CHAPTER 5

RESULTS

OBSERVED PHENOLOGICAL EVENTS

Table 8 shows the observed heading and maturity dates of RD7, NSPT, and KDML105 at five different planting dates.

Planting date treatment of RD 7 (photoperiod insensitive variety) does not considerably affect the growth duration (days from sowing to maturity). The observed heading dates range from 61 to 73 days after transplanting (DAT). The shortest duration from transplanting to heading was observed in September planting date (PD5) while the longest duration was found in May planting date (PD1). The observed number of days from heading to maturity range from 28 to 36 days. The growing period (sowing - maturity) range from 122 to 129 days.

The observed heading dates of NSPT and KDML105 (photoperiod sensitive varieties) occurred almost at the same time regardless of planting dates (Table 8). However, the growing season becomes shorter as the planting dates were shifted from June planting date (PD3) to September planting date (PD5) (Figure 2). It apparently shows the effect of day length on time of heading on the photoperiod sensitive rice variety. The duration of grain filling for all planting dates is attained about 33 - 37 days after heading.

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Table 8. Observed phenological events of rice planted at Multiple Cropping Centre Experiment Station.

Varieties	Sowing dates	Trans - planting dates	Heading dates	Maturity dates	Growing season (days)
RD7	Apr 5(95)	May 1(121)	Jul 13(194)	Aug 10(222)	127
	May 9(129)	Jun 4(155)	Aug 13(225)	Sep 12(255)	126
	Jun 6(157)	Jul 2(183)	Sep 8(251)	Oct 8(281)	124
	Jul 5(186)	Aug 1(213)	Oct 8(281)	Nov 14(315)	129
	Aug 8(220)	Sep 2(245)	Nov 2(306)	Dec 8(342)	122
NSPT	Apr 5(95)	May 1(121)	Oct 8(281)	Nov 12(316)	221
	May 9(129)	Jun 4(155)	Oct 8(281)	Nov 13(317)	188
	Jun 6(157)	Jul 2(183)	Oct 13(286)	Nov 14(318)	161
	Jul 5(186)	Aug 1(213)	Oct 19(292)	Nov 21(325)	139
	Aug 8(220)	Sep 2(245)	Oct 25(298)	Nov 28(332)	112
KDML105	Apr 5(95)	May 1(121)	Oct 5(278)	Nov 6(310)	215
	May 9(129)	Jun 4(155)	Oct 6(279)	Nov 6(310)	181
	Jun 6(157)	Jul 2(183)	Oct 13(286)	Nov 7(311)	154
	Jul 5(186)	Aug 1(213)	Oct 15(288)	Nov 21(325)	139
	Aug 8(220)	Sep 2(245)	Oct 24(297)	Nov 28(332)	112

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CALIBRATION AND DETERMINATION OF GENETIC COEFFICIENTS

The set of genetic coefficients of the 3 varieties RD7, NSPT, and KDML105 obtained from Jintrawet (1991) (Table 9) were used as an initial input to run the model using Minimum Data Set (MDS) from the Multiple Cropping Centre (MCC) Experiment Station.

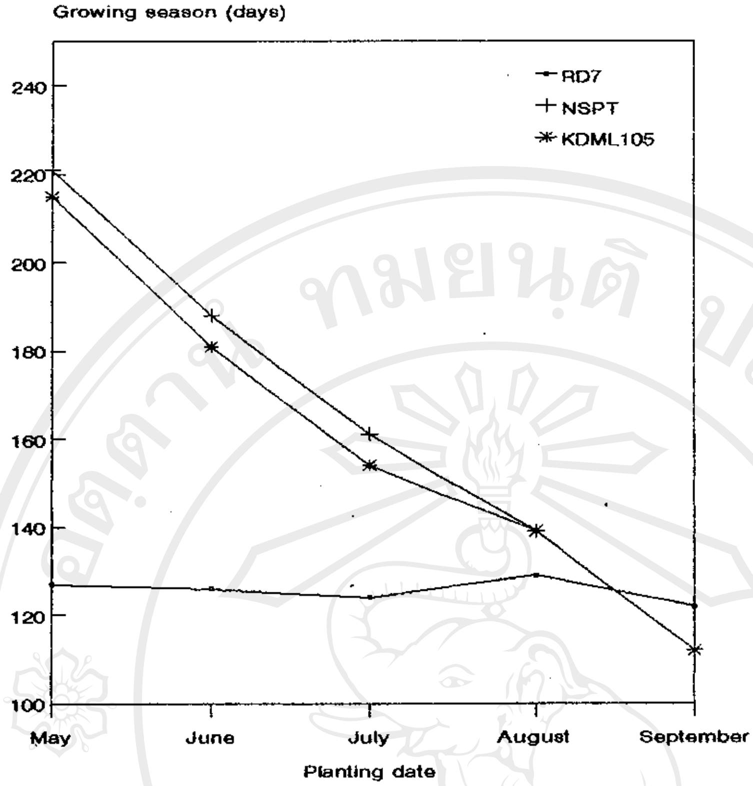

Figure 2. Growing season (days from sowing to maturity) of observed RD7, NSPT, and KDML105.

Table 9. Genetic coefficients of RD7, NSPT and KDML105 obtained from Jintrawet (1991).

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4
RD7	588.00	150.00	452.00	11.20	75.00	0.028	1.00	1.00
NSPT	480.00	1370.00	380.00	12.65	75.00	0.028	1.00	1.00
KDML105	480.00	1370.00	380.00	12.65	75.00	0.027	1.00	1.00

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Results obtained from this run revealed that the observed heading dates were underestimated which ranged from 14-23 days for RD7, 5-21 days for NSPT, and 2-17 days for KDML105. The observed maturity dates were also overestimated which ranged from 26-30 days for RD7, 1-26 days for NSPT and 7-30 days for KDML105 (Figure 3, 5, and 7). The RD7 at PD5 could not be simulated due to lack of weather data at later stage of growth for simulation processes. These results suggest that the genetic coefficients of the three varieties needed to be adjusted.

Using Hunt's technique (1989), new set of genetic coefficients (Table 10) was obtained by calibrating the former set of genetic coefficients. The new set of coefficients was then applied as genetics input to re-run the model using the previous MDS. Results of this run showed that the simulated heading dates and maturity dates were improved (Figure 4, 6, and 8). The average difference between observed and simulated heading and duration of grain filling are described at section of model testing.

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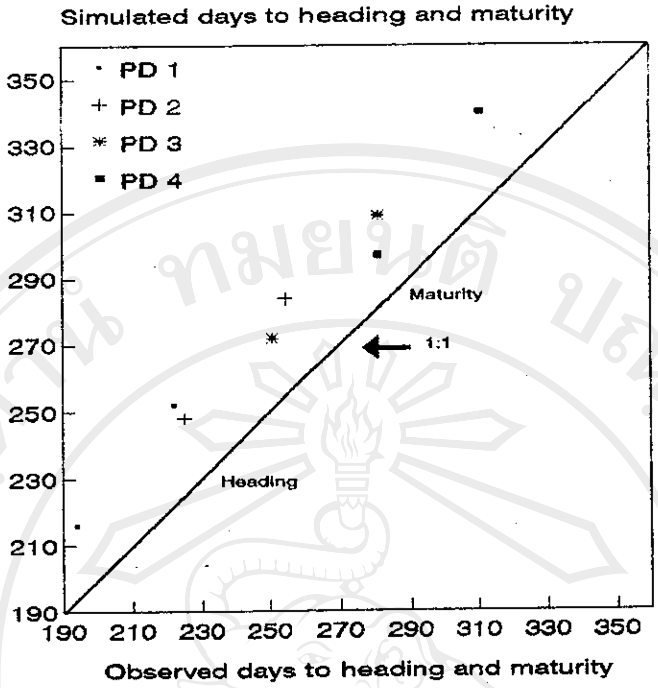

Figure 3. Comparison of observed and simulated days to heading and maturity of RD7 using genetic coefficients obtained from Jintrawet (1991).

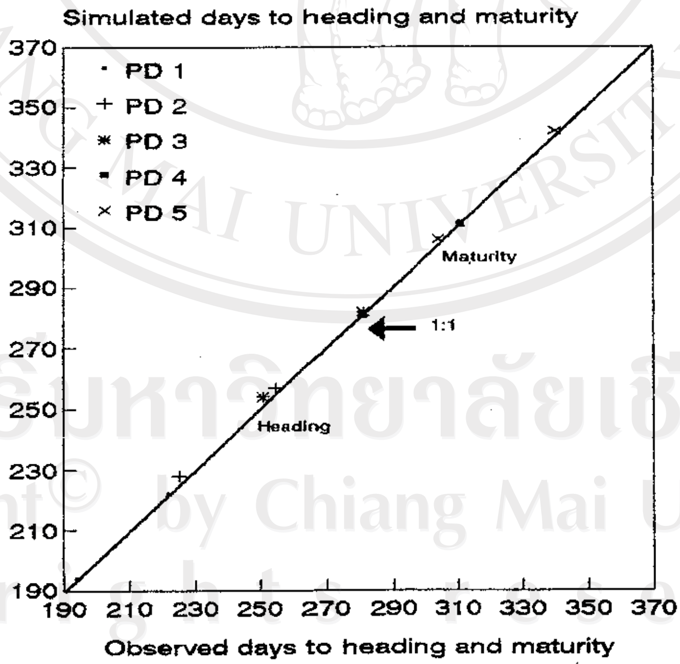

Figure 4. Comparison of observed and simulated days to heading and maturity of RD7 using new set of genetic coefficients which was obtained by calibrating Jintrawet's (1991) coefficients.

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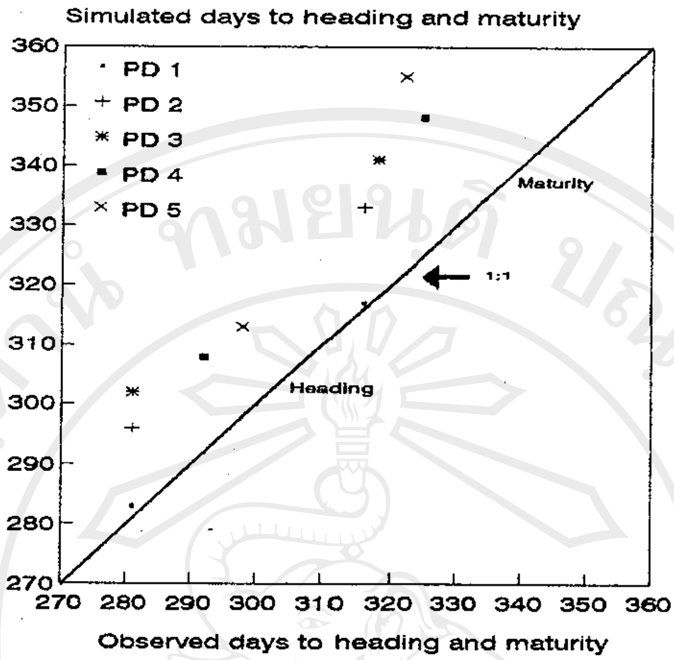

Figure 5. Comparison of observed and simulated days to heading and maturity of NSPT using genetic coefficients obtained from Jintrawet (1991).

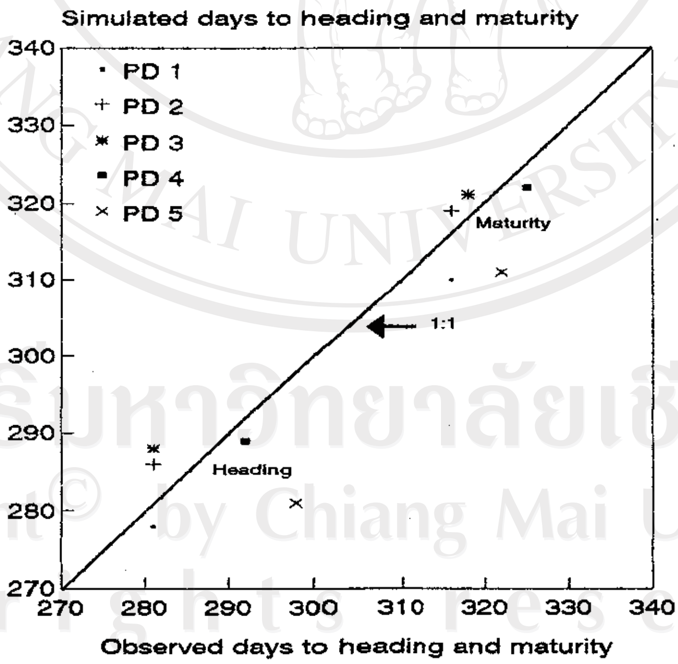

Figure 6. Comparison of observed and simulated days to heading and maturity of NSPT using new set of genetic coefficients which was obtained by calibrating Jintrawet's (1991) coefficients.

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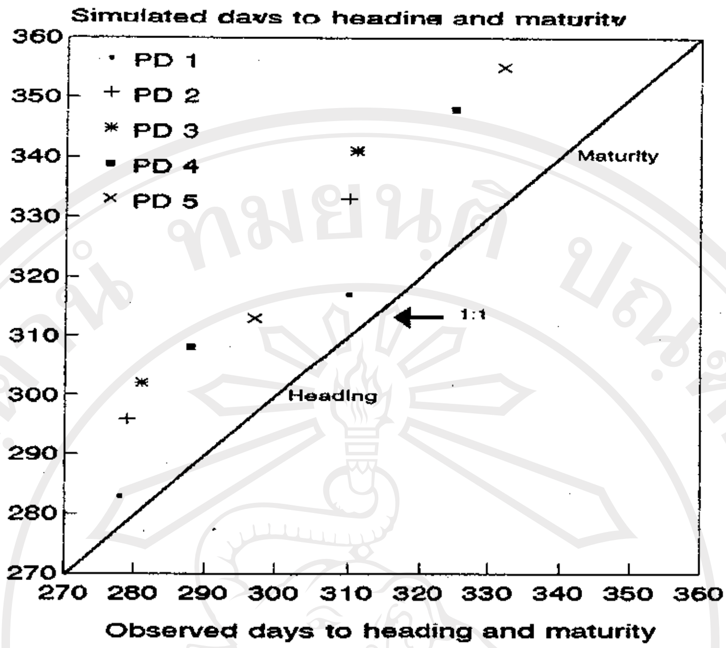

Figure 7. Comparison of observed and simulated days to heading and maturity of KDML105 using genetic coefficients obtained from Jintrawet (1991).

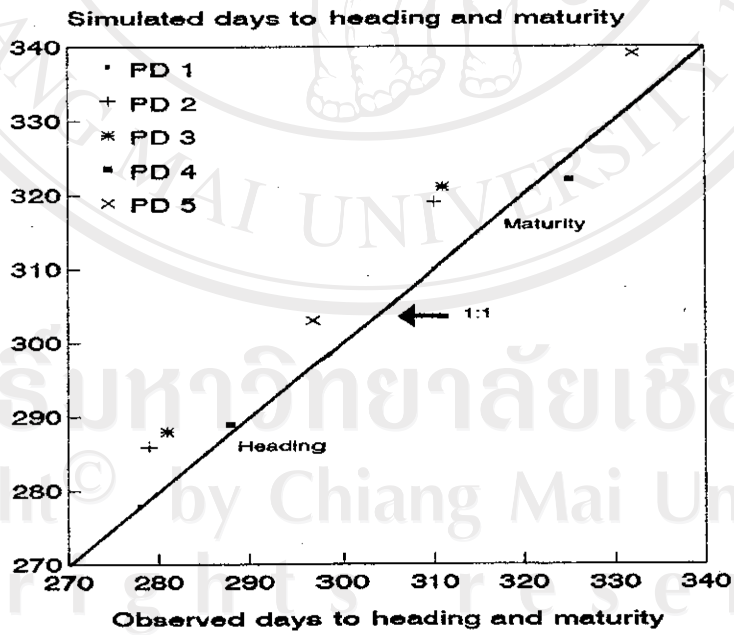

Figure 8. Comparison of observed and simulated days to heading and maturity of KDML105 using new set of genetic coefficients which was obtained by calibrating Jintrawet's (1991) coefficients.

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Table 10. Genetic coefficients of the RD7, NSPT and KDML105 obtained after calibration of Jintrawet's (1991) coefficients.

Variety	P1	P2R	P5	P20	G1	G2	G3	G4
RD7	460.00	94.00	320.00	11.90	75.00	0.028	1.00	1.00
NSPT	420.00	2000.00	350.00	13.00	75.00	0.028	1.00	1.00
KDML105	420.00	2000.00	350.00	13.00	75.00	0.027	1.00	1.00

MODEL TESTING

Results of the model testing which include comparison between observed field data from the experiment carried out at MCC Experiment Station and simulated results in terms of phenological events, growth and yield are presented in the following sections:

Phenological Simulations

<u>Heading date</u>

The model consistently underestimated the heading dates of RD7 by an average of 1 days and RMSE of 2 days compared with the observed data (Table 11). The model also consistently overestimated the heading dates of NSPT by an average of 1 day (RMSE = 3 days). The greatest difference between observed and simulated heading date of NSPT occurred at PD5 where the heading date was overestimated by 5 days. Similarly, the model also overestimated the heading date of KDML105 by an average

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of 4 days with RMSE of 5 days. The greatest difference between observed and simulated heading dates occurred at PD2 and PD3, where the heading dates were both overestimated by 7 days. Therefore, the simulated heading date of RD7 is more accurate than NSPT and KDML105 with the smallest RMSE (2 days) (Table 11).

Duration of grain filling (heading to maturity)

Table 12 shows the comparison of duration of grain filling between simulated and observed data. The results show that the simulated data consistently underestimate the duration of grain filling across varieties by an average of 1, 2, and 1 days for RD7, NSPT and KDML105, respectively. The RMSE for the three varieties are 1 day for RD7, 3 days for NSPT, and 2 days for KDML105. The greatest difference between simulated and observed data occurred at PD3 for NSPT and PD4 for KDML105 with underestimation of about 5 days and 4 days, respectively. Simulation of the duration of grain filling of RD7 is most accurate when compared with NSPT and KDML105.

The overall results indicate that the model is able to simulate growth duration (day from planting to maturity) fairly well which implies that model's simulation of phenological development is relatively accurate.

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Table 11. Simulated and observed heading date for RD7, NSPT and KDML105.

Varieties	Planting dates*	Heading date: Simulated	Observed	Difference
RD7		Julian day		dif
	PD1 (95)	194	194	0
	PD2 (129)	228	225	3
	PD3 (257)	254	251	3
	PD4 (286)	281	281	0
	PD5 (220)	304	306	-2
	Bias			0.8
	RMSE			2.10
NSPT				
	PD1 (95)	278	281	-3
	PD2 (129)	286	283	3
	PD3 (257)	288	286	2
	PD4 (286)	289	292	-3
	PD5 (220)	303	298	5
	Bias			0.8
	RMSE			3.34
KDML105				
	PD1 (95)	278	278	0
	PD2 (129)	286	279	7
	PD3 (257)	288	281	7
	PD4 (286)	289	288	1
	PD5 (220)	303	297	6
	Bias			3.2
	RMSE			5.20

* Number in the parenthesis is planting date expressed in Julian day.

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Table 12. Simulated and observed duration of grain filling (Heading to maturity) of RD7, NSPT, and KDML105.

Varieties	Planting dates*	duration of grain filling Simulated	Observed	Difference
		—— day ——		— dif —
RD7				
	PD1 (95)	28	28	0
	PD2 (129)	29	30	-1
	PD3 (257)	28	30	-2
	PD4 (286)	30	30	0
	PD5 (220)	35	36	-1
	Bias			-0.8
	RMSE			1.1
NSPT				
	PD1 (95)	31	35	-4
	PD2 (129)	32	35	-2
	PD3 (257)	32	37	-5
	PD4 (286)	33	33	0
	PD5 (220)	34	34	0
	Bias			-2.2
	RMSE			3.00
KDML105				
	PD1 (95)	31	32	-1
	PD2 (129)	32	31	1
	PD3 (257)	32	30	2
	PD4 (286)	33	37	-4
	PD5 (220)	34	35	-1
	Bias			-1.0
	RMSE			2.15

* Number in the parenthesis is planting date expressed in Julian day.

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Growth and Yield Simulation

Number of tillers m^{-2}

Figures 9, 10 and 11 show the comparison between simulated and observed number of tillers m^{-2} at 5 planting dates of the 3 varieties. It is obvious that the model overestimated tiller numbers m^{-2} across varieties and planting dates. The model overestimated tiller numbers m^{-2} of RD7 across planting dates by an average of 193.64, 226.27, 167, 141.03 and 216.12 tiller numbers m^{-2} (RMSE = 220.13, 248.69, 169.47, 148.11 and 223.54 tiller numbers m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively (Table 13). However, the observed and simulated number of days to reach maximum tillering of RD7 occurred almost at the same time, which is about 28-42 days depending on the planting date. The simulated and observed number of tillers declined and appeared to be constant after duration of heading. The observed maximum tiller numbers m^{-2} were 250-370 compared while the simulated tiller numbers m^{-2} were 490-620.

The model overestimated tiller numbers m^{-2} of NSPT by an average of 272.6, 282.6, 234.08, 194.97 and 70.2 tiller numbers m^{-2}(RMSE = 314.48, 316.86, 271.1, 207.80 and 75.07 tiller numbers m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively. The model also overestimated tiller numbers m^{-2} of KDML105 by an average of 262.47, 253.19, 210.08, 143.64 and 42.73 tiller numbers m^{-2} (RMSE = 296.47, 282.05, 246.00, 157.43 and 46.43 tiller numbers m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively (Table 13). Generally, the observed tiller numbers m^{-2} of NSPT and KDML105 of all planting dates continuously increased to

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maximum at about 35-42 DAT. Thereafter, the number of tillers declined and appeared to be constant after duration of heading. However, the simulated day to reach maximum tillering decreased as planting date was shifted from early planting date to late planting date. Figures 10 and 11 illustrate that the simulated tiller numbers m^{-2} reach maximum number about 91, 84, 63, 42, and 28 DAT for PD1, PD2, PD3, PD4, and PD5, respectively. The observed maximum tiller numbers m^{-2} were ranged 190-350 for NSPT and 230-320 for KDML105. The simulated maximum tiller numbers m^{-2} were ranged between 280-660 for both NSPT and KDML105.

Results of t-test on the intercept and slope of the 1:1 (observed : simulated) regression line for tiller numbers m^{-2} across varieties and planting dates were found significantly different. That is, the slope is significantly different from 1.0 and the intercept is significantly different from 0.0. This test, however, shows insignificant results for PD5 of KDML105.

Goodness of fit can be quantified by standardized bias (R) and a standardized mean square error (V) (Table 13). Judging by R and V, the best fits observed in the tiller numbers m^{-2} of RD7 were obtained at PD4 (R = 0.62, V = 0.36). Best fits for tiller numbers m^{-2} of NSPT and KDML105 were obtained at PD5 (R = 0.49, V = 0.25; and R = 0.25, V = 0.07, respectively).

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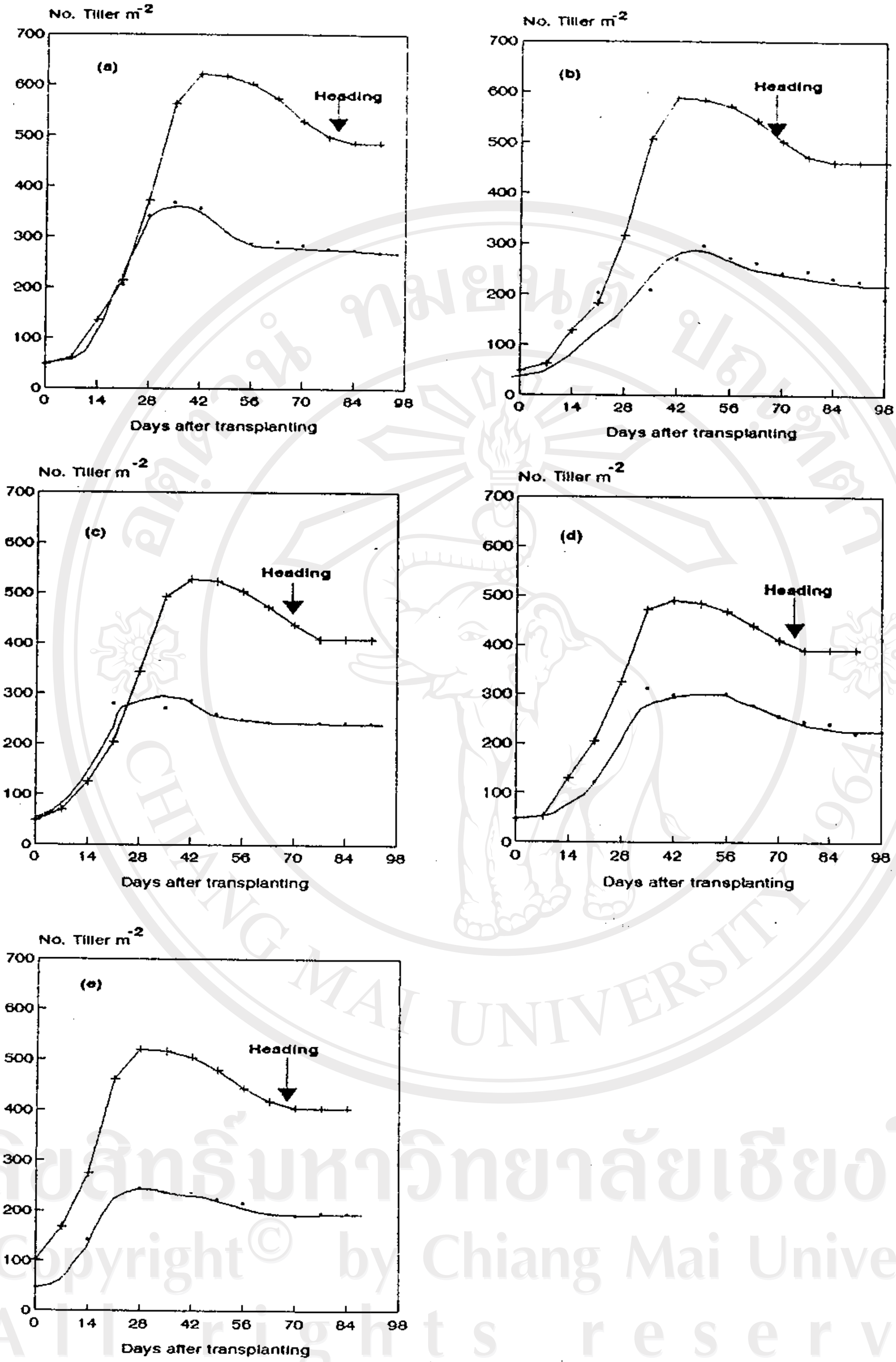

Figure 9. Comparison between simulated and observed tiller numbers m^{-2} of RD7 transplanted in (a) May, (b) June, (c) July, (d) August, and (e) September. + — + and ----- represent simulated and observed data, respectively.

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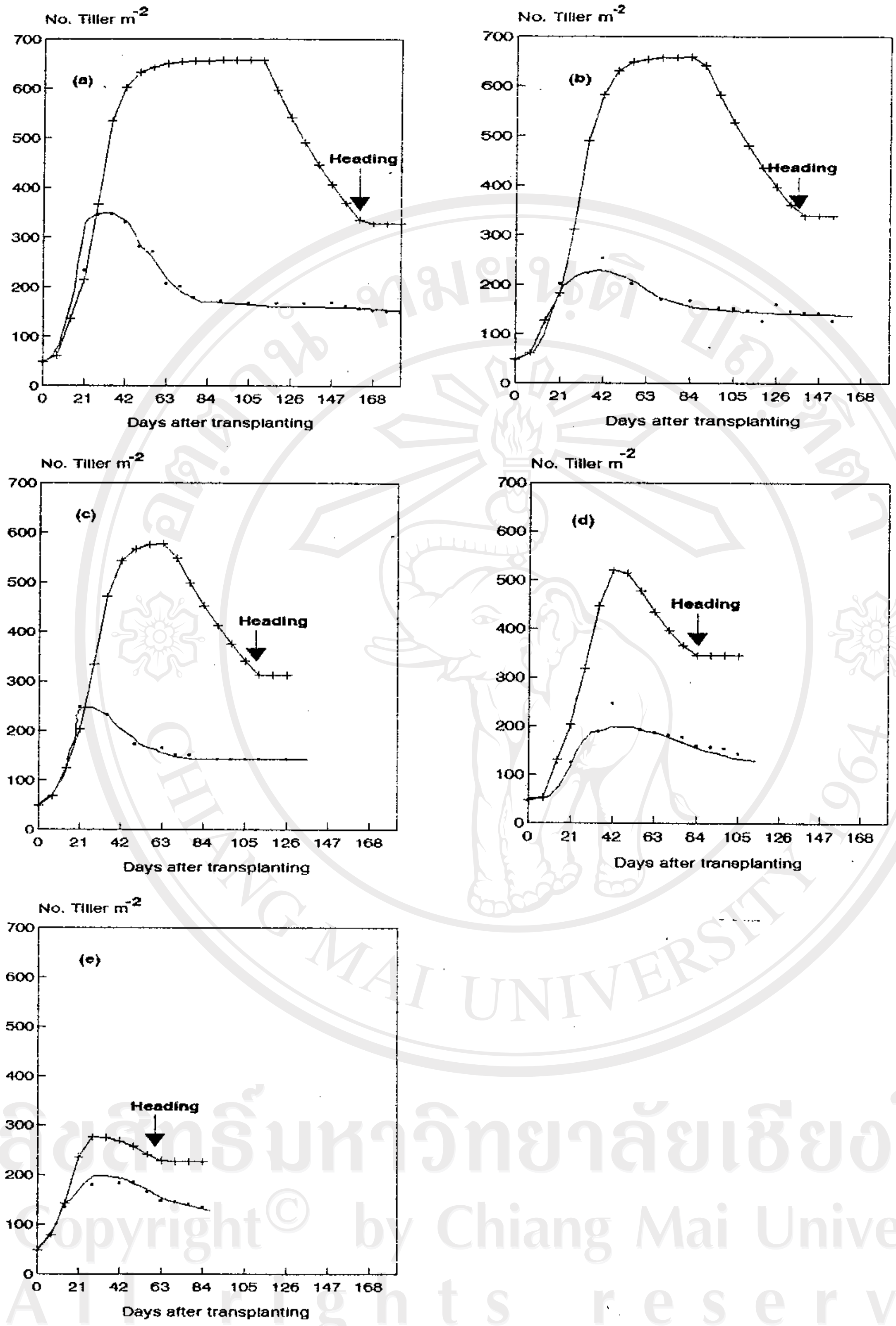

Figure 10. Comparison between simulated and observed tiller numbers m^{-2} of NSPT transplanted in (a) May, (b) June, (c) July, (d) August, and (e) September. + — + and ----· represent simulated and observed data, respectively.

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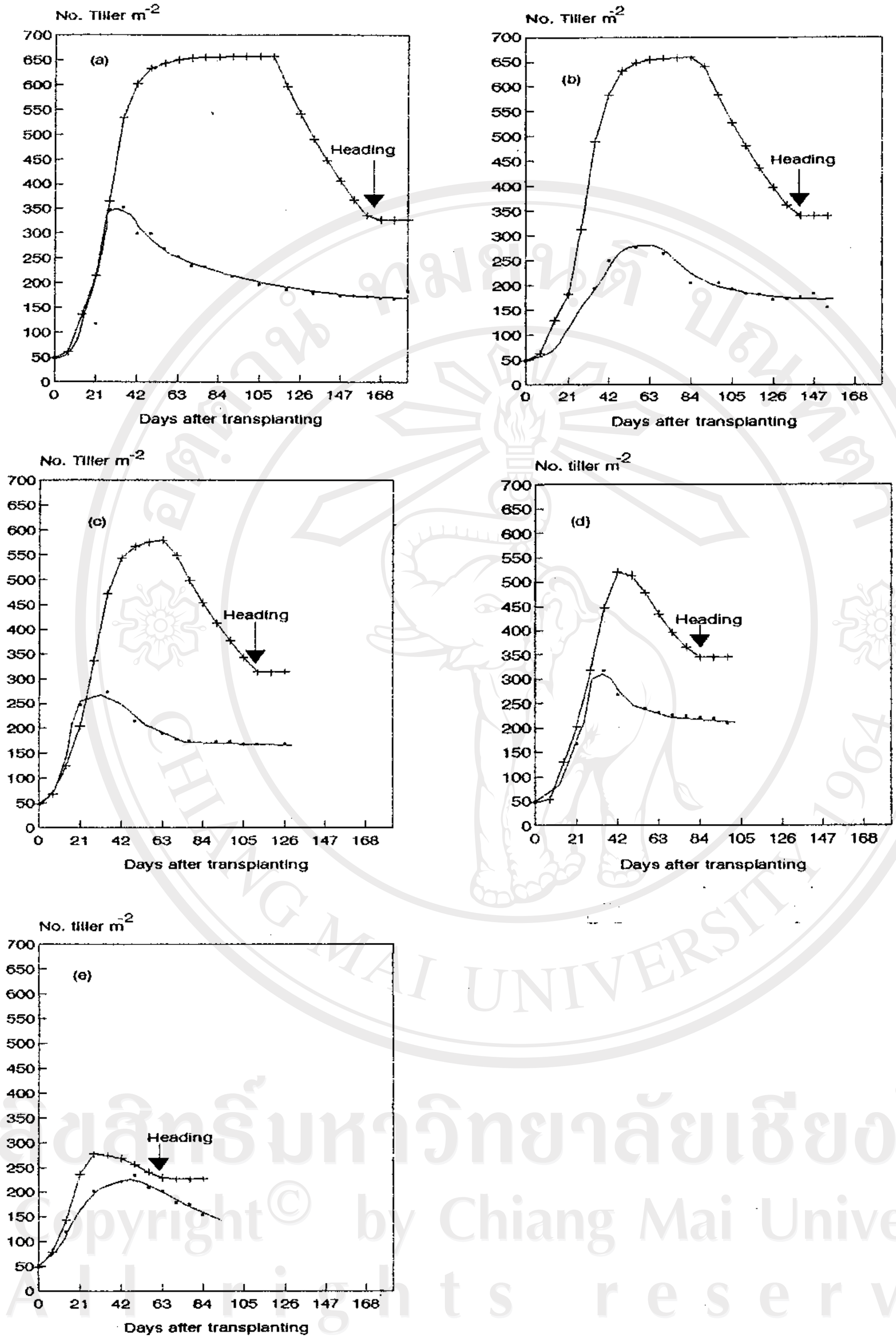

Figure 11. Comparison between simulated and observed tiller numbers m^{-2} of KDML105 transplanted in (a) May, (b) June, (c) July, (d) August, and (e) September. + — + and ·—· represent simulated and observed data, respectively.

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Table 13. Statistical analysis results of model performance for tiller numbers m^{-2} of RD7, NSPT, and KDML105.

Variety	Statistic parameters	PD1	PD2	PD3	PD4	PD5
RD7						
	Slope	-6.26**	-9.37**	-5.39**	-13.48**	-17.25**
1/	intercept	1.50ns	1.61ns	1.65ns	-1.69ns	-1.76ns
	R^2	0.71	0.77	0.58	0.99	0.98
	N	12	12	10	10	11
	Bias	193.64	226.27	167.00	141.03	216.12
	RMSE	220.13	248.69	196.47	148.11	223.54
	R	0.71	1.02	0.72	0.62	1.13
	V	0.59	1.06	0.65	0.36	1.24
NSPT						
	Slope	-8.50**	-12.80**	-8.34**	-16.04**	-3.82**
1/	intercept	2.27**	2.64**	2.23ns	0.87ns	0.003ns
	R^2	0.19	0.36	0.19	0.93	0.89
	N	20	16	12	12	10
	Bias	272.60	282.60	234.08	194.97	70.20
	RMSE	314.48	316.86	271.10	207.89	75.07
	R	1.35	1.78	1.51	1.21	0.49
	V	2.11	3.61	2.73	1.50	0.25
KDML105						
	Slope	-9.14**	-15.06**	-7.67**	-6.79**	-1.13ns
1/	intercept	1.95 ns	2.87*	2.2ns	1.04ns	-1.01ns
	R^2	0.42	0.71	0.32	0.84	0.92
	N	20	16	12	12	10
	Bias	262.47	253.19	210.08	143.64	42.73
	RMSE	296.47	282.05	246.00	157.43	46.43
	R	1.24	1.34	1.17	0.68	0.25
	V	1.73	2.06	1.70	0.49	0.07

* and ** are significant levels at 0.05 and 0.01 respectively.
ns represents non-significant.
1/ Student's t-test of the 1:1 (observed : simulated) regression line.

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Leaf Area Index (LAI)

Figure 12 shows the observed and simulated LAI of RD7. The model illustrates relatively good estimate of LAI across planting dates with the small bias and RMSE (bias of 0.08, -0.53, -0.12, -0.58 and 0.21; RMSE = 0.77, 0.62, 1.1, 0.68 and 0.59 for PD1, PD2, PD3, PD4 and PD5, respectively). The minus sign indicates the model's tendency to underestimate observed data.

Based on t-test of the 1:1 (observed : simulated) regression line of LAI for RD7, the slope and intercept are not significantly different from 1.0 and 0.0, respectively in across planting dates (Table 14). This indicates that the simulated LAI of RD7 corresponded well with the observed data across planting dates.

Comparison between observed and simulated LAI of NSPT and KDML105 are shown in Figure 13 and 14. The results show that the model greatly overestimates LAI at PD1, PD2, PD3 but underestimates LAI at PD5 of both NSPT and KDML105. The model slightly overestimates LAI at PD4 of both NSPT and KDML105.

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The results of t-test (Table 14) performed on the slope and intercept of the 1:1 (observed : simulated) regression line of LAI of NSPT and KDML105 show that the slope and intercept are not significantly different from 1.0 and 0.0 which were found at PD4 and PD5 of both NSPT and KDML105. Whereas in the other planting dates, the slope and intercept are significantly differently from 1.0 and 0.0, respectively. This indicates that the model is able to simulate LAI of NSPT and KDML105 fairly well at PD4 and PD5.

Goodness of fit of LAI can be quantified by standardized bias (R) and standardized mean square error (V) (Table 14). Judging by R and V, the best fit for observed LAI of RD7 was obtained at PD2 which R = -0.18 and V = 0.03. Best fit for observed LAI of NSPT and KDML105 both were obtained at PD4 which R = 0.14 and V = 0.08 for NSPT and R = -0.01 and V = 0.03 for KDML105. The minus sign of R indicates that the model's tendency to underestimate observed data.

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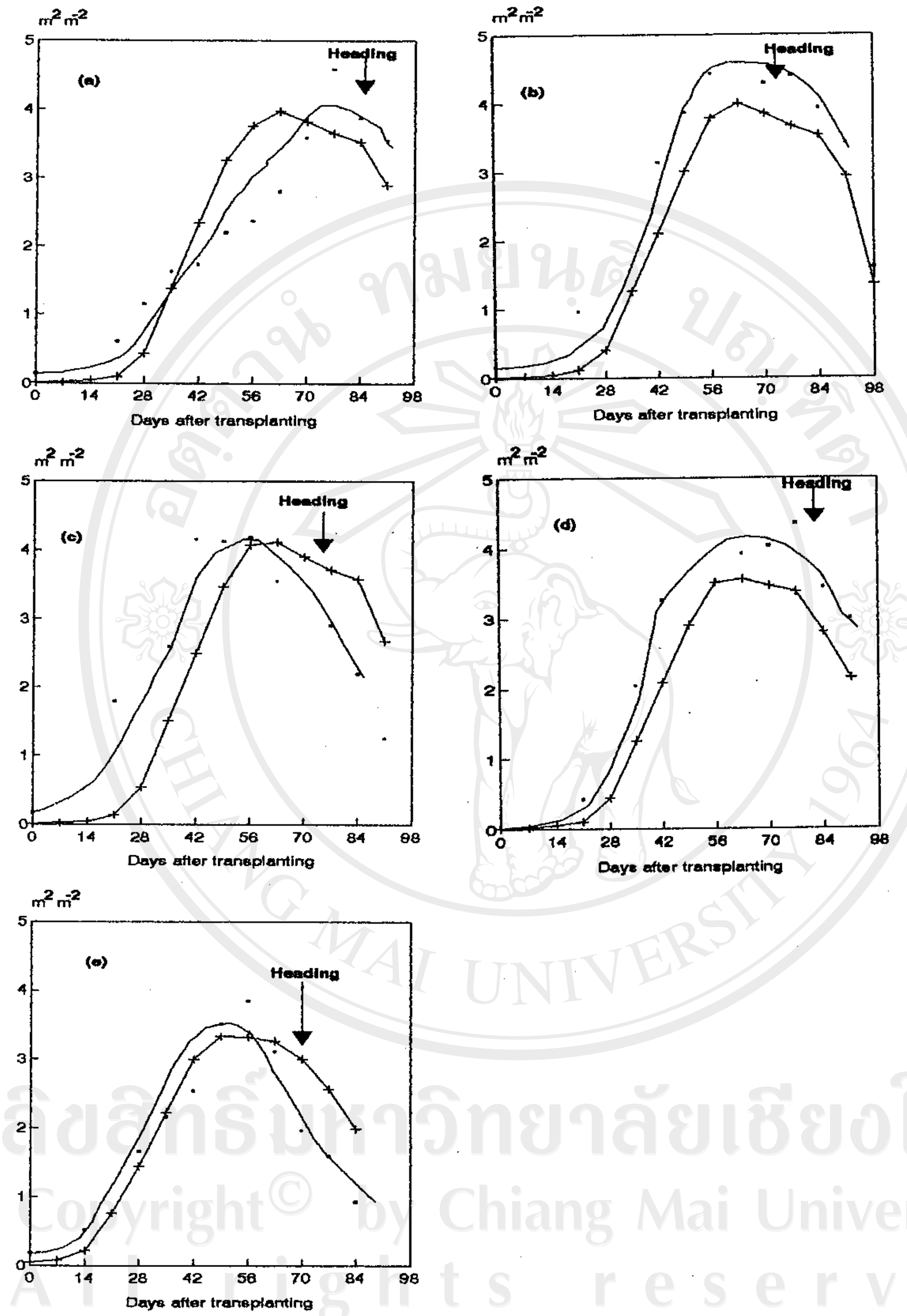

Figure 12. Comparison between simulated and observed LAI of RD7 transplanted in (a) May, (b) June, (c) July, (d) August, and (e) September. + — + and ---- represent simulated and observed data, respectively.

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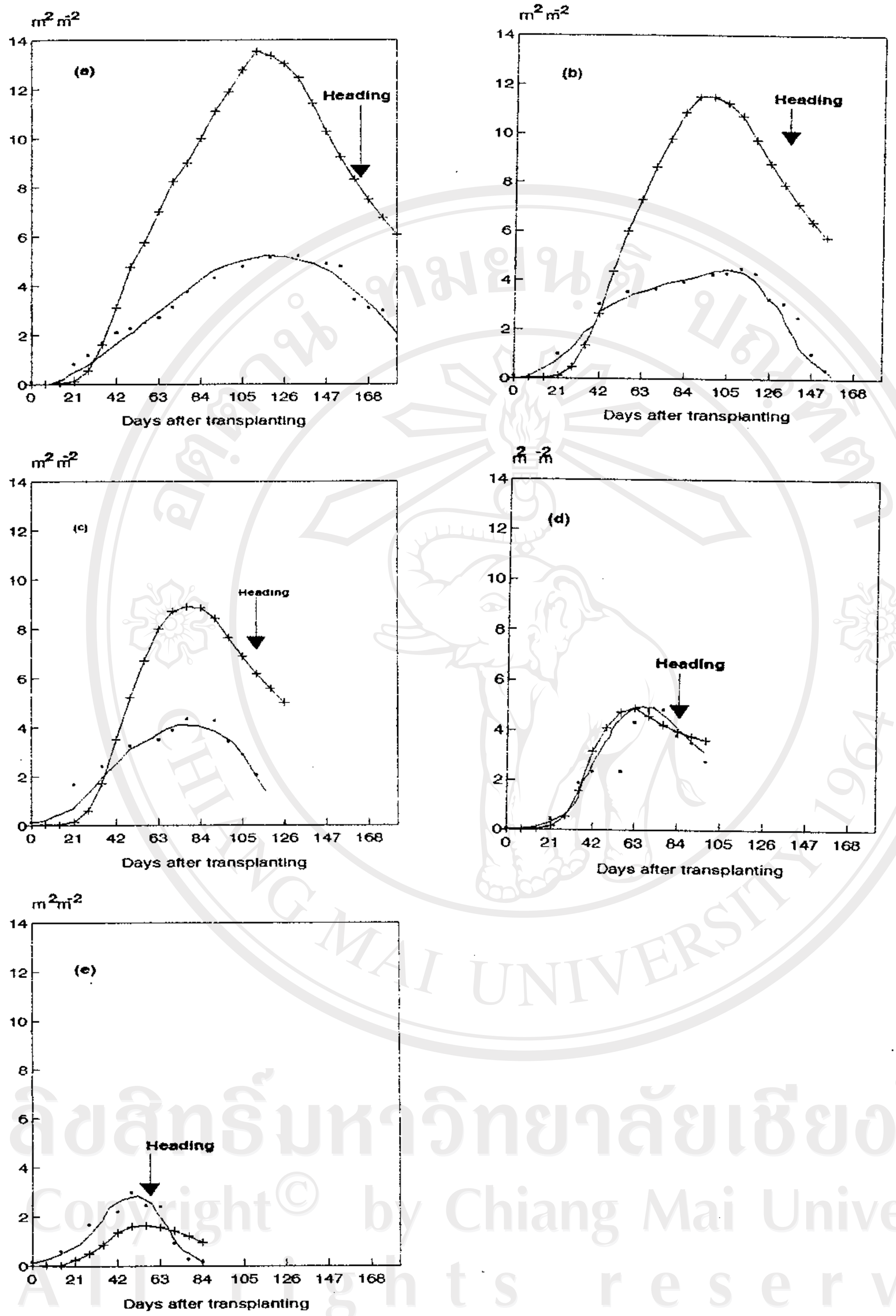

Figure 13. Comparison between simulated and observed LAI of NSPT transplanted in (a) May, (b) June, (c) July, (d) August, and (e) September. +—+ and ·—· represent simulated and observed data, respectively.

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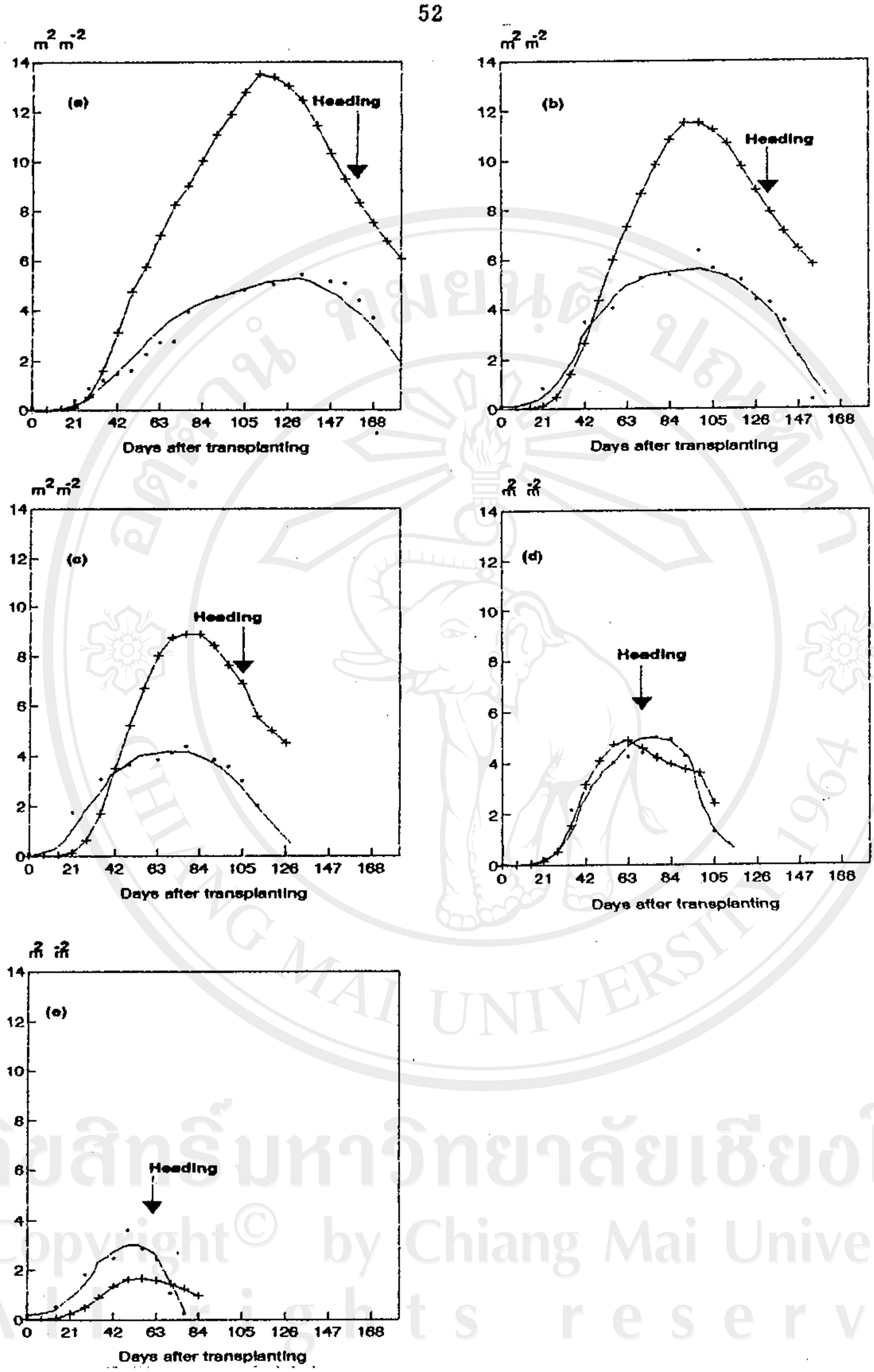

Figure 14. Comparison between simulated and observed LAI of KDML105 transplanted in (a) May, (b) June, (c) July, (d) August, and (e) September. + — + and ·—· represent simulated and observed data, respectively.

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Table 14. Statistical analysis results of model performance for LAI of RD7, NSPT and KDML105.

Variety	Statistic parameters	PD1	PD2	PD3	PD4	PD5
RD7						
	Slope	-1.62ns	0.91ns	-1.72ns	0.57ns	-0.77ns
1/	intercept	1.20ns	1.20ns	2.06ns	1.67ns	1.80ns
	R^2	0.73	0.96	0.48	0.94	0.78
	N	12	12	10	10	11
	Bias	0.08	-0.53	-0.12	-0.58	0.21
	RMSE	0.77	0.62	1.10	0.68	0.10
	R	0.03	-0.18	-0.04	-0.21	0.11
	V	0.08	0.03	0.13	0.05	0.07
NSPT						
	Slope	-27.07**	-3.30**	-7.24**	-1.24ns	0.23ns
1/	intercept	3.41**	0.52ns	1.39ns	0.34ns	0.46ns
	R^2	0.92	0.24	0.57	0.77	0.42
	N	20	16	12	12	10
	Bias	3.87	3.41	2.9	0.37	-0.36
	RMSE	4.72	4.89	3.69	0.86	0.87
	R	1.27	1.00	1.08	0.14	-0.26
	V	1.95	1.16	1.50	0.08	0.25
KDML105						
	Slope	-19.19**	-7.59**	-7.29**	-0.29ns	0.54ns
1/	intercept	1.11**	0.94**	1.73**	0.33ns	0.3ns
	R^2	0.90	0.75	0.56	0.87	0.42
	N	20	16	12	12	10
	Bias	3.92	3.14	2.67	-0.03	-0.50
	RMSE	4.67	3.87	3.52	0.60	1.05
	R	1.31	0.86	0.95	-0.01	-0.32
	V	1.85	0.86	1.26	0.03	0.29

* and ** are significant levels at 0.05 and 0.01 respectively.
ns represents non significant.
1/ Student's t-test of the 1:1 (observed:simulated) regression line.

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Above Ground Biomass Production

Figures 15-19 show the observed and simulated above ground biomass of RD7, which include stem, leaf, panicle and total dry masses. The model underestimates stem dry masses across planting dates by an average of 166.5, 174.9, 223.2, 93.86 , and 61.22 g m^{-2} (RMSE = 202.95, 213.59, 242.36, 155.42 and 123.34 g m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively (Table 15). Based on t-test of 1:1 (observed : simulated) regression line of stem dry masses of RD7, the slope and intercept are not significant from 1.0 and 0.0 which were found at PD2, PD4, and PD5. The results show that slope of stem dry masses at PD1 is not significantly different from one, but the intercept is significantly different from zero. Whereas, the stem dry masses at PD3, the slope and intercept are significantly different from one and zero, respectively. This indicates that the simulated stem dry masses of RD7 corresponded well with observed data at PD2, PD4 and PD5.

The model underestimates leaf dry masses of RD7 in early and late planting dates (PD1 and PD5) by an average of 17.88 and 14.04 g m^{-2} (RMSE = 23.74 and 22.11 g m^{-2}) but overestimate the PD2, PD3 and PD4 by an average of 21.37, 9.57 and 5.82 g m^{-2} (RMSE = 26.14, 43.69 and 27.9 g m^{-2}) respectively. The tests of significance for the intercept and slope of 1:1 (observed : simulated) regression line of leaf dry masses across planting dates show that the slope and intercept are not significantly different from one and zero except PD3 in which slope and intercept show significantly different from one and zero (Table 15). This indicates that the model is able to simulate leaf dry masses of RD7 relatively well across planting dates except PD3.

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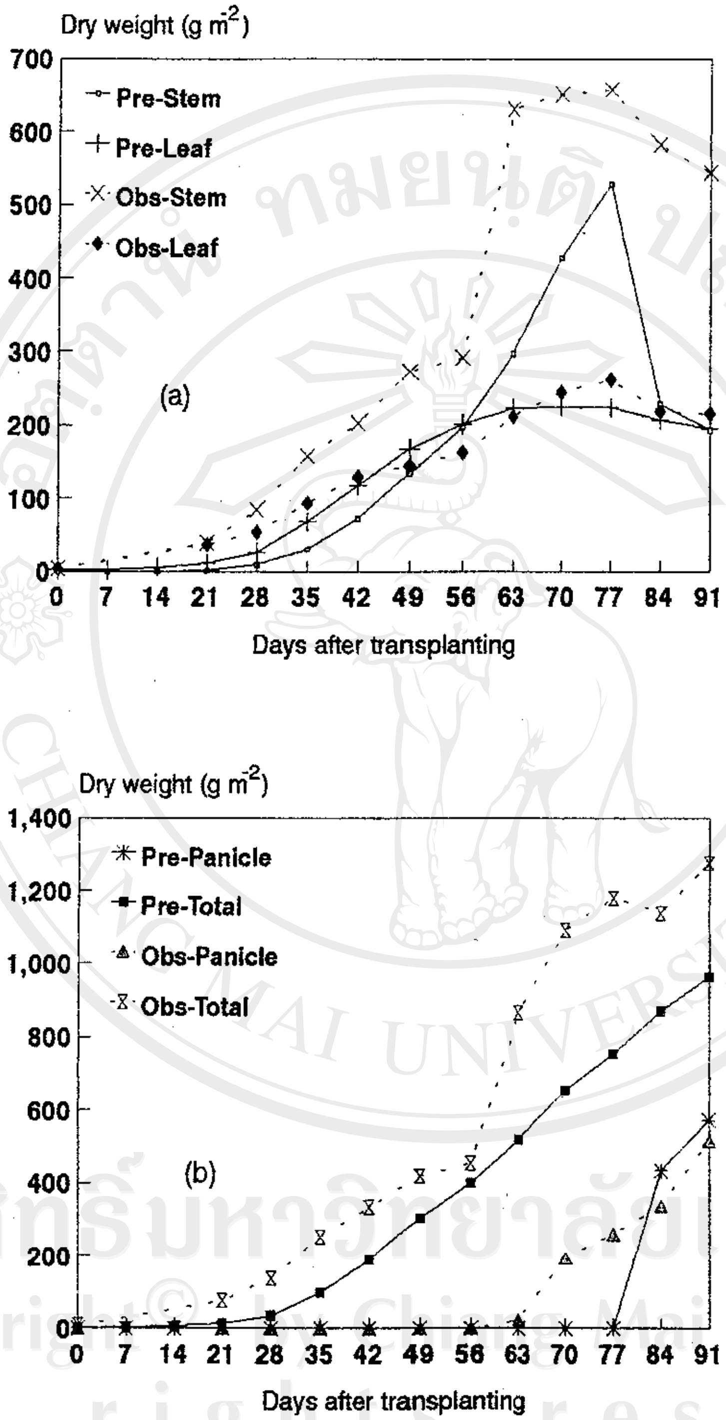

Figure 15. Comparison between simulated and observed above ground biomass of RD7 at May planting date; (a) stem and leaf, (b) total dry weight and panicle.

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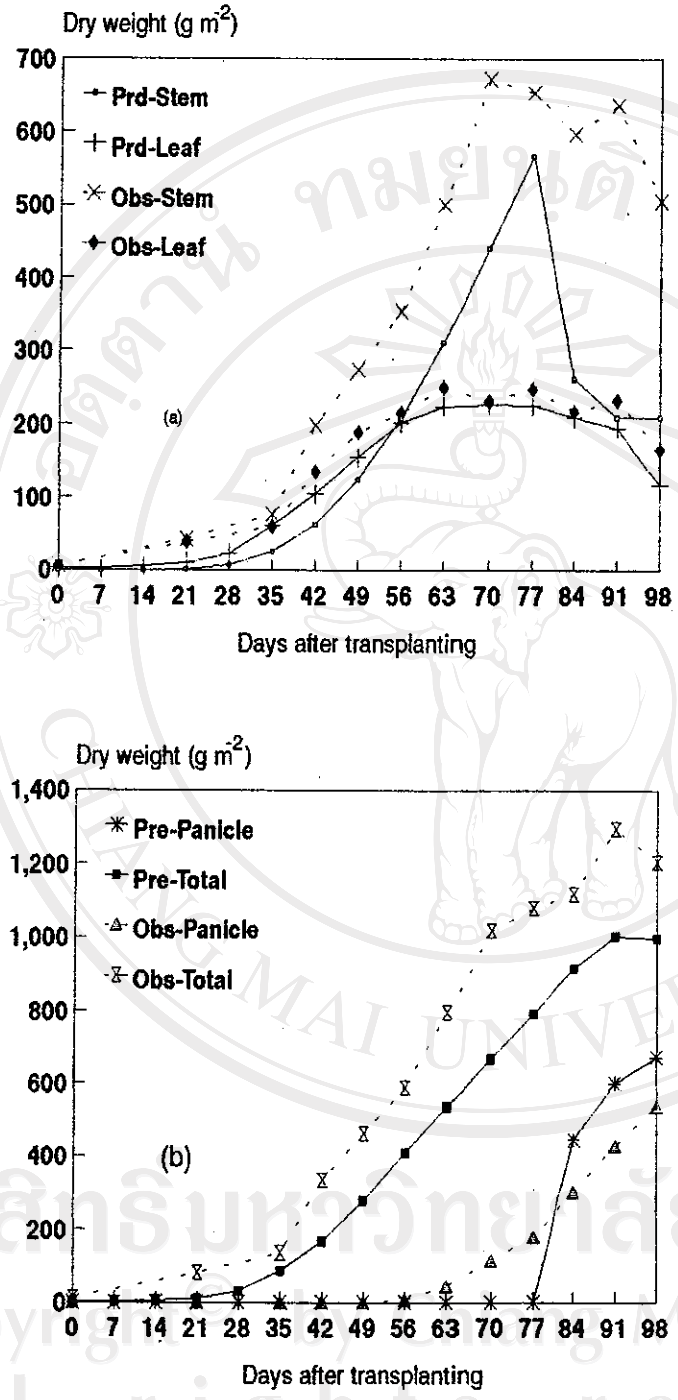

Figure 16. Comparison between simulated and observed above ground biomass of RD7 at June planting date; (a) stem and leaf, (b) total dry weight and panicle.

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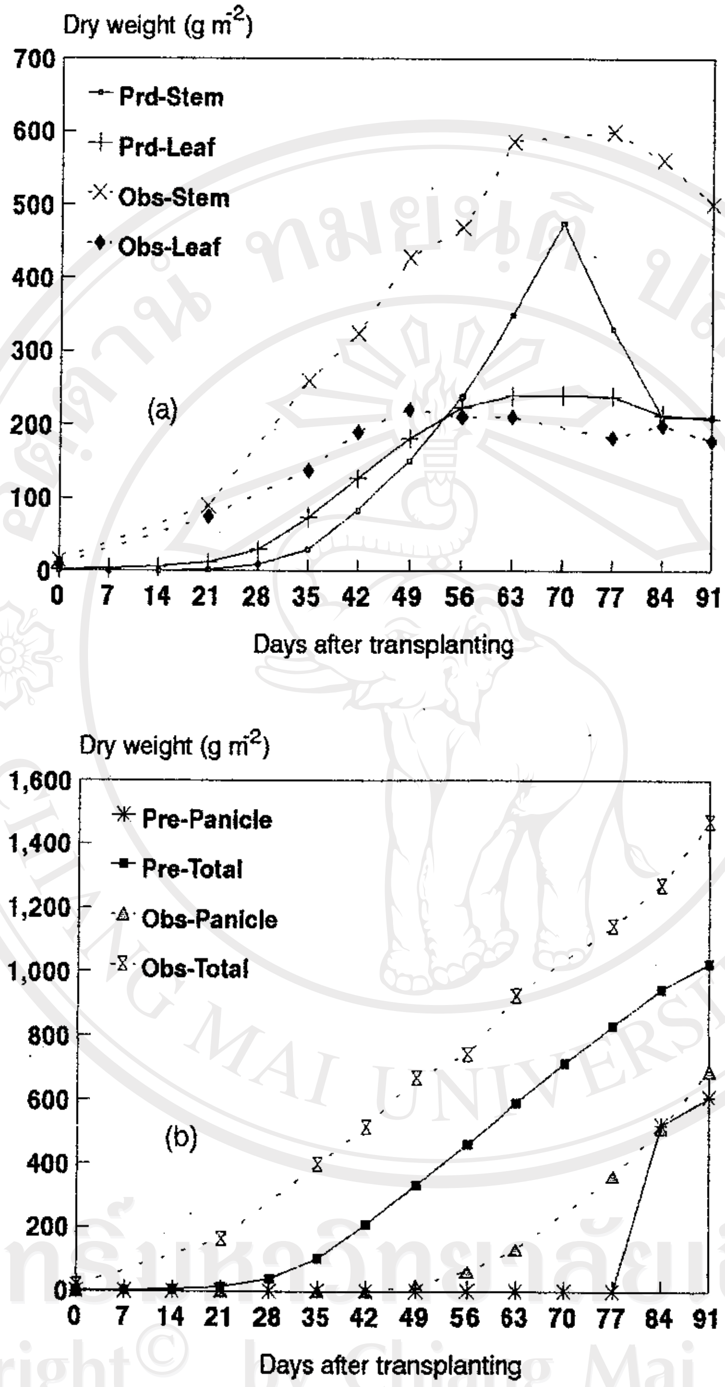

Figure 17. Comparison between simulated and observed above ground biomass of RD7 at July planting date; (a) stem and leaf, (b) total dry weight and panicle.

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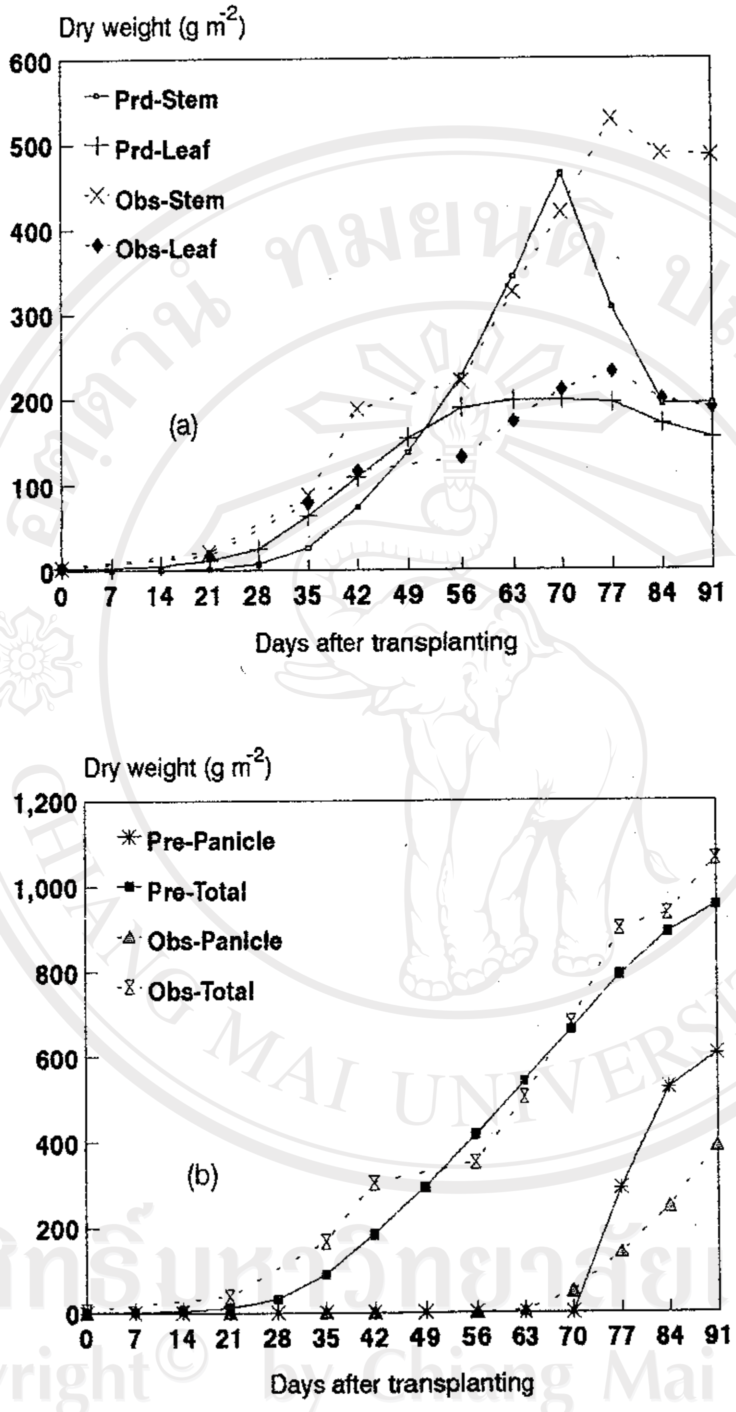

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Figure 18. Comparison between simulated and observed above ground biomass of RD7 at August planting date; (a) stem and leaf, (b) total dry weight and panicle.

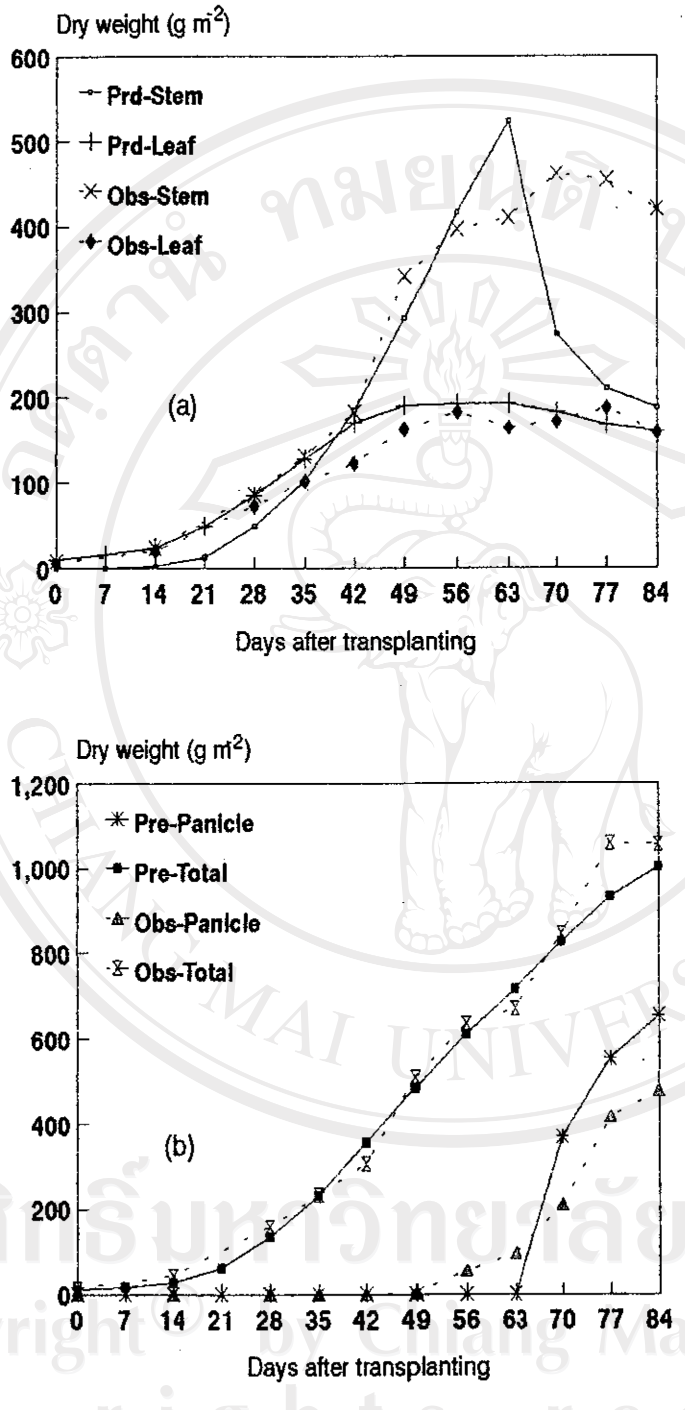

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Figure 19. Comparison between simulated and observed above ground biomass of RD7 at September planting date; (a) stem and leaf, (b) total dry weight and panicle.

Table 15. Statistical analysis results of model performance for above ground biomass (g m^{-2}) of RD7.

	Statistic parameters	PD1	PD2	PD3	PD4	PD5
Stems						
	Slope	1.71ns	1.13ns	2.31*	-0.13ns	-0.65ns
1/	intercept	2.28*	2.21ns	3.41**	2.46ns	1.59ns
	R^2	0.82	0.77	0.86	0.58	0.63
	N	12	12	10	10	11
	Bias	-166.54	-174.92	-223.27	-93.86	-61.22
	RMSE	202.95	213.59	242.36	155.42	123.34
	R	-0.49	-0.46	-0.58	-0.34	-0.23
	V	0.23	0.23	0.32	0.21	0.15
Leaves						
	Slope	-0.85ns	0.21ns	-2.79*	-0.25ns	-0.85ns
1/	intercept	1.43ns	2.01ns	2.86*	0.52ns	-0.32ns
	R^2	0.93	0.97	0.78	0.87	0.93
	N	12	12	10	10	11
	Bias	17.88	-21.37	-9.57	-5.82	14.04
	RMSE	23.74	26.14	43.69	27.90	22.11
	R	-0.06	-0.13	-0.06	-0.04	0.11
	V	0.02	0.02	0.06	0.03	0.03
Panicle						
	Bias	12.74	26.29	-7.45	64.70	42.99
	RMSE	32.21	64.65	26.39	121.57	82.81
	R	0.18	0.21	-0.06	0.83	0.43
	V	0.03	0.10	0.009	0.64	0.17
Total above ground biomass 1/	Slope	4.14**	3.92*	3.03*	0.54ns	1.37ns
	intercept	1.53ns	2.60*	4.27**	0.74ns	-0.36ns
	R^2	0.96	0.98	0.97	0.97	0.98
	N	12	12	10	10	11
	Bias	-257.49	-300.22	-373.64	-212.80	-18.12
	RMSE	247.77	212.71	301.94	72.68	48.93
	R	-0.26	-0.20	-0.25	-0.05	-0.04
	V	0.09	0.05	0.09	0.008	0.006

* and ** are significant levels at 0.05 and 0.01 respectively.
ns represents non significant.
1/ Student's t-test of the 1:1 (observed:simulated) regression line.

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The observed and simulated panicle dry masses of RD7 for each planting date could not be tested for the slope and intercept of 1:1 (observed : simulated) by linear regression due to small sample size of simulated data. However, the simulated results show overestimation by an average of 12.74, 26.29, 64.7 and 42.99 g m^{-2} (RMSE = 32.21, 64.65, 121.57, 82.81 g m^{-2}) at PD1, PD2, PD4 and PD5, respectively except PD3 which the simulated result shows underestimation by an average of 7.45 g m^{-2} (RMSE = 26.39 g m^{-2}).

The model underestimates total above ground biomass of RD7 across planting dates by an average of 257.4, 300.2, 373.6, 212.8 and 18.12 g m^{-2} (RMSE = 247.77, 212.71, 301.94, 72.68 and 48.93 g m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively. Based on t-test of the 1:1 (observed : simulated) regression line of total above ground biomass of RD7, the slope and intercept are not significantly different from 1.0 and 0.0 for PD1, PD2 and PD3 which were found at PD4 and PD5. Whereas the tested slope and intercept are significantly different from 1.0 and 0.0. This indicates that the model simulated total above ground biomass of RD7 relatively good at PD4 and PD5.

Figures 20 to 24 show the observed and simulated above ground biomass of NSPT which included stem, leaf, panicle and total dry masses. The model underestimated stem dry masses across planting dates by an average of 628.80, 636.86, 466.37, 251.10 and 139.33 g m^{-2} (RMSE = 796.96, 754.00, 530.92, 311.11 and 161.62 g m^{-2}) for PD1, PD2,PD3, PD4 and PD5, respectively.

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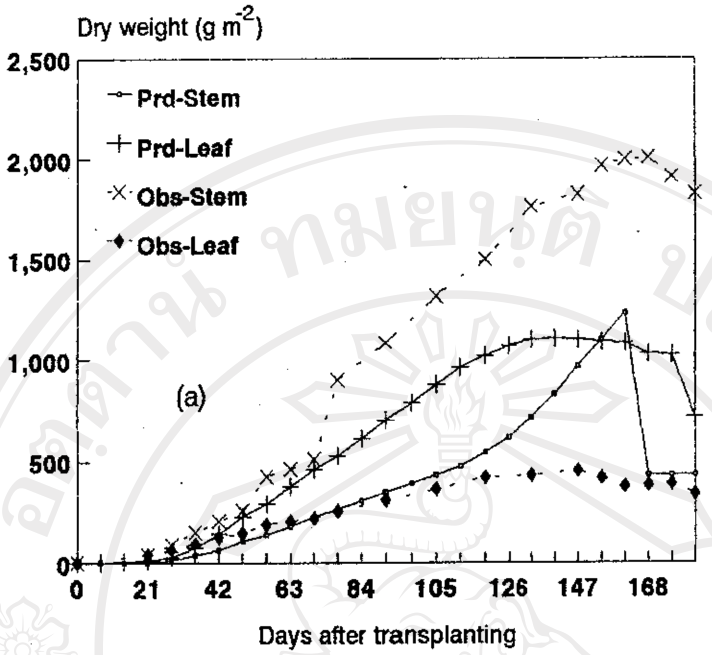

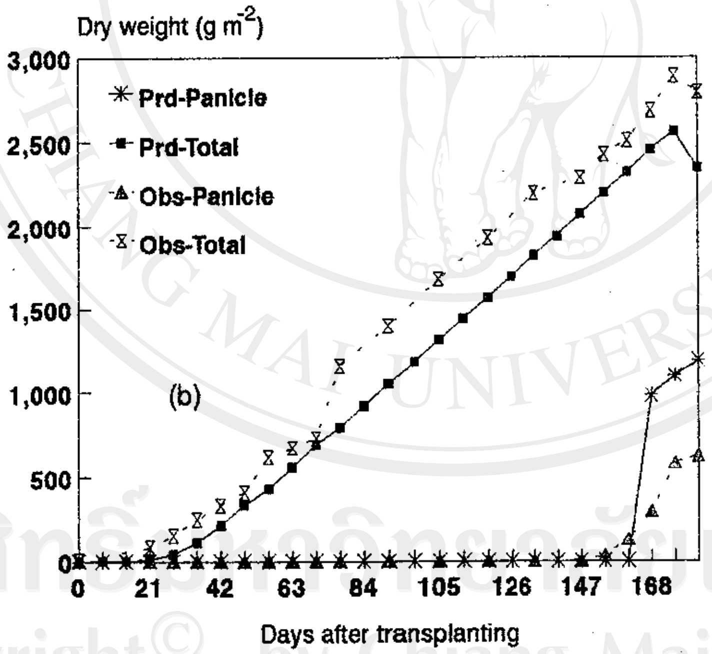

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Figure 20. Comparison between simulated and observed above ground biomass of NSPT at May planting date; (a) stem and leaf, (b) total dry weight and panicle.

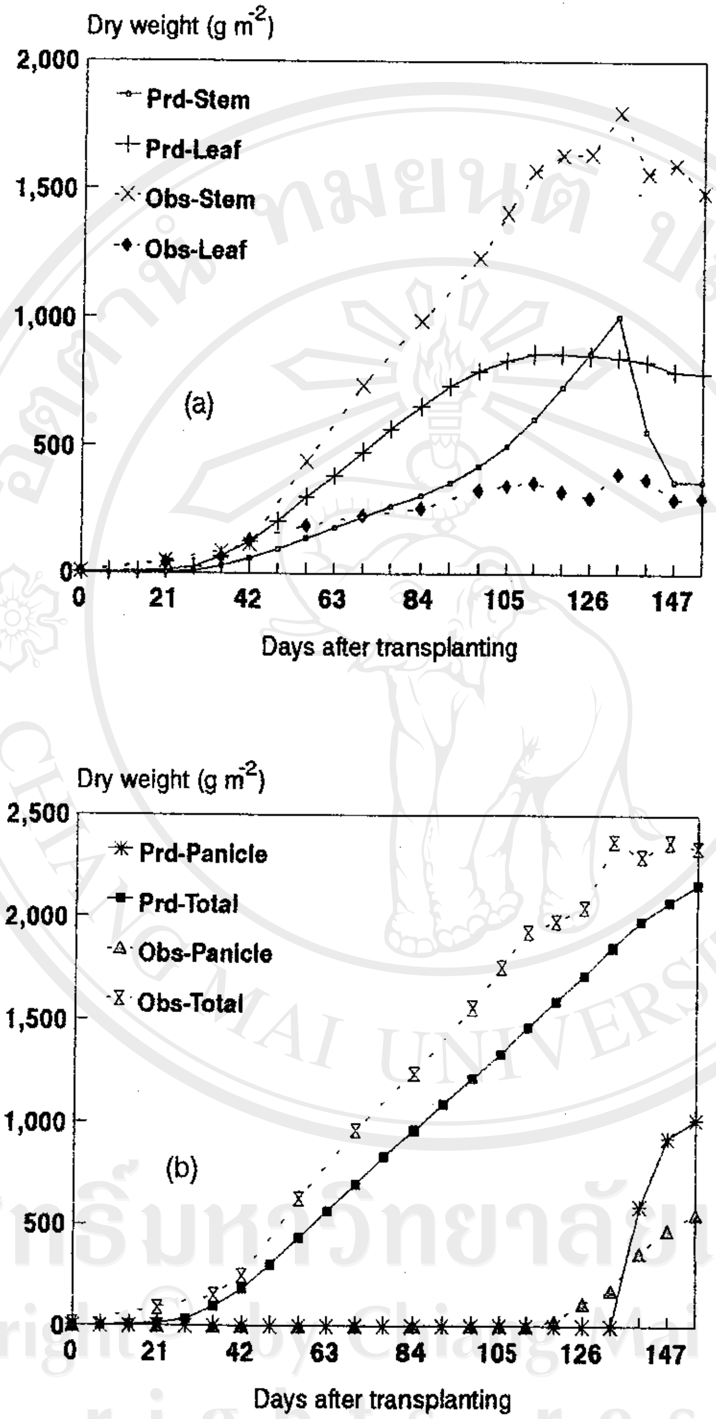

Figure 21. Comparison between simulated and observed above ground biomass of NSPT at June planting date; (a) stem and leaf, (b) total dry weight and panicle.

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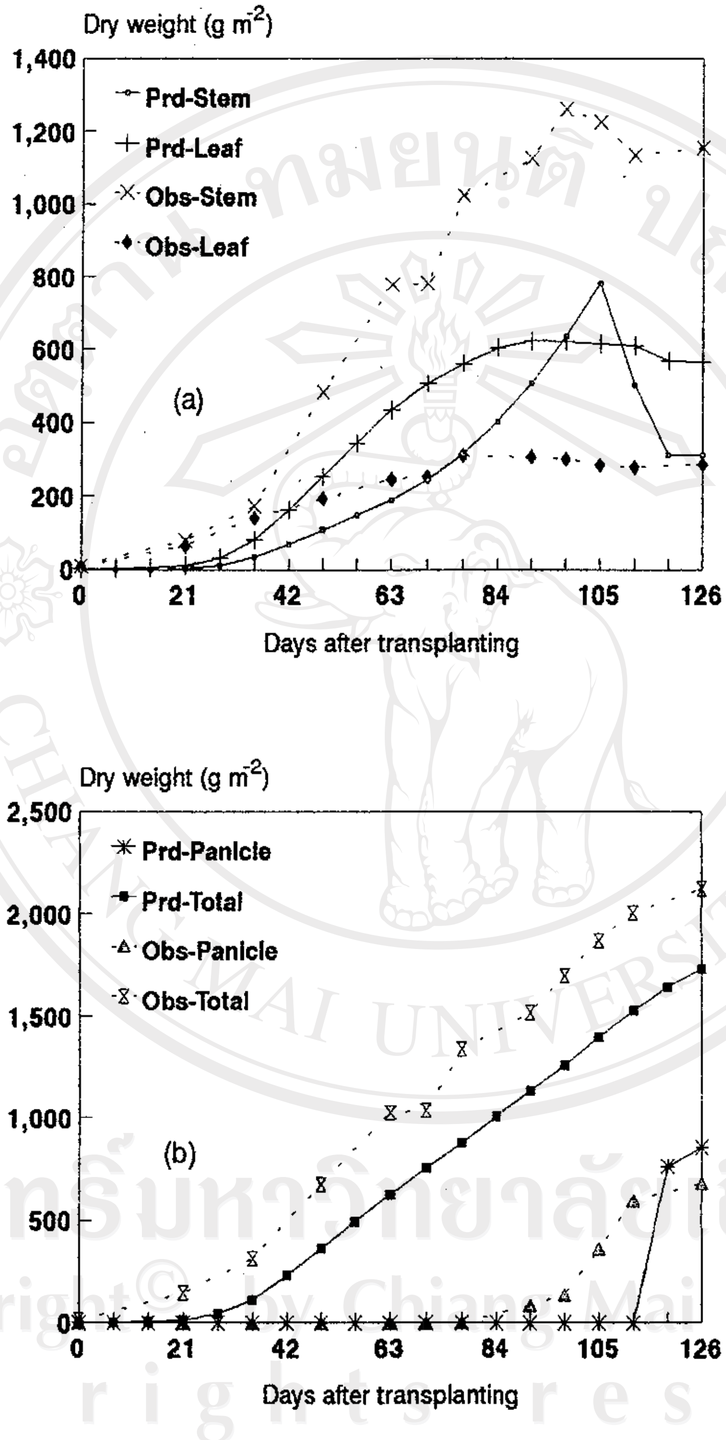

Figure 22. Comparison between simulated and observed above ground biomass of NSPT at July planting date; (a) stem and leaf, (b) total dry weight and panicle.

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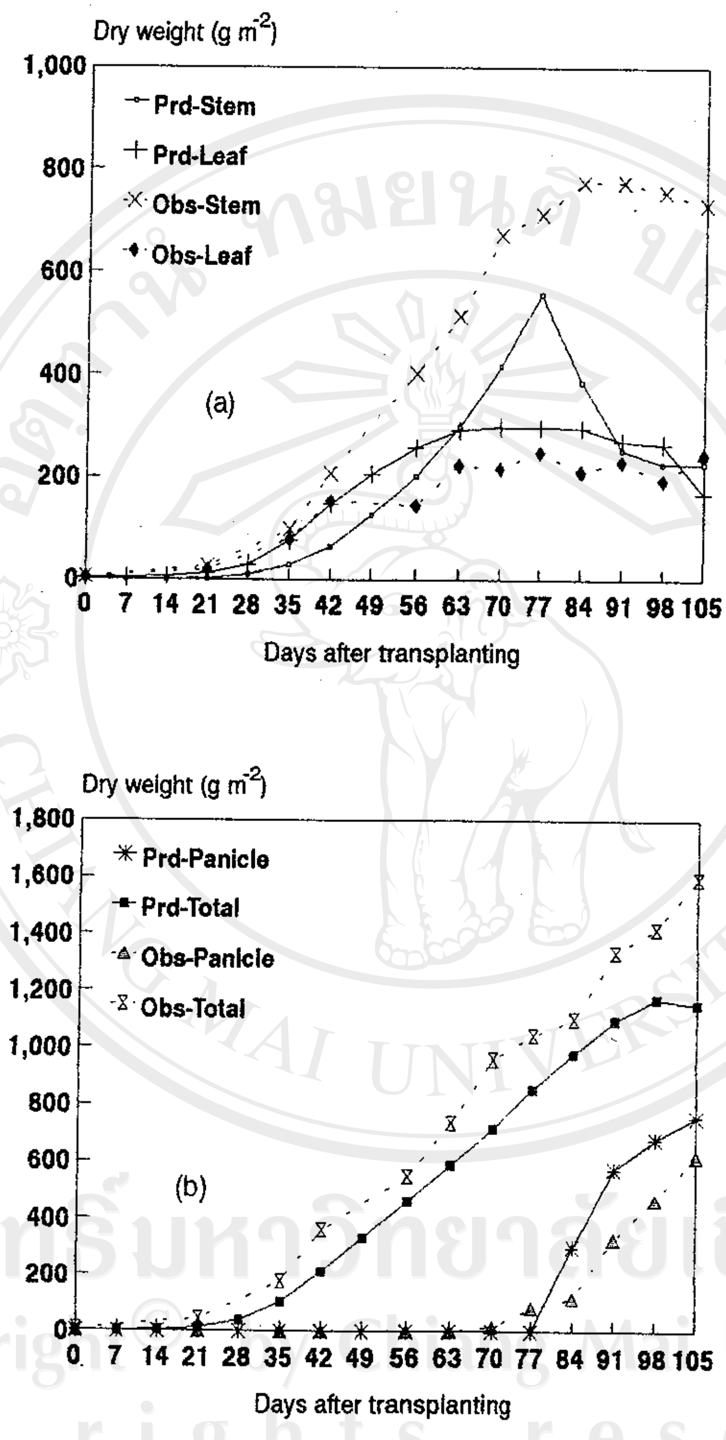

Figure 23. Comparison between simulated and observed above ground biomass of NSPT at August planting date; (a) stem and leaf, (b) total dry weight and panicle.

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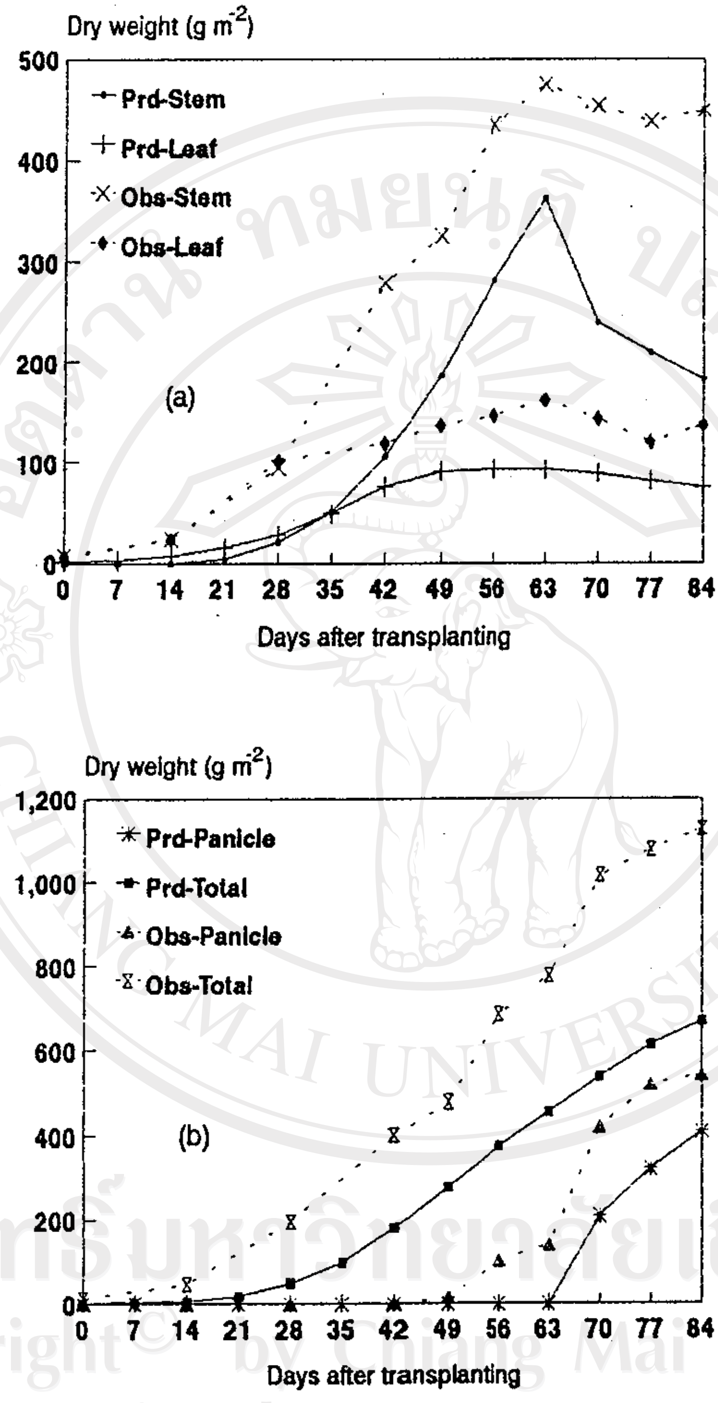

Figure 24. Comparison between simulated and observed above ground biomass of NSPT at September planting date; (a) stem and leaf, (b) total dry weight and panicle.

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The results of t-test on the slope and intercept of the 1:1 (observed : simulated) regression line for stem dry masses of NSPT were found not significantly different from 1.0 and 0.0 at PD4 and PD5, respectively (Table 16). Whereas the slope and intercept of PD1, PD2, and PD3 are significantly different from 1.0 and 0.0. This indicates that the simulated stem dry masses of NSPT corresponded well with the observed data at PD4 and PD5.

The simulated leaf dry masses of NSPT was overestimated at PD1, PD2 and PD3 by an average of 333.46, 332.15 and 184.20 g m^{-2} (RMSE = 433.03, 391.79 and 236.77 g m^{-2}) but underestimated at PD4 and PD5 by an average of 134.8 and 45.86 g m^{-2} (RMSE = 171.55 and 50.36 g m^{-2}). The tests of significance for the intercept and slope of 1:1 (observed : simulated) regression line for leaf dry masses of NSPT reveal that the slope and intercept are not significantly different from 1.0 and 0.0 which were found only at PD5. This indicates that the model is able to simulate leaf dry masses fairy well at PD5.

The model overestimates panicle dry masses of NSPT across planting dates except PD5 when compared with observed data. The simulated results the observed data overestimates by an averages of 88.63, 71.18, 76.5 and 65.04 g m^{-2} (RMSE = 230.5, 170.76, 156.56 and 114.86 g m^{-2}) for PD1, PD2, PD3 and PD4 ; and the observed data underestimates by an average of 54.12 g m^{-2} (RMSE = 100.57 g m^{-2}) for PD5. The simulated and observed panicle dry masses of NSPT could not be tested for significance of the slope and intercept of 1:1 (observed : simulated) regression line due to small sample size of simulated data.

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Table 16. Statistical analysis results of model performance for above ground biomass (g m^{-2}) of NSPT.

	Statistic parameters	PD1	PD2	PD3	PD4	PD5
Stems						
	Slope	3.14**	3.71**	2.40*	1.49ns	2.04ns
1/	intercept	2.34*	2.20*	2.75*	1.71ns	1.90ns
	R^2	0.73	0.81	0.80	0.69	0.86
	N	20	16	12	12	10
	Bias	-628.80	-636.86	-466.37	-251.10	-139.33
	RMSE	796.96	754.00	530.92	311.11	161.62
	R	-0.62	-0.62	-0.61	-0.53	-0.55
	V	0.40	0.39	0.36	0.31	0.26
Leaves						
	Slope	-47.68**	-27.9**	-17.62**	4.01**	2.19ns
1/	intercept	6.10**	3.06**	3.94**	-0.38ns	1.84ns
	R^2	0.97	0.94	0.93	0.87	0.89
	N	20	16	12	12	10
	Bias	333.46	322.15	184.20	-134.87	-45.86
	RMSE	433.03	391.79	236.77	171.55	50.36
	R	1.27	1.33	0.83	-0.80	-0.42
	V	2.10	2.08	0.95	0.82	0.18
Panicle						
	Bias	88.63	71.18	76.50	65.04	-54.12
	RMSE	230.50	170.76	156.56	114.86	100.57
	R	1.18	0.82	0.56	0.51	-0.37
	V	1.31	0.70	0.31	0.22	0.14
Total						
above	Slope	3.67**	4.01**	4.8**	4.26**	11.12**
ground	intercept	3.03**	2.11ns	3.86**	0.90ns	2.36*
biomass	R^2	0.99	0.99	0.99	0.98	0.99
1/	N	20	16	12	12	10
	Bias	-215.26	-266.03	-419.72	-193.17	-415.82
	RMSE	250.41	300.73	360.25	199.88	310.95
	R	-0.16	-0.19	-0.24	-0.18	-0.29
	V	0.02	0.03	0.07	0.04	0.13

* and ** are significant levels at 0.05 and 0.01 respectively.
ns represents non significant.
1/ Student's t-test of the 1:1 (observed:simulated) regression line.

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The model underestimates total above ground biomass of NSPT across planting dates by an average of 215.26, 266.03, 419.72, 193.17 and 415.82 g m^{-2} (RMSE = 250.41, 300.73, 360.25, 199.88 and 310.95 g m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively. The results of t-test performed on the slope and intercept of the 1:1 (observed : simulated) regression line for total above ground biomass of NSPT indicates that the slope across planting dates are significantly different from 1.0 and the intercept also are significantly different from 0.0 except PD2 and PD4 which the intercept is not significantly different from 0.0 (Table 16). However, all the planting date treatments of NSPT reveal both slope and intercept are significantly different from 1.0 and 0.0. Therefore, this indicates that the simulated total above ground biomass of NSPT is not corresponded well with the observed results across planting dates.

Figures 25 to 29 show the observed and simulated above-ground biomass of KDML105 which included stem, leaf, panicle and total dry masses. The simulated stem dry masses are underestimated by an average of 470.02, 605.45, 344.83, 192.58, and 102.38 g m^{-2} (RMSE = 645.02, 714.45, 403.72, 263.01 and 118.62 g m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively (Table 17). The model overestimates leaf dry masses by an average of 341.89, 228.02, 153.55 and 18.29 g m^{-2} (RMSE = 430.99, 284.62, 215.81 and 49.80 g m^{-2}) for PD1, PD2, PD3 and PD4, respectively. However, the model underestimates leaf dry masses at PD5 by an average of 42.4 g m^{-2} (RMSE = 46.17 g m^{-2}).

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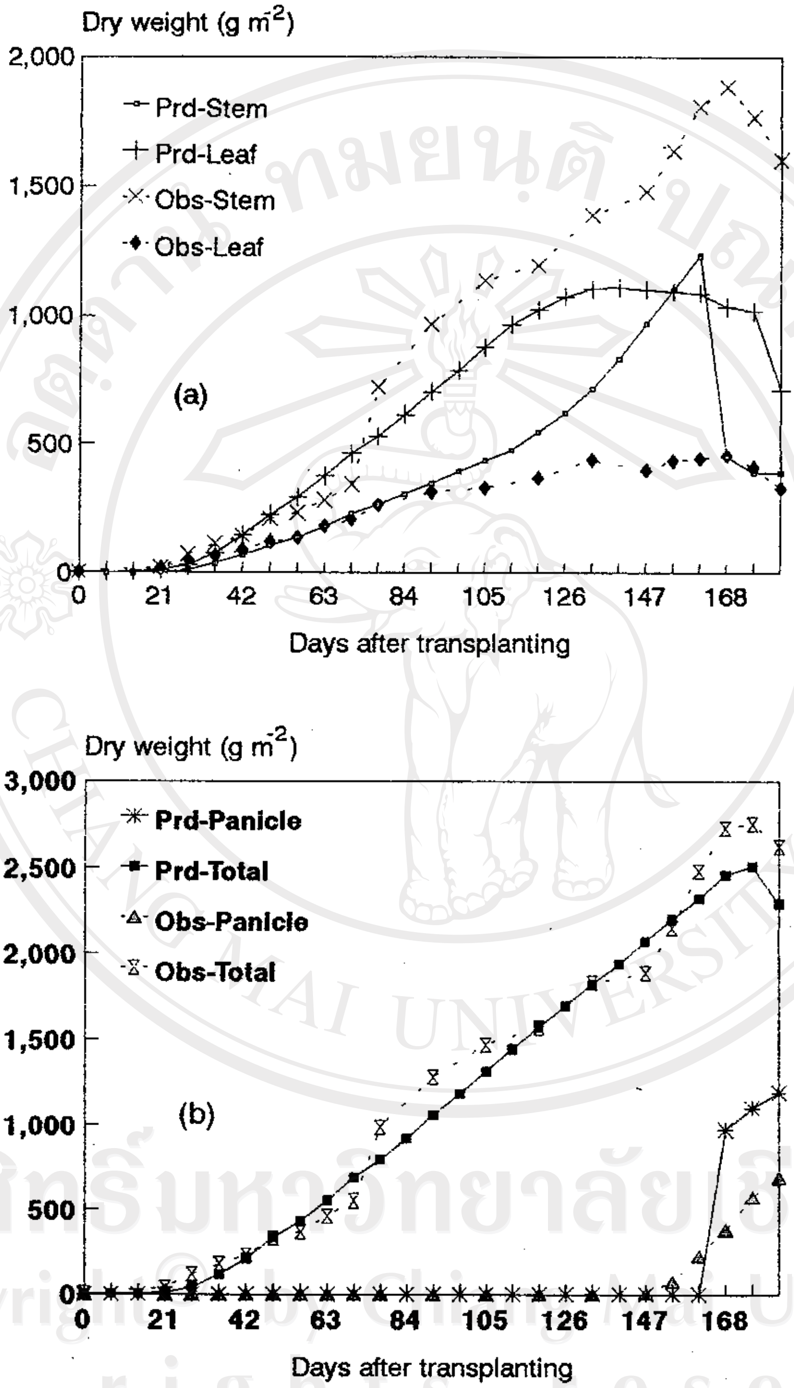

Figure 25. Comparison between simulated and observed above ground biomass of KDML105 at May planting date; (a) stem and leaf, (b) total dry weight and panicle.

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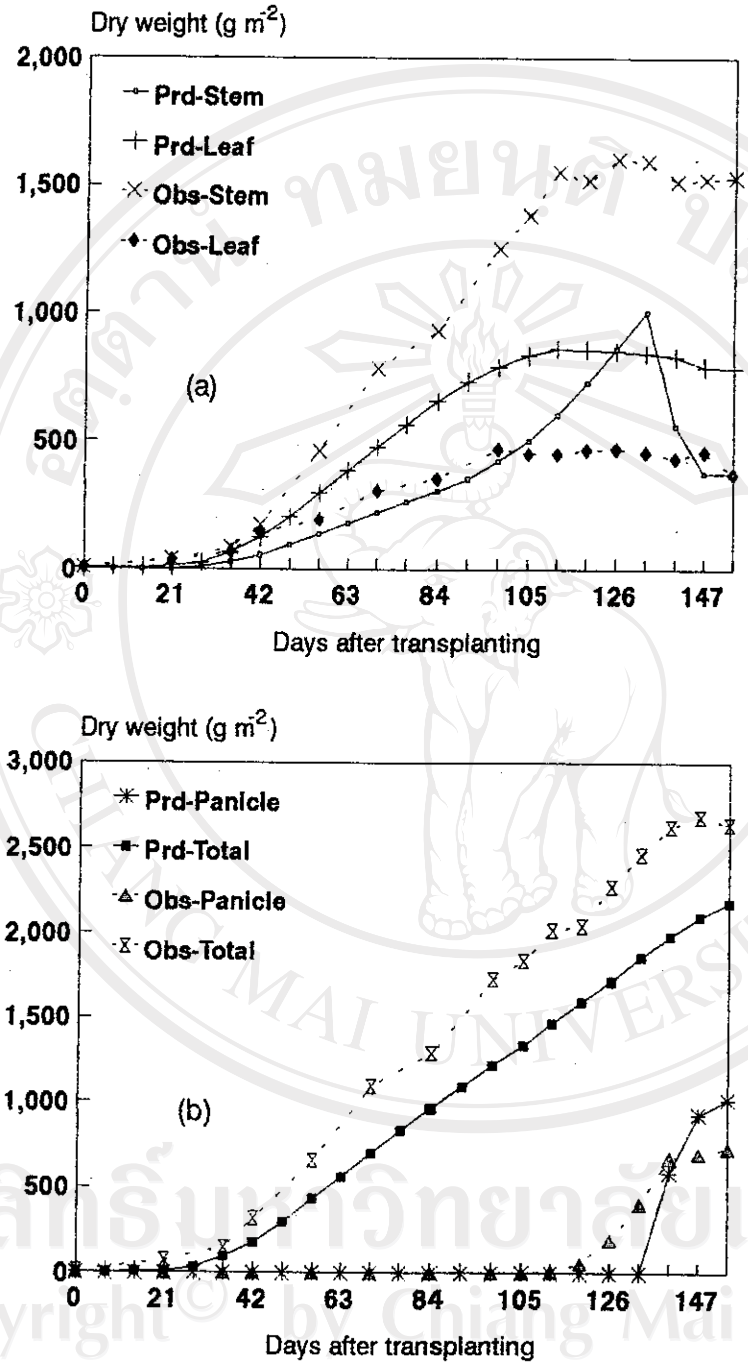

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Figure 26. Comparison between simulated and observed above ground biomass of KDML105 at June planting date; (a) stem and leaf, (b) total dry weight and panicle.

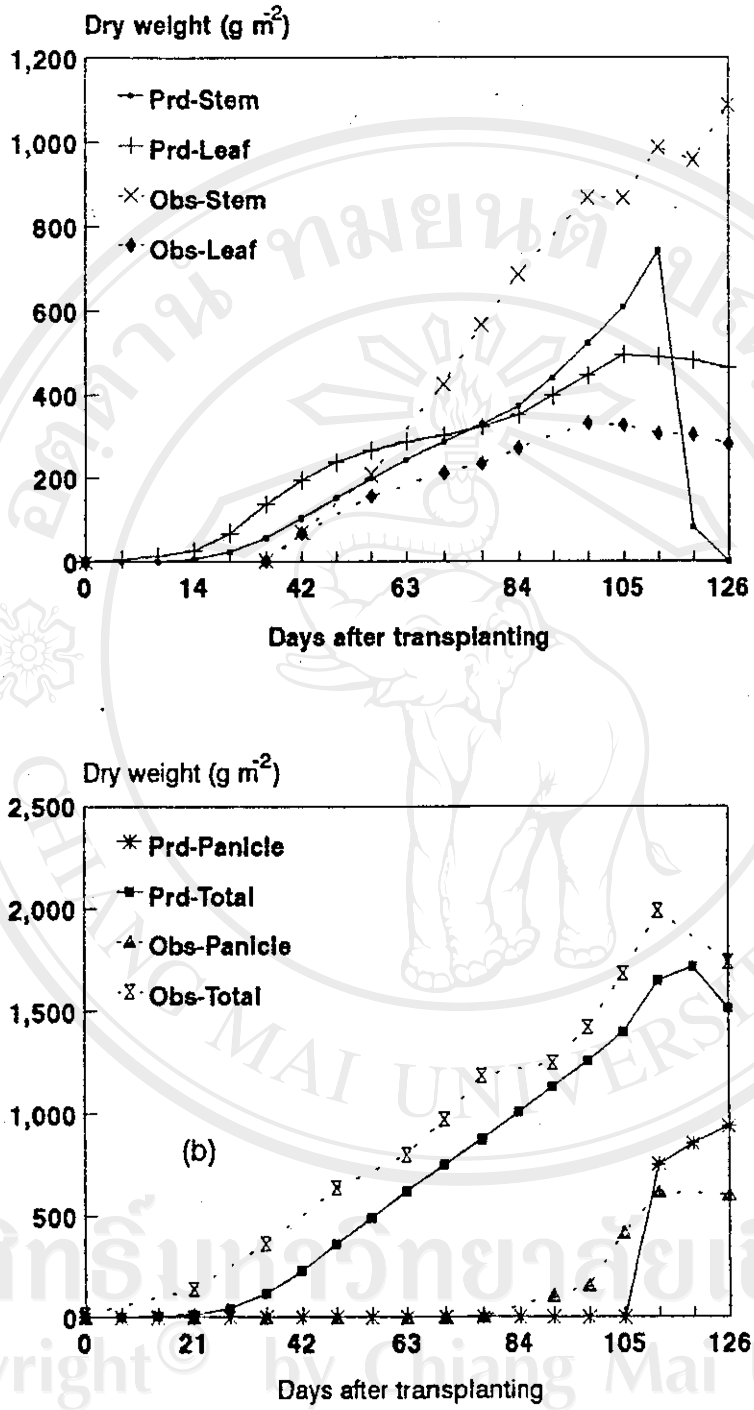

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Figure 27. Comparison between simulated and observed above ground biomass of KDML105 at July planting date; (a) stem and leaf, (b) total dry weight and panicle.

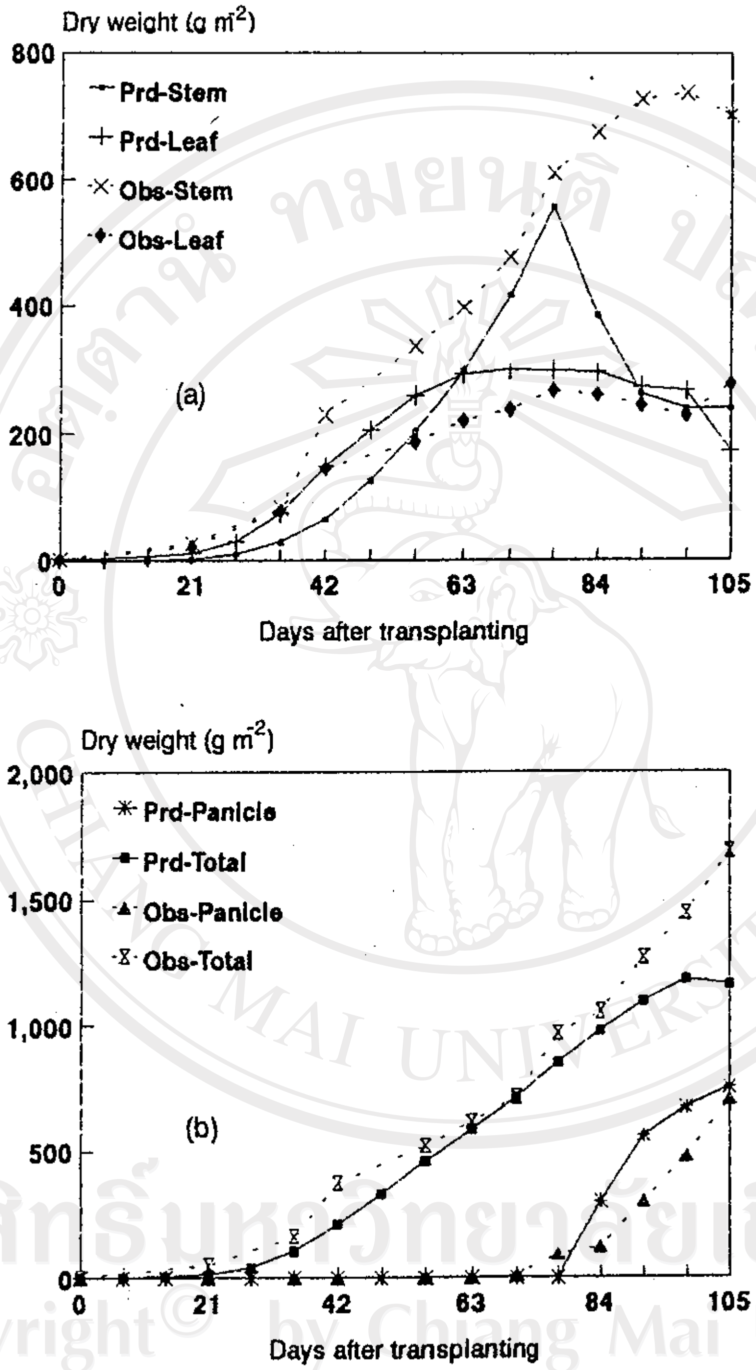

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Figure 28. Comparison between simulated and observed above ground biomass of KDML105 at August planting date; (a) stem and leaf, (b) total dry weight and panicle.

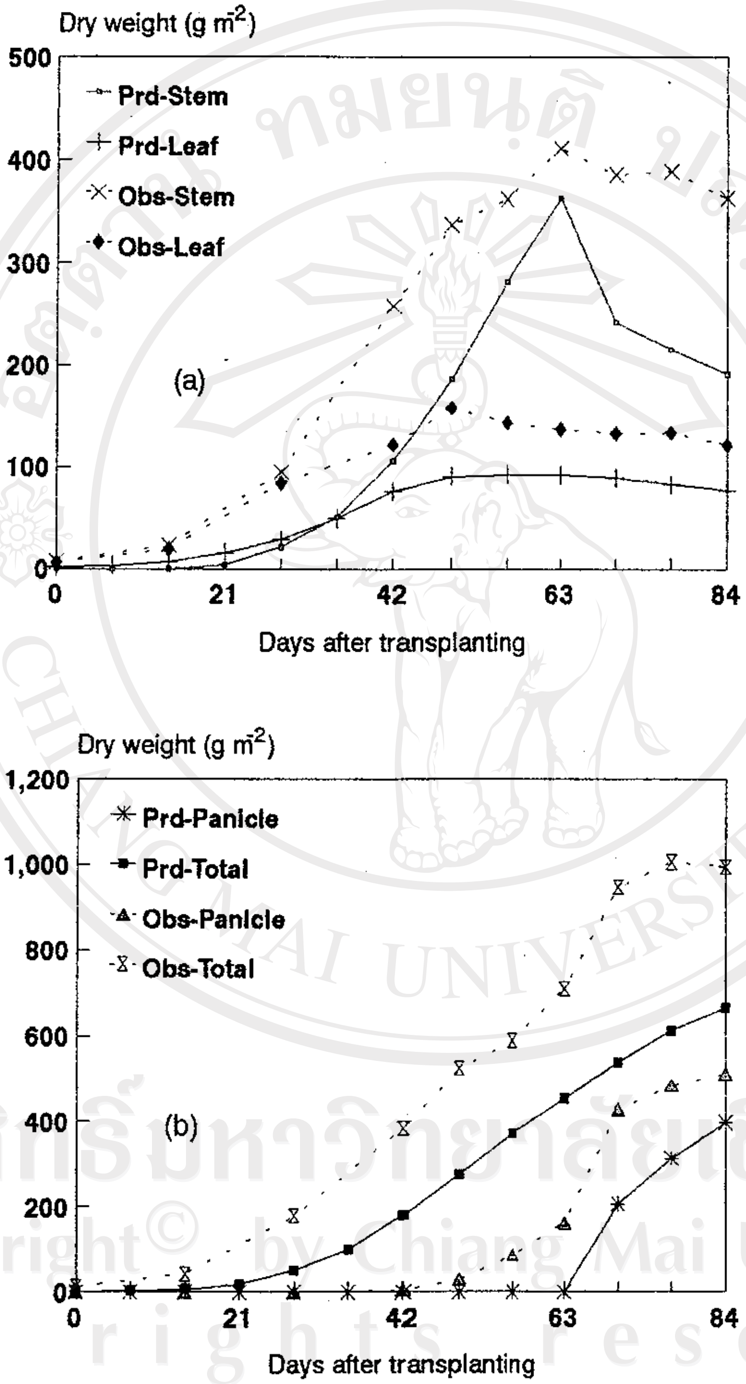

Figure 29. Comparison between simulated and observed above ground biomass of KDML105 at September planting date; (a) stem and leaf, (b) total dry weight and panicle.

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Table 17. Statistical analysis results of model performance for above ground biomass (g m^{-2}) of KDML105.

	Statistic parameters	PD1	PD2	PD3	PD4	PD5
Stems						
1/	Slope	2.12*	2.96*	0.83ns	0.61ns	1.13ns
	intercept	1.92ns	2.35*	2.81*	1.60ns	2.18ns
	R^2	0.67	0.76	0.68	0.57	0.86
	N	20	16	12	12	10
	Bias	-470.02	-605.45	-344.83	-192.58	-102.38
	RMSE	645.02	714.45	403.72	263.01	118.62
	R	-0.55	-0.61	-0.55	-0.46	-0.39
	V	0.35	0.38	0.31	0.28	0.15
Leaves						
1/	Slope	-49.00**	-7.60**	-11.67**	-1.94ns	3.41**
	intercept	3.58**	0.79ns	3.51**	1.10ns	1.93ns
	R^2	0.98	0.85	0.83	0.82	0.95
	N	20	16	12	12	10
	Bias	341.89	228.02	153.55	18.29	-42.40
	RMSE	430.99	284.62	215.81	49.80	46.17
	R	1.35	0.67	0.68	0.10	-0.40
	V	2.10	0.53	0.77	0.06	0.16
Panicle	Bias	80.40	26.90	75.40	57.32	-0.50
	RMSE	208.07	94.38	152.55	109.00	95.13
	R	0.97	0.21	0.55	0.43	-0.35
	V	0.91	0.10	0.30	0.17	0.13
Total above ground biomass 1/	Slope	1.70ns	9.12**	1.74ns	2.46*	7.02**
	intercept	-0.03**	2.42*	3.39**	0.03ns	2.27ns
	R^2	0.98	0.99	0.98	0.96	0.98
	N	20	16	12	12	10
	Bias	-63.01	-397.01	-324.81	-135.49	-223.08
	RMSE	152.33	448.53	227.8	188.63	257.61
	R	-0.05	-0.26	-0.17	-0.15	-0.28
	V	0.01	0.06	0.03	0.04	0.12

* and ** are significant levels at 0.05 and 0.01 respectively.
ns represents non significant.
1/ Student's t-test of the 1:1 (observed:simulated) regression line.

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The results of t-test performed on the intercept and slope of the 1:1 (observed : simulated) regression line for stem and leaf dry masses of KDML105 show that the slope and the intercept are not significantly different from 1.0 and 0.0 which were found at PD4 and PD5 for stem dry masses and only PD5 for leaf dry masses. This indicates that the model is able to simulate relatively well of stem dry masses for KDML105 at PD4 and PD5 and leaf dry masses at PD5.

The simulated and observed panicle dry masses of KDML105 also could not be tested for slope and intercept of 1:1 (observed : simulated) regression line due to the small sample size of simulated data. However, the simulated panicle dry masses show overestimation across planting dates by an average of 80.40, 26.90, 75.40 and 57.32 g m^{-2} (RMSE = 208.07, 94.38, 152.55 and 109.00 g m^{-2}) for PD1, PD2, PD3 and PD4, respectively except PD5 which shows underestimation by an average of 0.50 g m^{-2} (RMSE = 95.13 g m^{-2}).

The simulated total above ground biomass of KDML105 is underestimated across planting dates by an average of 63.01, 397.01, 324.81, 135.49 and 223.08 g m^{-2} (RMSE = 152.33, 448.53, 227.80, 188.63 and 257.61 g m^{-2}) for PD1, PD2, PD3, PD4 and PD5, respectively. Based on the t-test of the significance for the slope and intercept of 1:1 (observed : simulated) regression line, the results show that both slope and intercept are not significantly different from 1.0 and 0.0, respectively for all planting date treatments. This indicates that the simulated total above-ground biomass of KDML105 is not corresponded well with the observed results.

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Goodness of fits are judged by standardized bias (R) and a standardized mean square error (V) (Table 15, 16, and 17). The best fits are observed in stem, leaf, panicle and total above ground biomass of RD7 which are obtained at PD5 for stem (R = -0.23, V = 0.15) and total above ground biomass (R = -0.04, V = 0.006), at PD1 for leaf (R = -0.06, V = 0.02) and at PD3 for panicle (R = -0.06, V = 0.009). The best fits were observed in stem, leaf, panicle and total above ground biomass of NSTP which are obtained at PD5 for stem (R = -0.55, V = 0.26), leaf (R = 0.42, V = 0.18), and panicle (R = 0.37, V = 0.14) and at PD1 for total above ground biomass (R = 0.16, V = 0.02). The best fits are observed in stem, leaf, panicle and total above ground biomass of KDML105 which are obtained at PD5 for stem (R = 0.39, V = 0.15), at PD4 for leaf (R = 0.10, V = 0.60), at PD2 for panicle (R = 0.21, V = 0.10) and at PD1 for total above ground biomass (R = -0.05, V = 0.01).

Grain Yield and Yield Components

Table 18 shows the comparison between simulated and observed grain yield and yield components of RD7, NSPT and KDML105. The difference in percentage between the simulated and observed was calculated as ((Simulated - observed) ÷ observed) x 100. Generally, the simulated data greatly overestimated panicle numbers m^{-2} by an average of 82.9% for RD7 (bias of 189.6 numbers m^{-2}; RMSE = 195.08 numbers m^{-2}), 129% for NSPT (bias of 175.4 numbers m^{-2}; RMSE = 181.46 numbers m^{-2}) and 82% for KDML105 (bias of 140 numbers m^{-2}; RMSE = 148.68 numbers m^{-2}). The observed panicle numbers m^{-2} ranged between 190-266 for RD7, 121-193 for NSPT and 142-168 for KDML105. While the simulated panicle numbers m^{-2} ranged between 390-486 for RD7 and 227-345 for both

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Table 18. Simulated and observed grain yield and yield components of three rice varieties at five different planting dates

Planting dates	Grain yield ($Kg\ ha^{-1}$)		Panicle m^{-2}		Spikelet m^{-2}		1000-grain (g)	
	Si	Ob	Si	Ob	Si	Ob	Si	Ob
RD7								
PD1	6093	3693	486	237	18714	27072	28	27.9
PD2	6415	3954	461	266	19710	27531	28	27.2
PD3	6178	5582	409	212	18974	29032	28	28.0
PD4	6093	6022	345	238	18713	32746	28	27.2
PD5	6855	3564	390	190	21053	22890	28	27.8
Mean	6326	4563	418	228	19432	27854.2	28	27.62
Bias		1963.8		189.6		-8421.40		0.380
RMSE		2198.70		195.08		9300.40		0.516
NSPT								
PD1	11123	4230	328	121	34165	21945	28	28.2
PD2	10002	4607	339	127	30720	25211	28	28.1
PD3	8883	4943	313	132	27285	26434	28	27.9
PD4	7277	5348	345	153	22657	27116	28	29.0
PD5	4258	5014	227	142	13077	21019	28	28.9
Mean	8308	4828	310	135	25580	24345	28	28.42
Bias		3480.2		175.4		1235.80		-0.42
RMSE		4391.71		181.46		7157.54		0.61
KDML105								
PD1	11122	4550	328	145	35426	26852	27	27.5
PD2	10001	5495	339	168	31854	26997	27	27.6
PD3	8883	5678	313	162	28293	24913	27	27.2
PD4	7376	5078	345	193	23493	24698	27	27.1
PD5	4138	4513	227	184	13182	22520	27	26.2
Mean	8304	5062	310	170	20329	25196	27	27.12
Bias		3241.20		140		1253.60		-0.120
RMSE		3979.66		148.68		6279.79		0.510

Si = simulated data Ob = observed data

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NSPT and KDML105. In general, the simulated and observed panicle numbers of the RD7 were found greater than NSPT and KDML105. The lowest simulated panicle numbers m^{-2} among planting date of all varieties were obtained at PD5. In contrast the lowest observed panicle numbers m^{-2} were found when planted at early planting date (PD1) for both NSPT and KDML105 however, the observed panicle numbers m^{-2} of RD7 was found the lowest at PD5.

The simulated spikelet numbers m^{-2} ranged between 18713-21053 for RD7, 13077-34165 for NSPT and 13182-35426 for KDML105. The observed data range between 22890-32746, 21019-27116 and 22520-26997 for RD7, NSPT and KDML105, respectively. The simulated spikelet numbers m^{-2} was underestimated across planting dates for RD7 when compared with the observed data. Whereas NSPT and KDML105 were overestimated at PD1, PD2 and PD3 but underestimate at PD4 and PD5. The average difference between simulated and observed spikelet numbers m^{-2} are underestimate by an average of 30.23% (bias of 8421.4 numbers m^{-2}; RMSE = 9300.04 numbers m^{-2}) for RD7, 5.08% (bias of 1235.8 numbers m^{-2}; RMSE = 7157.54 numbers m^{-2}) for NSPT and 4.98% (bias of 1253.6 numbers m^{-2}; RMSE = 6279.79 numbers m^{-2}) for KDML105.

The simulated 1000-grain weight of RD7 is slightly overestimated by an average of 1.38% (bias of 0.38 g; RMSE = 0.52 g) while for NSPT and KDML105 are slightly underestimated by an average of 1.48% and 0.44% (bias of -0.42, -0.12 g; RMSE = 0.61, 0.51 g), respectively.

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The model overestimated grain yield across planting dates by an average of 45%, 72%, and 64% (bias of 1.7, 3.5, 3.2 Mg ha^{-1}; and RMSE = 2.2, 4.4, 4.0 Mg ha^{-1}) for RD7, NSPT, and KDML105, respectively (Table 18). The simulated maximum grain yields are 6.8, 11.1, and 11.1 Mg ha^{-1} for RD7, NSPT, and KDML105, respectively. This corresponded to September and May planting dates, respectively. The observed maximum grain yield of RD7, NSPT, and KDML105 are 6.02, 5.35, 5.68 Mg ha^{-1} which correspond to July, August, and July planting dates, respectively.

The observed grain yields when tested statistically (ANOVA) (Table 19) shows that there is significant difference among planting date treatments. However, no significant difference was detected among variety and varieties * planting dates interaction. The average maximum grain yield was obtained at PD4 which is 5.48 Mg ha^{-1} (Figure 30).

Table 19. Analysis of variance for observed grian yield.

Source of variation	df	MS	
Rep (A)	2	1.63E+05	NS
PD (B)	4	3.24E+06	**
Error (a)	8	1.96E+05	
VAR (C)	2	9.37E+06	NS
B*C	8	1.06E+06	NS
Error (b)	20	1.82	

CV (a) 9.19%

CV (b) 8.85%

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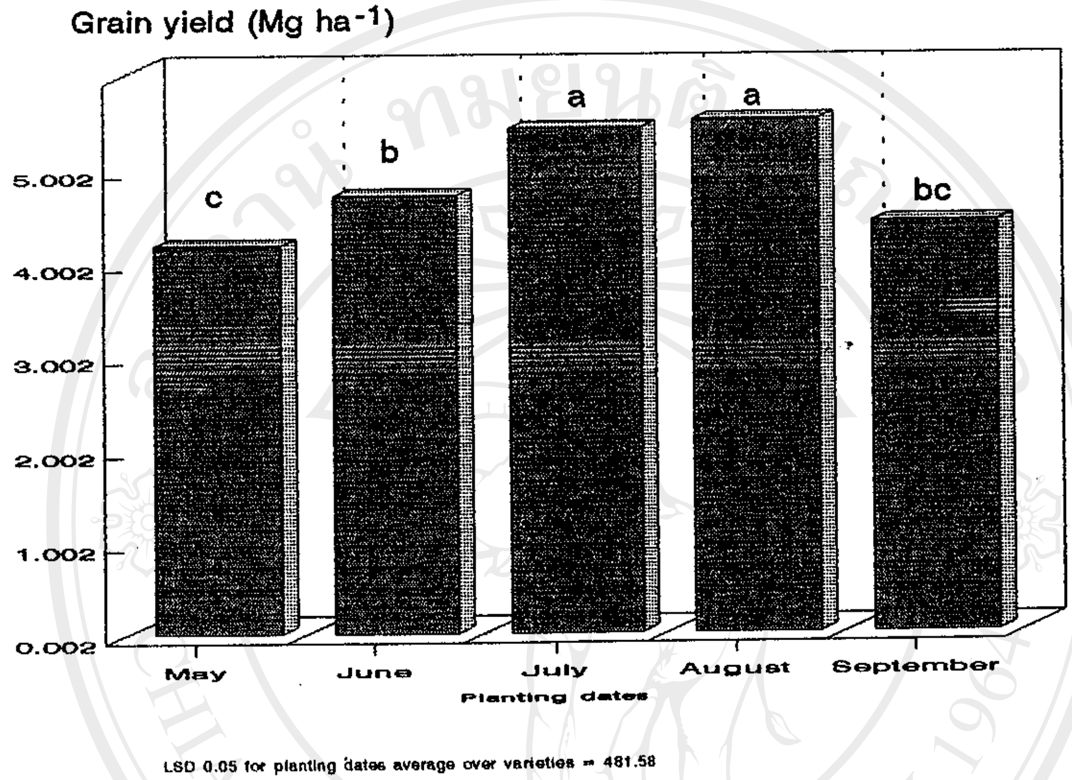

Figure 30. Mean comparison of observed grain yield at various planting dates of RD7, NSPT, and KDML105.

MODEL VALIDATION

Figures 31, 32 and 33 show comparison between observed and simulated heading and maturity dates of RD7, NSPT and KDML105, respectively during 1989 to 1991 experiment at San Pa Tong Rice Experiment Station. These results show that the model simulates reasonably both heading and maturity dates across planting dates and varieties. The simulated heading and maturity dates of RD7 are both consistently underestimated by an average of 2 days (RMSE of 2 days) compared with the observed data (Table 20).

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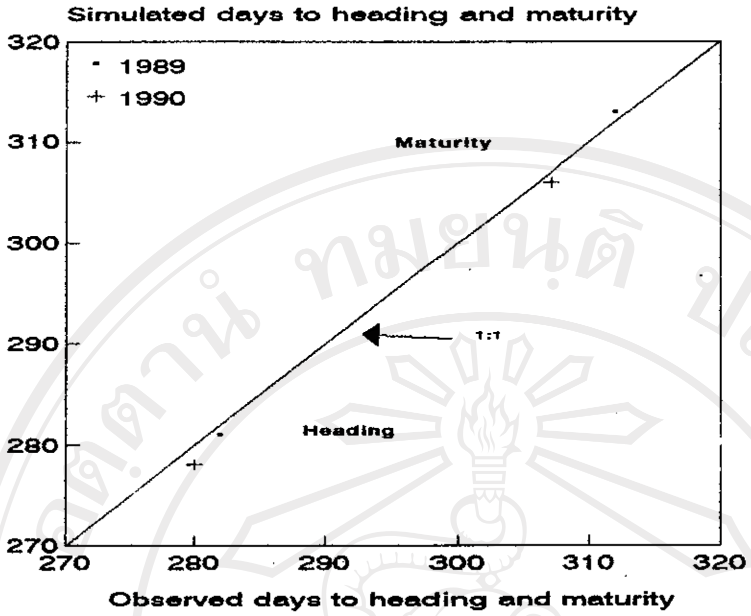

Figure 31. Comparison between simulated and observed days to heading and maturity of RD7 during the 1989 to 1990 experiment at San Pa Tong Rice Experiment Station. Note: the 1991 data are not available.

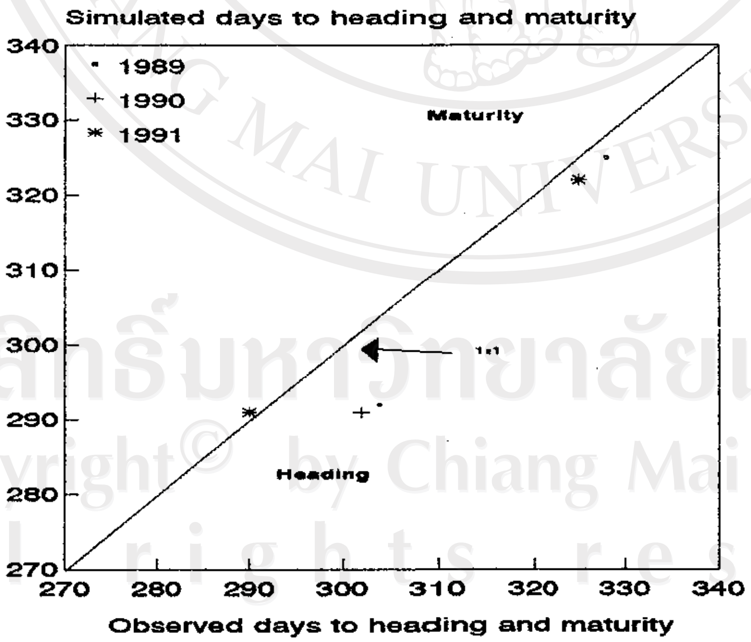

Figure 32. Comparison between simulated and observed days to heading and maturity of NSPT during the 1989 to 1991 experiment at San Pa Tong Rice Experiment Station.

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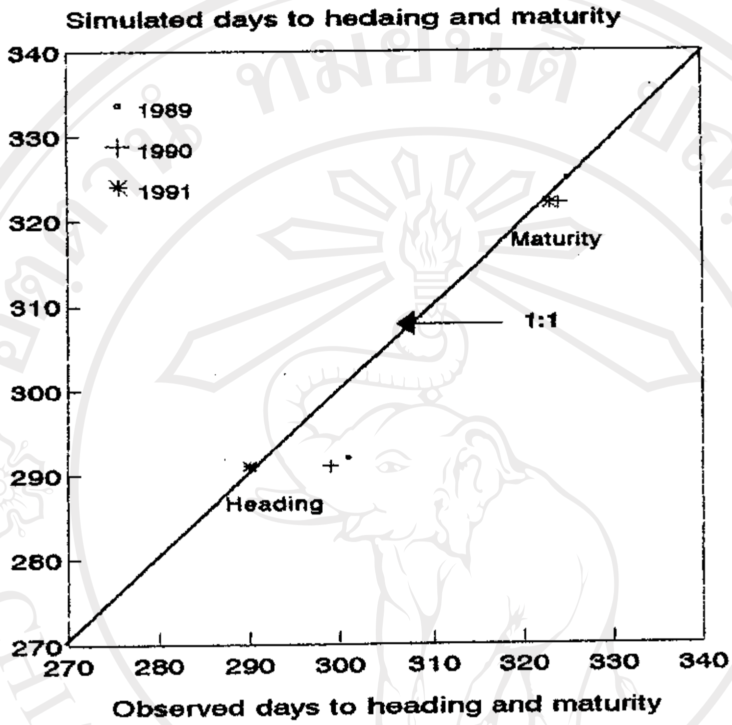

Figure 33. Comparison between simulated and observed days to heading and maturity of KDML105 during the 1989 to 1991 experiment at San Pa Tong Rice Experiment Station.

The model also underestimates heading dates for NSPT by an average of 5 days (RMSE = 9.42 days) and 4 days for KDML105 (RMSE = 6.98 days). The simulated maturity dates of both NSPT and KDML105 were underestimated by an average of 4 and 2 days (RMSE = 3 and 1.4 days), respectively. Hence, the simulated results of the model for heading and maturity dates are more accurate in RD7 with the smallest RMSE, compared with NSPT and KDML105 (Table 20).

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Table 20. Simulated and observed heading and maturity dates (Julian day) and grain yield (kg ha^{-1}) of RD7, NSPT and KDML105

Variety	Year	Heading date			Maturity date			Grain yield		
		S	O	dif	S	O	dif	S	O	dif
RD7										
	1989	281	282	-1	310	312	-2	4581	3462	1119
	1990	278	280	-2	306	307	-1	4935	4594	341
	Mean	279.5	281		308	309		4758	4028	
	Bias			-1.50			-1.50			730.00
	RMSE			1.581			1.58			675.38
NSPT										
	1989	292	304	-12	325	328	-3	4937	3063	1874
	1990	291	302	-11	322	325	-3	4648	4594	54
	1991	291	290	1	322	325	-3	4907	3337	1570
	Mean	291.3	298		323.5	326		4792	3828.5	
	Bias			-5.5			-1.5			1166.00
	RMSE			9.416			2.44			1411.85
KDML105										
	1989	292	301	-9	325	326	-1	4944	2482	2462
	1990	291	299	-8	322	324	-2	4655	3825	830
	1991	291	290	1	322	323	-1	5120	3375	1745
	Mean	291.3	296.0		323.5	325		4799	3153.5	
	Bias			-4			-1			1679
	RMSE			6.976			1.29			1807.60

S = Simulated
O = Observed
dif = difference

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Figure 34 shows the simulated and observed grain yield for 3 rice varieties. The simulated grain yield is higher than those observed data across varieties by an average of 0.73, 1.16, and 1.29 Mg ha^{-1} (RMSE = 0.68, 1.41, and 1.81 Mg ha^{-1}) for RD7, NSPT, and KDML105, respectively. The observed maximum grain yield across varieties were obtained in 1990, which are 4.6, 4.6 and 3.8 Mg ha^{-1} for RD7, NSPT and KDML105, respectively. The simulated maximum grain yield of RD7, NSPT, and KDML105 are 4.94, 4.59 and 5.12 Mg ha^{-1}, respectively which correspond to the year 1990 for RD7, 1989 for NSPT, and 1991 for KDML105.

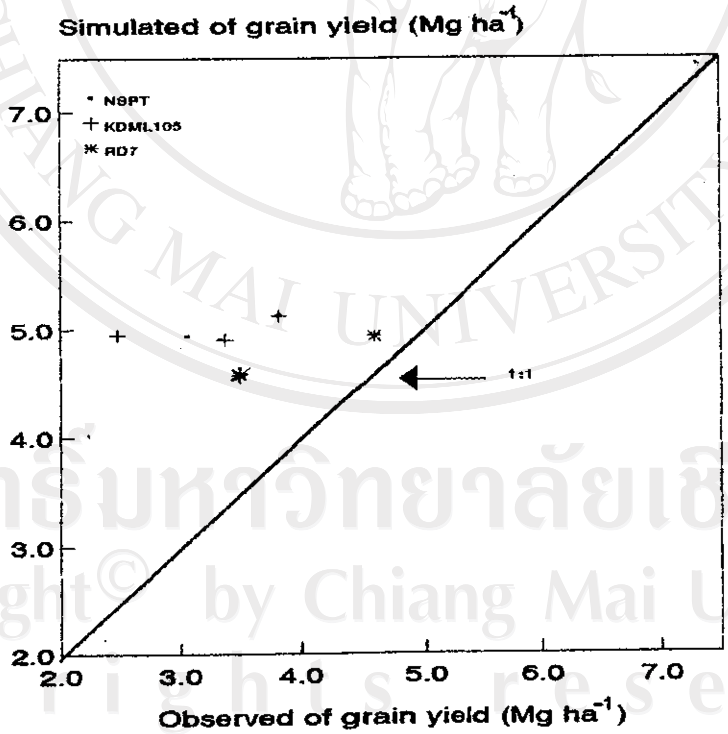

Figure 34. Comparison between simulated and observed grain yield of RD7, NSPT, and KDML105 during the 1989 to 1991 experiment at San Pa Tong Rice Experiment Station.

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