18	353	29.4	14.6	16.69	10.9
19	354	29.0	16.5	16.10	10.9
20	355	28.2	12.9	15.00	10.9
21	356	28.4	12.9	14.51	10.9
22	357	28.1	14.0	14.87	10.9
23	358	29.7	14.5	10.41	10.9
24	359	29.3	15.5	14.24	10.9
25	360	30.2	15.1	14.27	10.9
26	361	31.5	18.6	15.98	10.9
27	362	23.0	19.0	15.71	10.9
28	363	27.5	16.5	15.13	10.9
29	364	27.6	16.1	16.79	10.9
30	365	30.0	15.4	16.78	10.9
31	366	30.5	14.3	16.57	10.9

5.6.4 Phenology data

In order to simulate flowering and maturity dates of each particular variety, the model required observed accumulated growing degree days from planting to flowering (ObsGDDF) and observed accumulated growing degree days from flowering to maturity (GFillGDD).

Variety	Planting date1		Planting date2	
	ObsGDDF (°C)	GFillGDD (°C)	ObsGDDF (°C)	GFillGDD (°C)
MHS1	1173	530	1020	462
Samoeng 3	1254	449	1133	521
PGMHS 6	1173	530	1020	462
PGMHS 15	1173	530	1020	462
PGMHS 17	1222	481	1172	462

5.7 Model simulation output

Varieties used in this study can be grouped into 2 groups according to field observation of rice development i.e. flowering date. The first group (MHS1, PGMHS 6, PGMHS 15) had earlier flowering date in which average observed accumulated growing degree days from planting to flowing was 1,173 ^{o}C. The second group Samoeng 3 and PGMHS 17) had longer period to flowering date in which average observed accumulated growing degree days from planting to flowing was 1,238 ^{o}C. Thus, simulation of group 1 purple glutinous rice varieties in this study represented simulated output of MHS1, PGMHS 6, and PGMHS 15. Similarly, the simulated output of group 2 represented Samoeng 3 and PGMHS 17 variety.

In order to compare simulated output and observed data available in this study, selected results of model simulation i.e. biomass accumulation (CropWeight), grain yield, and total phenolic content of leave, stem and brown rice grain are presented in the following section.

5.7.1 Biomass accumulation (CropWeight)

Comparison of simulated biomass accumulation and observed data of MHS1, PGMHS 6, PGMHS 15 variety planted on 9 August and 1 September are shown in figure 5.6 and figure 5.7 respectively. Simulation results and observed biomass had similar pattern of biomass accumulation at early growing period. However the observed data showed decreasing of biomass about 2 weeks before maturity. The simulated biomass, nonetheless kept increasing till maturity. The pattern of simulated biomass accumulation did not mimic the behavior of observed biomass accumulation at the end of growing season because the growth rate function used in the model.

GrowthRate=IF(DAT<=0)or(DATEH=1)THEN0 ELSE FSV*LNuseCoef*LeafN*(1-exp(-(epsilon*avRadiation)/(LNuseCoef*LeafN*0.1)))

The above equation is simple rate of growth of the crop which did not accommodate the decreasing behavior but become 0 when the condition is met i.e. when rice plant is set to maturity (Date of rice harvest; DATEH=1). At maturity, the simulated crop weight is at maximum. However, the observed maximum crop weight can be reached few days earlier when observed data is analyzed using growth curve function i.e. 3rd order polynomial (Figure 5.10 and 5.11). While the simulated maximum biomass was at 105 days after planting, the observed biomass reached maximum at 87 days for MHS1, PGMHS 6 and PGMHS 17 and 94 days for PGMHS 15 and 105 days for Samoeng 3. Nevertheless, the maximum crop weight of simulated and observed were in closed range. Thus it can be concluded that the simple function of crop growth rate used in the model can satisfactory simulate the value of biomass accumulation.

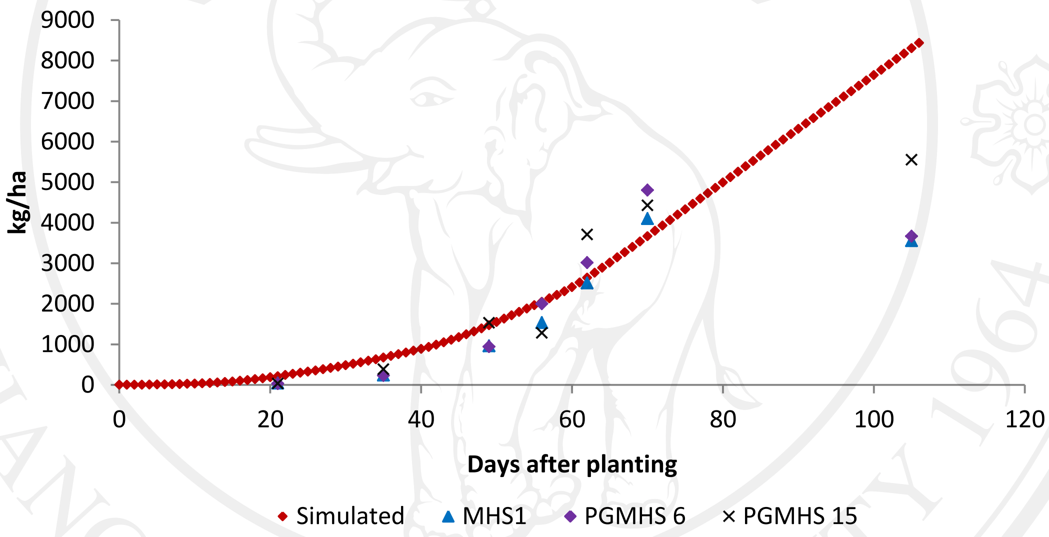


Figure 5.6 Simulated and observed biomass accumulation (Crop weight) of MHS1, PGMHS 6 and PGMHS 15 planted on 9 August.

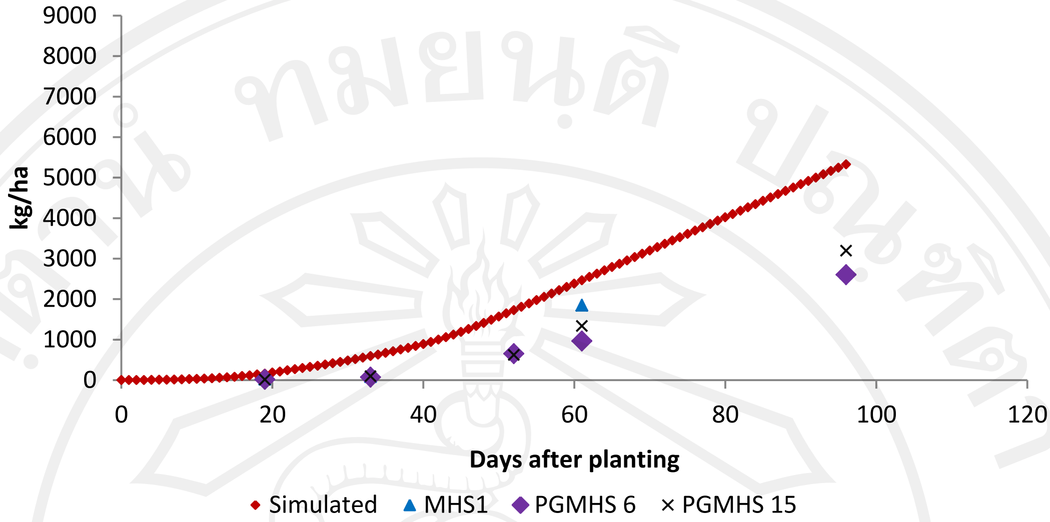


Figure 5.7 Simulated and observed biomass accumulation (Crop weight) of MHS1, PGMHS 6 and PGMHS 15 planted on 1 September.

Comparison of simulated and observed biomass accumulation of the 2nd group (Samoeng 3 and PGMHS 17) is shown in figure 5.8 for August planting and figure 5.9 for September planting. Note that both Samoeng 3 and PGMHS 17 of both August planting and September planting reached maturity almost the same growth duration (number of days to maturity). But it took longer period for MHS1, PGMHS 6, PGMHS 15 planted in August to reach maturity than September planting.

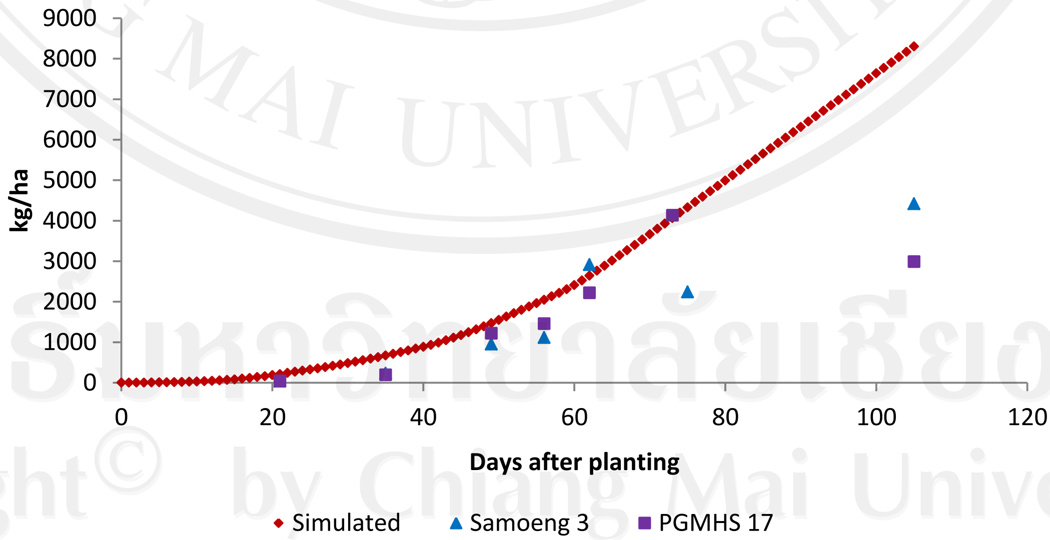


Figure 5.8 Simulated and observed biomass accumulation (Crop weight) of Samoeng 3 and PGMHS 17 planted on 9 August.

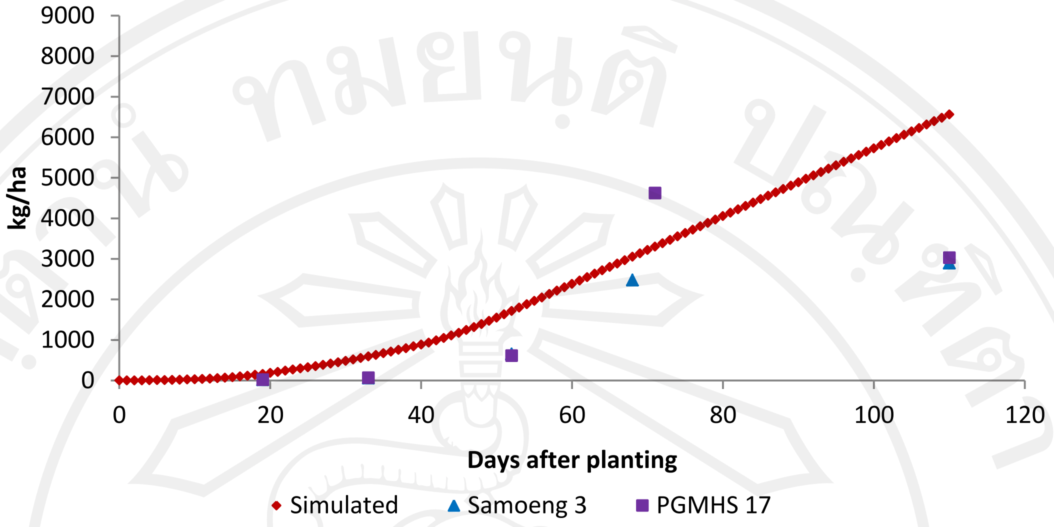


Figure 5.9 Simulated and observed biomass accumulation (Crop weight) of Samoeng 3 and PGMHS 17 planted on 1 September.

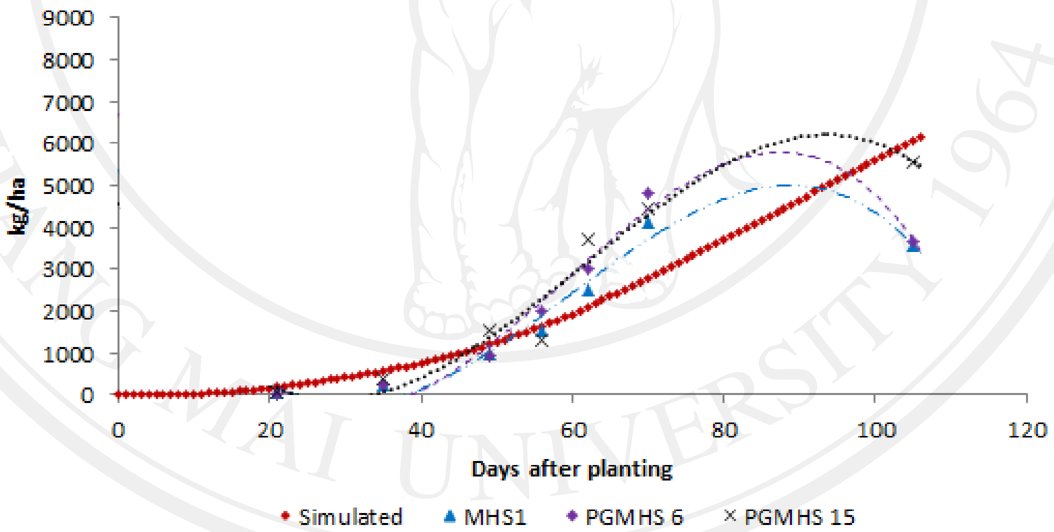


Figure 5.10 Observed maximum biomass accumulation (Crop weight) using 3rd order polynomial function of MHS1, PGMHS 6 and PGMHS 15 planted on 9 August as compared to simulated biomass accumulation.

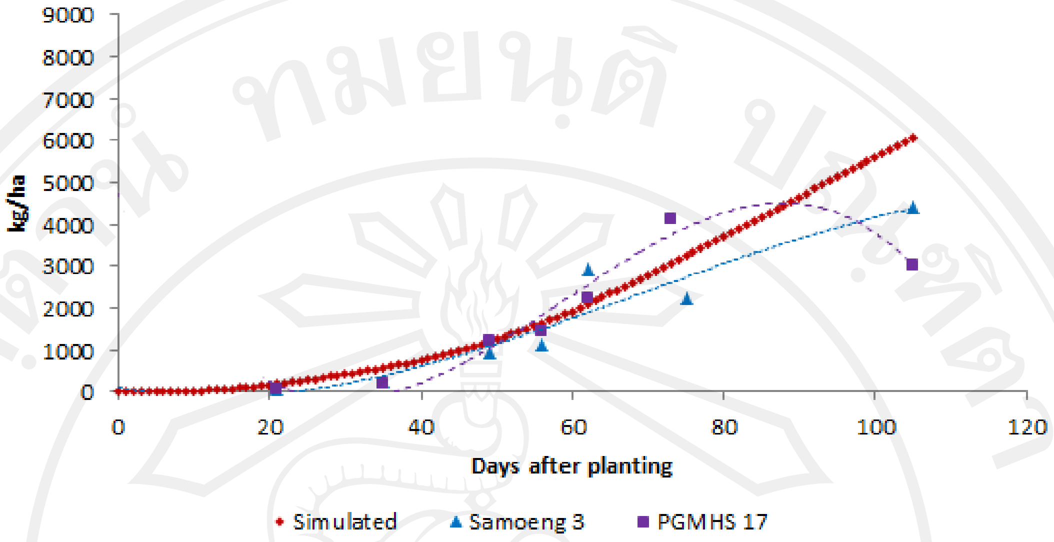
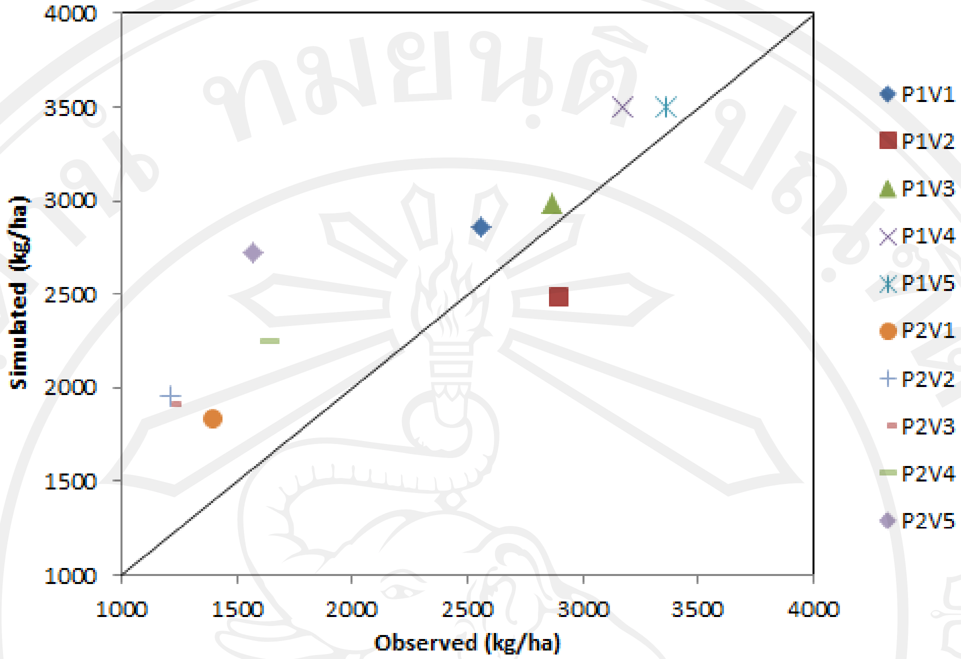


Figure 5.11 Observed maximum biomass accumulation (Crop weight) using 3rd order polynomial function of Samoeng 3 and PGMHS 17 planted on 9 August as compared to simulated biomass accumulation.

5.7.2 Grain yield

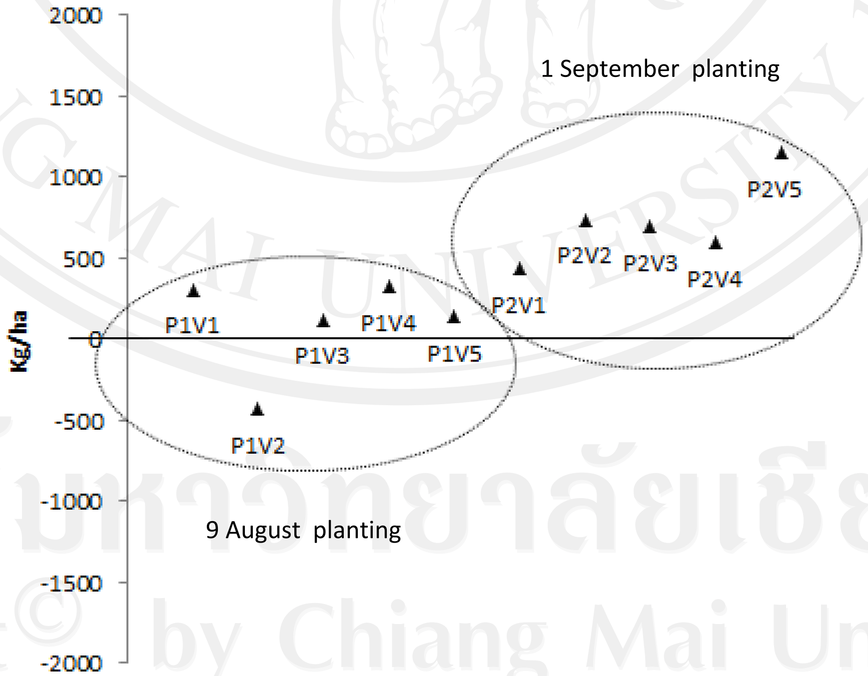
Figure 5.12 shows 1:1 line comparing simulated and observed grain yield. Generally the model underestimated grain yield for the August planting but overestimated grain yield for September planting. Grain yield is calculated using 50% of total dry matter or shoot weight (WSHT, kg/ha) when rice plant is set to maturity. With this simple assumption, grain yield could be underestimated or overestimated because it did not include yield components which are specific factors that determining grain yield of each particular variety (Yoshida, 1981). Result from simulation of grain yield indicated that a single coefficient value (50% of total dry matter or shoot weight) cannot satisfy the calculation of grain yield for different treatments. However, the difference between simulated and observed grain yield was in the range of 118-1149 kg/ha (Figure 5.13) depending on variety. Thus in order to improve grain yield simulation, the specific coefficient of each rice variety is needed to be considered.



P1 = 9 August planting P2 = 1 September planting

V1 = MHS 1 V2 = Samoeng 3 V3 = PGMHS 6 V4 = PGMHS 15 V5 = PGMHS 17

Figure 5.12 Comparison of simulated and observed grain yield for 5 varieties and 2 planting dates shown in 1:1 line graph.



P1 = 9 August planting P2 = 1 September planting

V1 = MHS 1 V2 = Samoeng 3 V3 = PGMHS 6 V4 = PGMHS 15 V5 = PGMHS 17

Figure 5.13 Difference between simulated and observed grain yield.

5.7.3 Total phenolic content

Observed dynamic of total phenolic content of leave, stem and grain data were obtained from PGMHS 15. The model utilized quadratic function to simulate the dynamic of leave and stem total phenolic content. Simulation results show decreasing trend of total phenolic content in stem but increasing trend in leave from 10 days till 40 days after planting (Figure 5.14 and 5.15). After 40 days after planting, the stem total phenolic content started to increase and leave total phenolic content began to decrease. However, leave total phenolic content was greater than that of stem.

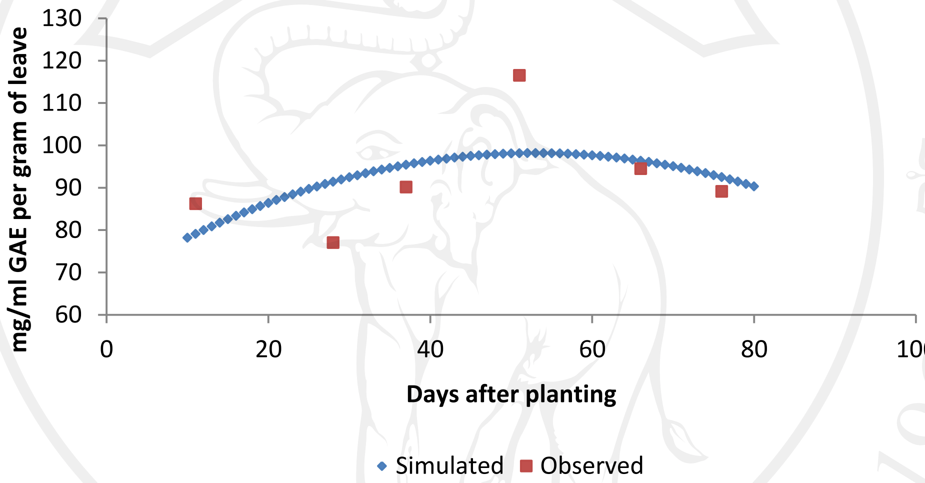


Figure 5.14 Simulated total phenolic content in leave as a function of growing period. Data obtained from Kuppatarat (2010).

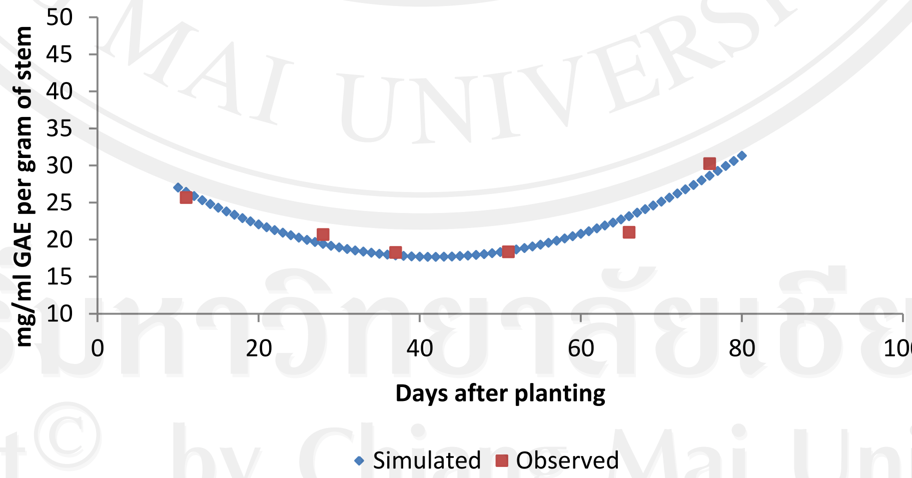


Figure 5.15 Simulated total phenolic content in stem as a function of growing period. Data obtained from Kuppatarat (2010).

The model utilized 3rd order polynomial function to simulate the dynamic of rice grain total phenolic content of the grains in the upper, middle, and lower part of the panicle (Figure 5.16). Simulation results show an increasing trend of total phenolic content from heading date (Figure 5.17). Total phenolic content of grain in the upper part of panicle reached maximum at 10 days after heading while grain in the middle and lower part of the panicle had highest total phenolic content around 7 days after heading. The maximum amount of simulated total phenolic content in grain from the upper, middle and lower part of the panicle were 71, 55.74 and 64.6 mg/ml GAE per gram of rice grain.

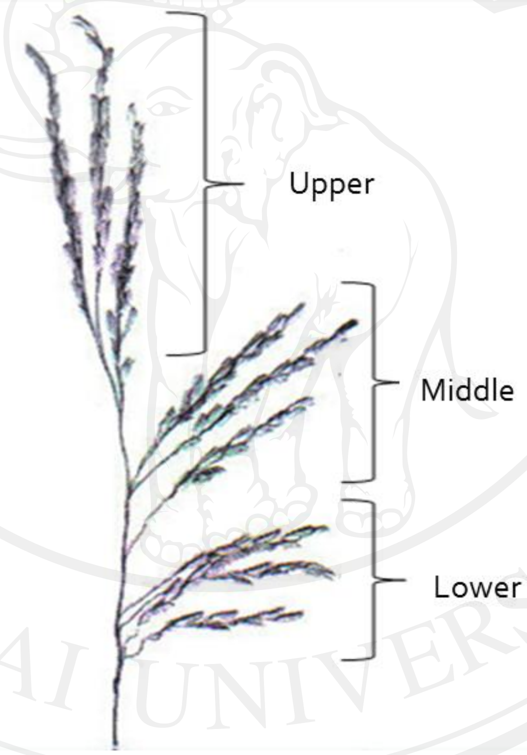


Figure 5.16 Position of grains on panicle i.e. upper, middle and lower where total phenolic content was determined.

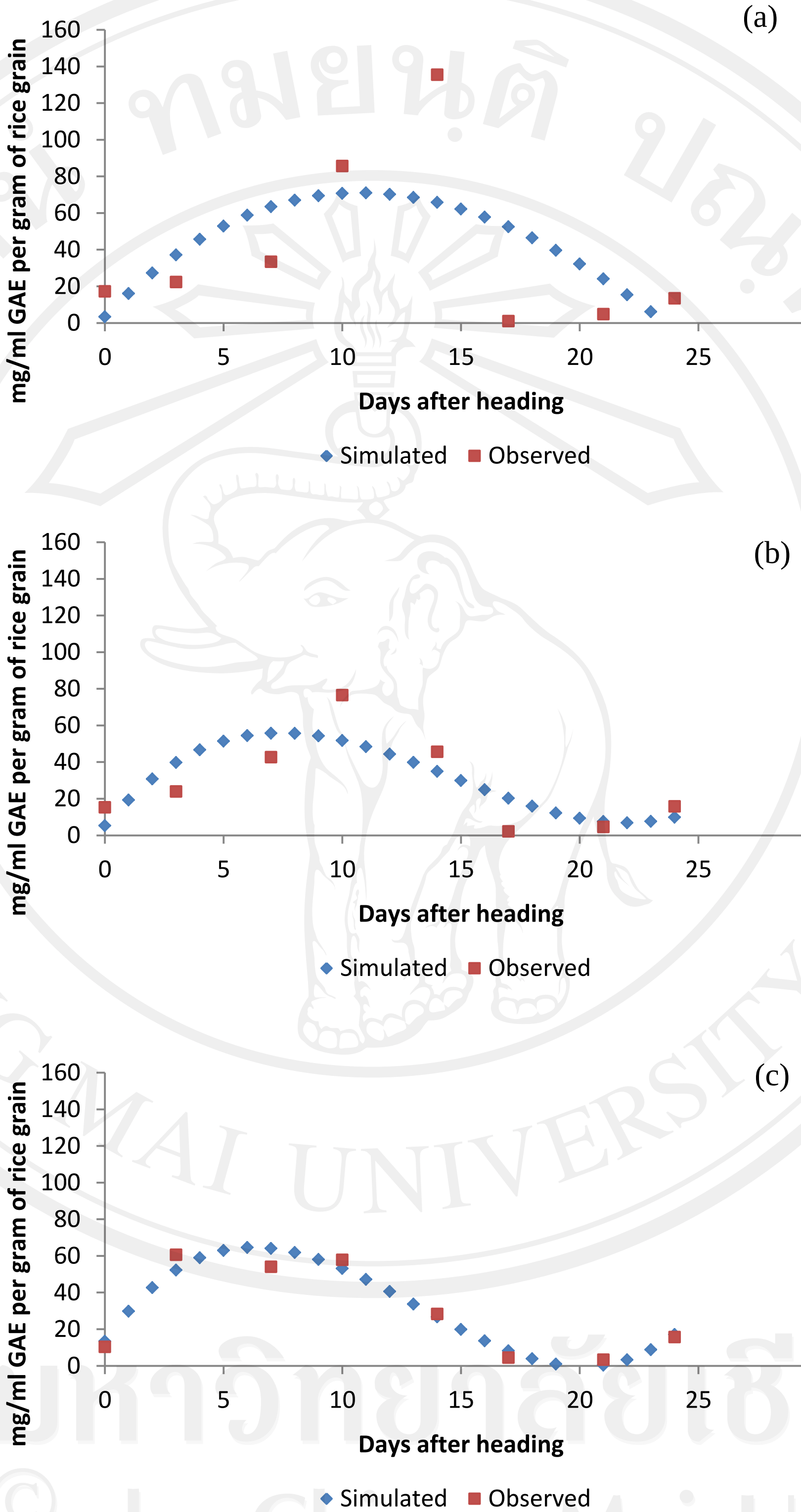


Figure 5.17 Grains total phenolic content (a) upper part (b) middle part and (c) lower part of the panicle.

Simulation of total phenolic content in this model is a simple empirical function based on observed data from field experiment. In this model, the simulation of total phenolic is only a function of growing duration. It did not include related factors that could influence the dynamic of total phenolic content e.g. nitrogen management, light intensity which varied among planting date and variety.

5.8 Model validation

Data obtained from Kuppatarat (2010) experiment were used to validate the purple glutinous rice model. Purple glutinous rice varieties namely Samoeng 4, PGMHS 12, PGMHS 13 and PGMHS 17 were planted on 3 August 2008. Nitrogen were applied at the rate of 4 kgN/ha and 4.6 kgN/ha were applied at 25 and 50 days after planting respectively.

Simulation results of biomass accumulation (Figure 5.18) demonstrated that the model overestimated biomass accumulation but showing similar pattern at early growth stage till maximum weight was reached. Similar result was found in the simulation of previous simulation which has pointed out the satisfactory model simulation.

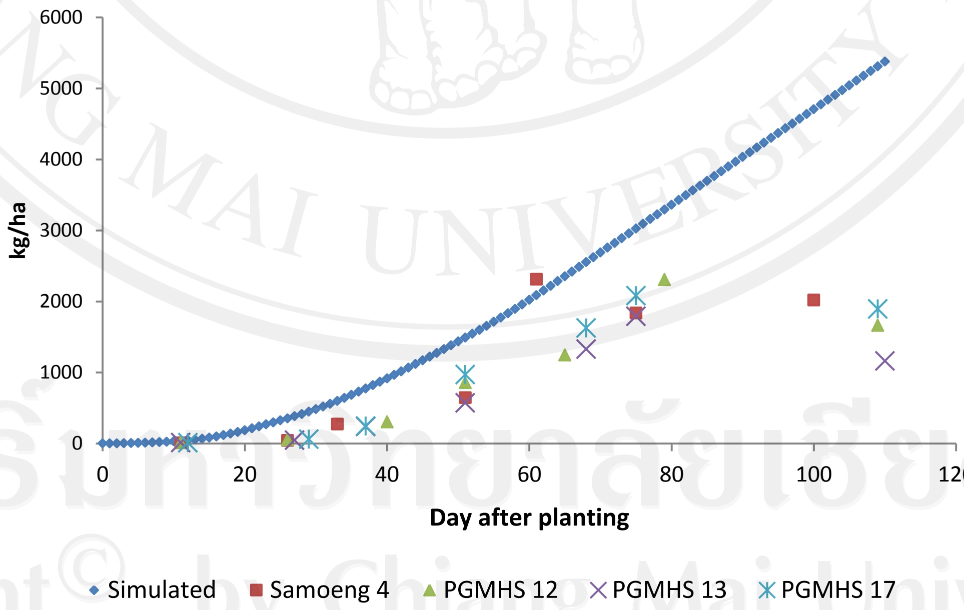


Figure 5.18 Model validation as compared the simulated and observed biomass accumulation (Crop weight) of purple glutinous rice varieties planted by Kuppatarat (2010)

Figure 5.19 compares the simulated and observed grain yield as a result of model validation. The model overestimated grain yield of Samoeng 4, PGMHS 12 and PGMHS 13. The result demonstrated the potential yield of those varieties since the assumption of model was that rice is planted under good management practices i.e. no pest infection, no water stress and no grain loss from bird and shattering. However the model under estimated yield of PGMHS 17. This was because of the observed 1000-grain weight is small. Note that the model used the 1000-grain weight as one of the factors determining grain yield.

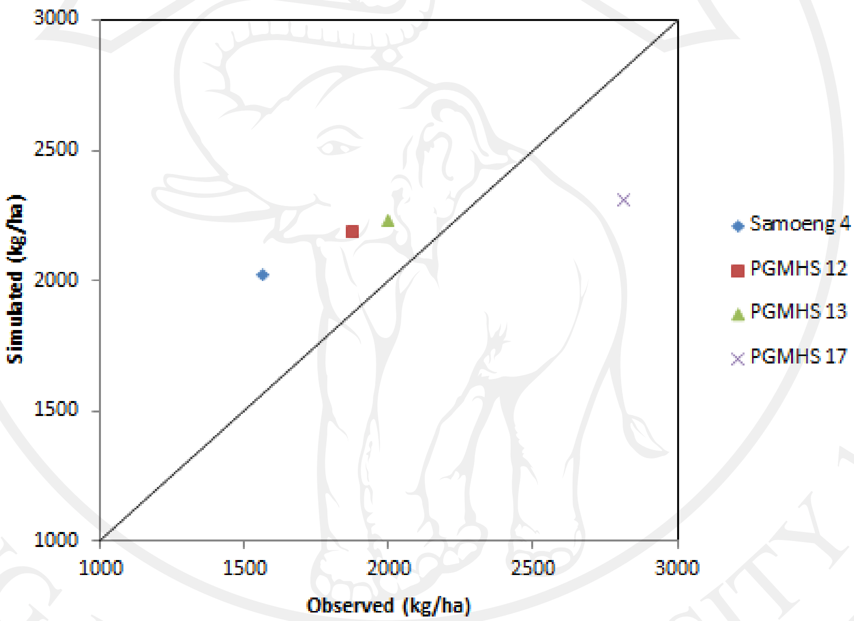


Figure 5.19 Model validation as compared the simulated and observed grain yield shown in 1:1 line graph. Observed data were obtained from Kuppatarat (2010).

5.9 Conclusion

The purple glutinous rice model in this study used ORYZA0 model as a base model in which it is a simple mechanistic model based on physiological process. The model utilized solar radiation as a driven variable that determine rice growth rate. The nitrogen sub model is built into the model thus allows user to set nitrogen management strategies. Using observed data of field experiment conducted with 5 varieties of purple glutinous rice and 2 planting dates, the model was modified by incorporating the phenology sub model. This sub model is used to estimate the flowering and maturity date. Simulation of dynamic of total phenolic content in leave, steam and grain was also integrating into the model.

Even though the model is a simple in which it used solar radiation as a driven variable and accumulation of growing degree days with day length to determine flowering and maturity dates but it has ability to simulate growth (biomass accumulation), grain yield, leave nitrogen and total nitrogen in rice plant. Comparing simulated and observed data of 5 varieties of rice with 2 planting dates, the analysis results were satisfied at certain level. However, the model could be further improved so that it can simulate specific variety yield as well as to simulate dynamic of total phenolic content as a function of related variables such as nitrogen.

In summary, despite the fact that the model is constructed with simple phonological and physiological concepts it could be used to investigate rice growth under difference environmental conditions i.e. differences in solar energy and day length as well as differences nitrogen management. Further improvement of the model can be performed once more necessary data are collected. However, because the model tends to be predictive model not explanatory model, it should kept as simple as possible.