# Experiment 4 : Estimation of Genetic Coefficients of Some Thai Maize Varieties for CERES-Maize Model

## Objectives

The objective of this study are :

1. To estimate the genetic coefficients of Thai maize varieties i.e., NS 1, NSX 9210 and SW 3601.
2. To validate the CERES-Maize model using the estimation of genetic coefficients on three maize genotypes with differing in planting dates under irrigated area.

## Materials and Methods

### I. Genetic Coefficients Estimation

#### Field experiment

The experiment was conducted on sandy loam (Phen series) at Phitsanulok Field Crops Experiment Station, Phitsanulok, Thailand (16.47 N and 100.16 E) during November 1997 to December 1998.

A split plot in randomized complete block design with four replications was used. Five planting dates (December, January, March, May and July) were the main plots and three maize varieties (NS 1, NSX 9210; SW 3601 as drought-susceptible, drought-intermediate tolerant and drought-tolerant varieties, respectively) were the sub plots. Experimental unit was laid in 6.0 x 6.0 m plot size.

The land was plowed, harrowed and fertilized with 50-62.5-0 N-$P_2O_5$-$K_2O$ kg/ha. Maize seeds were sown with 0.75 x 0.25 meter spacing with 2 seeds/hill. To ensure uniform crop emergence, 30 mm. of irrigation water was uniformly applied by sprinkler to the experimental area immediately after sowing. One week after emergence, plants were thinned to 1 plant/hill. Weeds were controlled with metolachlor at 240 g a.i./rai applied immediately after sowing, followed by one handweeding at one month after sowing. Urea at 156 kg/ha was used as a top-dressing fertilizer after hand weeding. Carbosulfan and carbofuran were used for insect control.

## Data Collection

### Crop data

Each planting date, crop phenology i.e., leaf appearance date, silking date, and physiological maturity date were recorded. Dates for phenological events were established when 50% of the plants in each treatment had reached that stage of development.

Plants from an area of 1.5 $m^2$ in all plots was sampled for growth analysis. Plant samples were collected at 7 day intervals from planting until physiological maturity. Both senescent leaves and dropped leaves were included in the total dry matter. Plant samples of each plot was separated into stalk, leaf, and kernel (when present) to determine the distribution of dry weight in different treatments. Plant parts were dried at 60 °C for 48 h and weighted. Yield data was collected from an area of 9.0 $m^2$ in each subplot. Yields was immediately determined by measuring ear weights and moisture contents. Seeds were threshed, dried and measured in seed yield adjusted to a standard 0 % moisture content for DSSAT model. Each plot was measured for analysis of yield components in terms of ears number $m^{-2}$, ears number per plant, kernels number $m^{-2}$, number of kernels per ear and kernel weight (g).

### Soil data

Soil samples were collected and analyzed for soil physical and chemical properties at each plot in soil depth of 0.2 m increments to 1.0 m prior to sowing and after harvesting shown as Appendix Table 1. Soil data namely Phen series obtained from ThaiSIS (SOIL.SOL) which adjusted with actual data of soil physical and chemical properties from the experimental site were used as a input for simulation model in DSSAT v.3.0 (Appendix Table 4).

Climatic data

The model requires daily rainfall, minimum and maximum air temperature and solar radiation as inputs. These data were recorded by Data Logger at the weather station of the Phitsanulok Rice Research Center (16.47 N and 100.16 E).

## Data Analysis

Bias (eq.1) and Root Mean Square Error (RMSE) (eq.2) were used as measures of model performance (Willmolt, 1982). Goodness of fit was evaluated visually and by computing a standard bias (R) (eq.3) and a standardized mean square error (V) (eq.4) (Graf *et al.*, 1991).

$$\text{Bias} = (1/N)\sum_{i=1}^{N}(Si-Oi) \text{ ------------------------------------}(1)$$

$$\text{RMSE} = (1/N)\sum_{i=1}^{N}(Si-Oi)^2 \text{ ------------------------------------}(2)$$

$$R = \sum_{i=1}^{N}(Si-Oi) \,/\, \sum_{i=1}^{N}(Oi) \text{ ----------------------------------}(3)$$

$$V = \sum_{i=1}^{N}(Si-Oi)^2 \,/\, \sum_{i=1}^{N}(Oi)^2 \text{ ---------------------------------}(4)$$

Where N = Number of field observation, Oi and Si are observed and simulated values, respectively.

## Description of Genetic Coefficients

The definition of the genetic coefficients of the maize crop are presented in Table 19. There are two types of genetic coefficients which are the developmental phenological or phasic coefficient designated as "P" coefficients and the growth coefficients which designated as "G". The P coefficients enable the model to predict phenological events such as flowering and maturity. The P1 and P5 coefficients define the duration of the vegetative and kernel filling stages, respectively. The P1 coefficient varies greatly among varieties. As the value of the P1 and P5 coefficients increase, the time required by a variety to reach maturity also increase. The growth coefficients represent the potential value for particular variety. Kernel yield is the product of kernel size and kernel number which are determined by the genetic coefficient G2 and G3, respectively.

Table 19. Phenology and growth genetic coefficients for maize used in the DSSAT Version 3.0.

| Genetic coefficients | Definitions |
|---|---|
| ---------Phenology coefficients--------- | |
| P1 | Termal time from seedlng emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8 °C) during which the plant is not responsive to changes in photoperiod. |
| P2 | Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hour). |
| P5 | Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 °C). |
| ---------Growth coefficients--------- | |
| G2 | Maximum possible number of kernels per plant. |
| G3 | Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day). |

Source : DSSAT (1994)

## Determination of Genetic Coefficients

This study used the Genotype Coefficient Calculator (GenCalc) which was developed to facilitate determination of the genotype coefficients as input file for simulation model (Hunt and Pararajasingham, 1994). The main steps of using GenCalc v.3 for genetic coefficients estimation required as input data in terms of growth and development (FILEA and FILEX) from field experiment to compare between observed and simulated data in addition to soil data, weather data and management practices. In GenCalc, the file designated as FILEA and FILEX which are necessary for running the model. FILEA contains experimental data used to determine the goodness-of -fit of simulated results. FILEX which was the inputs to the model for this experiment to be simulated. The set of genetic coefficients of SW 1 as a Thai open-pollinated variety from DSSAT version 3.0 (Table 20) was used as the initial values to estimate the genetic coefficients of three maize varieties differing in degree of drought tolerance (NS 1, NSX 9210 and SW 3601 as drought-susceptible, drought-intermediate tolerant and drought-tolerant varieties, respectively) which was obtained from the first experiment. In GenCalc, P coefficients (P1, P2 and P5) were firstly calculated until the simulated and observed phenological events were agree and then G coefficient (G2 and G3) could further run. Each suitable coefficient could be averaged between old and new values and showed CV. (coefficient of variation) with SD. (standard deviation). The file components used for the estimation of genetic coefficients in DSSAT v. 3.0 are presented in Figure 28.

Table 20. Genetic coefficients of SW 1 obtained from DSSAT version 3.0

| Variety | P1 | P2 | P5 | G2 | G3 |
|---|---|---|---|---|---|
| SUWAN-1 | 380.0 | 0.600 | 780.0 | 825.0 | 7.00 |

Source : DSSAT (1994)

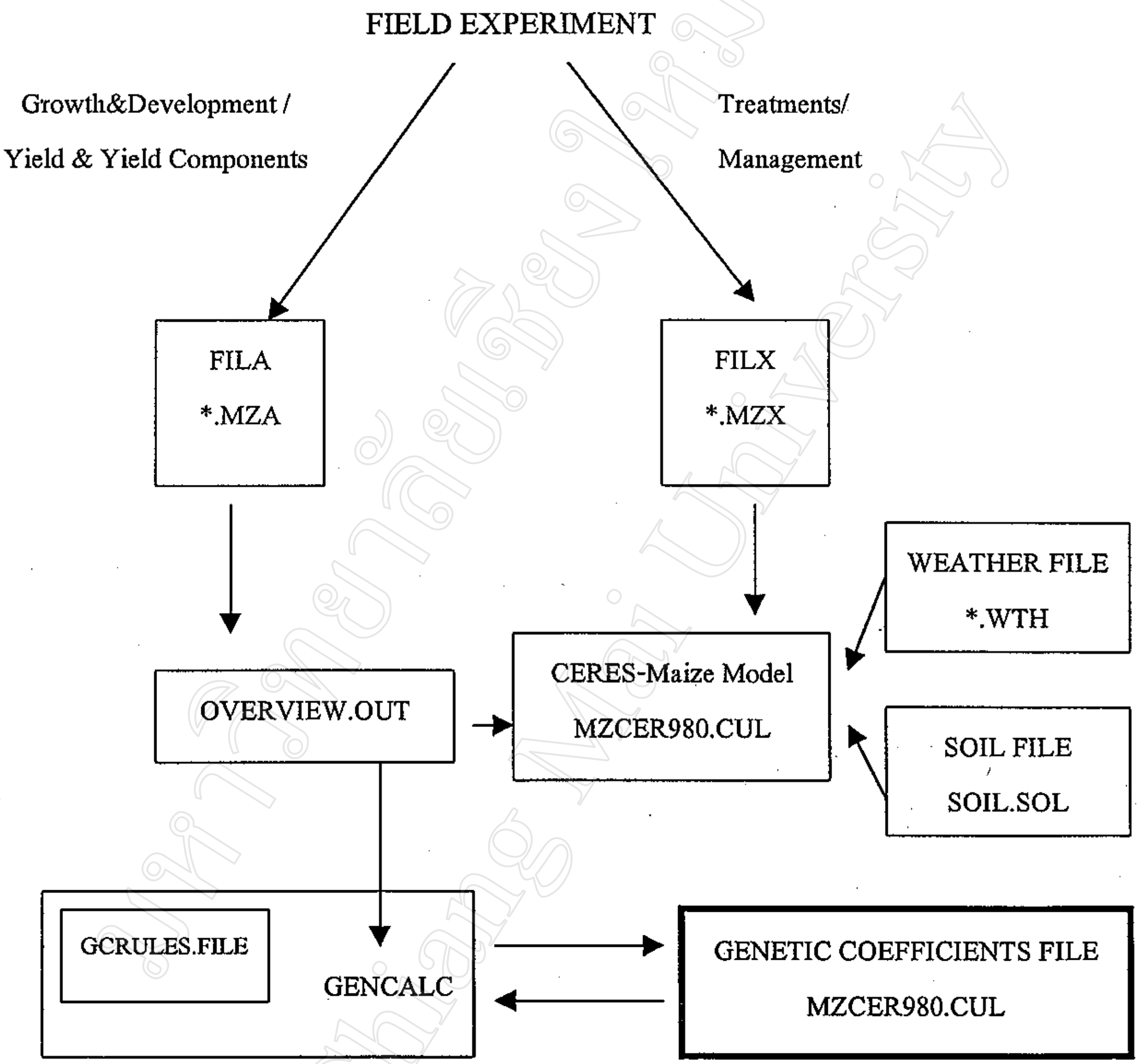


Figure 28. File components assigned to estimate genetic coefficients of maize in DSSAT v.3.0 (Hunt and Pararajasingham, 1994).

## II. Model Validation

### Field experiment

The model validated using data from the trial of planting dates for three Thai maize varieties grown after lowland rice under irrigation condition at the farm of Phitsanulok Field Crops Experiment Station during November 1998 to May 1999. The experimental design was a split plot in randomized complete block design with four replications. Three planting dates (December, January and February) were the main plots and three maize varieties (NS 1, NSX 9210; SW 3601) were subplots. Planting, silking and maturity dates were recorded as shown in Table 21. Each plot size was 4.5 x 6.0 m. The land was plowed, harrowed and fertilized with 50-62.5-0 N-$P_2O_5$-$K_2O$ kg/ha. Plant spacing was 0.75 x 0.25 m with 1 plant per hill for all varieties. Irrigation water was uniformly applied by sprinkler to the experimental area through the growing season. Weeds were controlled with metolachlor at 240 g a.i./rai applied immediately after sowing, followed by one handweeding at one month after sowing. Urea at 70 kg N/ha was used as a top-dressing fertilizer after hand weeding. Carbosulfan and carbofuran were used for insect control.

Table 21. Planting, silking and maturity dates from the experiments of NS 1, NSX 9210 and SW 3601 at Phitsanulok Field Crops Experiment Station in 1998-1999.

| Varieties | Year | Sowing dates | Silking Date | Maturity Date |
|---|---|---|---|---|
| NS 1 | 1998 | Nov 27 (331*) | Jan 29 (29) | Mar 11 (70) |
| | 1999 | Jan 28 (28) | Mar 29 (88) | May 4 (124) |
| | 1999 | Feb 26 (87) | Apr 22 (112) | June 1 (152) |
| NSX 9210 | 1998 | Nov 27 (331) | Jan 29 (29) | Mar 13 (72) |
| | 1999 | Jan 28 (28) | Mar 29 (88) | May 6 (126) |
| | 1999 | Feb 26 (87) | Apr 23 (113) | Jun 3 (154) |
| SW 3601 | 1998 | Nov 27 (331) | Jan 27 (27) | Mar 10 (69) |
| | 1999 | Jan 28 (28) | Mar 27 (86) | May 4 (124) |
| | 1999 | Feb 26 (87) | Apr 22 (112) | June 1 (152) |

* Julian day

## Data Collection

### Crop data

Crop phenology i.e., leaf appearance date, silking date, and physiological maturity date were recorded. Dates for phenological events were established when 50% of the plants in each treatment had reached that stage of development.

Plants from an area of 1.5 $m^2$ in all plots was sampled for growth analysis. Plant samples were collected at 7 day intervals from planting until physiological maturity. Both senescent leaves and dropped leaves were included in the total dry matter. Plant samples of each plot was separated into stalk, leaf, and kernel (when present) to determine the distribution of dry weight in different treatments. Plant parts were dried at 60 °C for 48 h and weighted. Yield data was collected from an area of 9.0 $m^2$ in each subplot. Yields was immediately determined by measuring ear weights and moisture contents. Seeds were threshed, dried and measured in seed yield adjusted to a standard 0 % moisture content for DSSAT model. Each plot was measured for analysis of yield components in terms of ears number $m^{-2}$, ears number per plant, kernels number $m^{-2}$, number of kernels per ear and kernel weight (g).

### Soil data

The soil samples at the experimental site were collected and analyzed for soil physical and chemical properties at each plot differing in soil depth (0.2 m increments to 1.0 m) prior to sowing.

### Weather data

Daily rainfall, minimum and maximum air temperature and solar radiation was obtained from the Phitsanulok Rice Research Center (16.47 N and 100.16 E).

## Data Analysis

A 1:1 line was used to perform between the observed and simulated data. Bias and Root Mean Square Error (RMSE) were also used as additional measures of model performance (Willmolt, 1982). Goodness of fit was evaluated visually and by computing a standard bias (R) and a standardized mean square error (V) (Graf *et al.*, 1991).

## Validation Process

Model validation is an essential step and continuous processing system simulation process prior to its application. The validation process is simply the comparison of model outputs with observed field data (Jintrawet, 1990). The model was validated using data from planting dates trial including Thai maize varieties i.e., NS 1, NSX 9210 and SW 3601 which obtained the genetic coefficients from previous study.

# Results and Discussion

## I. Genetic Coefficients Estimation

### Observed Phenological Events

The observed silking and maturity dates of NS 1, NSX 9210, and SW 3601 at five planting dates are presented in Table 22. The results indicated that there was quite different among planting date treatments, however, among three genotypes across planting dates was not different. The observed number of days from sowing to maturity range from 92 to 107. The growing season of all genotypes becomes shorter as the planting dates were shifted from November planting date to July. The shorter duration from sowing to maturity was observed from January to July planting date (92 - 97 days). On the other hand, the longer duration from sowing to maturity was observed at November planting date (101 - 104 days). This effect was probably due to the influence of temperature on the rate of maize development (Fisher and Palmer, 1983). Tollenaar (1977) had been reported concerning environmental on rate and duration of ear development e.g. temperature, photoperiod, irradiance, moisture stress and mineral nutrition.

Table 22. Observed phenological events of maize planted at Phitsanulok Field Crops Experiment Station in 1997-1998.

| Genotypes | Sowing dates | Emergence Dates. | Silking Date | Maturity Date | Growing season (days) |
|---|---|---|---|---|---|
| NS 1 | Nov 28(332*) | Dec 3(337) | Jan 26(26) | Mar 12(71) | 104 |
| | Jan 28(28) | Feb 2 (33) | Mar 25(84) | May 1(121) | 93 |
| | Mar 28(87) | Apr 1 (91) | May 23(143) | Jun 29(180) | 93 |
| | May 29(149) | Jun 3 (154) | Jul 24(205) | Sep 2(245) | 96 |
| | Jul 29(210) | Aug 1 (213) | Sep 22(265) | Oct 30(303) | 93 |
| NSX 9210 | Nov 28(332) | Dec 3(336) | Jan 27(27) | Mar 12(71) | 104 |
| | Jan 28(28) | Feb 2 (32) | Mar 27(86) | May 4(124) | 96 |
| | Mar 28(87) | Apr 1 (90) | May 23(143) | Jun 30(181) | 94 |
| | May 29(149) | Jun 3 (154) | Jul 25(206) | Sep 3(246) | 97 |
| | Jul 29(210) | Aug 1 (213) | Sep 22(265) | Oct 31(304) | 94 |
| SW 3601 | Nov 28(332) | Dec 3(336) | Jan 24(24) | Mar 12(68) | 101 |
| | Jan 28(28) | Feb 2 (32) | Mar 24(83) | May 1(120) | 92 |
| | Mar 28(87) | Apr 1 (90) | May 23(142) | Jun 29(180) | 93 |
| | May 29(149) | Jun 3 (154) | Jul 25(205) | Sep 2(245) | 96 |
| | Jul 29(210) | Aug 1 (213) | Sep 21(264) | Oct 30(303) | 93 |

*Julian day

## Estimation of Genetic Coefficients

In GenCalc, FILEA and FILEX which was the inputs to the model for this experiment to be simulated are presented in Appendix Table 5-8. The statistics procedure in terms of standard deviation showed the deviation of mean for each suitable coefficient as shown in Appendix Table 9. Results also illustrated that the set of genetic coefficients in terms of P coefficients (P1, P2 and P5) and G coefficient (G2 and G3) of the 3 maize varieties; namely NS1, NSX9210 and SW3601, which was estimated by using GenCalc v.3.0 (Table 23). However, these coefficients except P2 among three maize varieties which obtained from GenCalc were quite different. This is probably due to the influence of photoperiod though the year in Thailand are small different.

Table 23. Genetic coefficients of NS1, NSX 9210 and SW 3601 obtained after estimation by running GenCalc from DSSAT version 3.0.

| Variety | P1 | P2 | P5 | G2 | G3 |
|---|---|---|---|---|---|
| NS 1 | 364.0 | 0.600 | 840.0 | 710.3 | 6.66 |
| NSX 9210 | 372.0 | 0.600 | 863.2 | 784.8 | 6.75 |
| SW 3601 | 352.0 | 0.600 | 845.0 | 824.8 | 6.87 |

## Model Testing

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

## 1. Phenological Simulation

### Silking and Maturity Dates

The simulated and observed silking and maturity dates for 3 maize genotypes are presented in Table 24. The model consistently overestimated the silking dates of NS 1, NSX 9210 and SW 3601 by an average of 1 days and RMSE of 2 days compared with the observed data. The greatest difference between observed and simulated silking date of all genotypes occurred at PD5 (July planting date) where the silking date was overestimated 3-4 days. This is probably due to heavy rain during vegetative growth stage. It is clear that the simulated silking date of all maize genotypes is quite accurate due to less RMSE value (2 days).

The results indicate that the simulated data consistently underestimated the maturity dates of NS 1, NSX 9210 and SW 3601 by an average of 1 days and RMSE of 2 days, respectively compared with the observed data. The greatest difference between observed and simulated silking date of all genotypes occurred at PD5 with overestimated 4-6 days due to waterlogging problem during reproductive growth stage. It is also clear that the simulated maturity date of all maize varieties are quite accurate due to less RMSE value.

It is concluded that the CERES-Maize model is able to simulate growth duration, namely the time of silking and maturity, fairly well which implies that model's simulation of phenological development is relatively accurate. Mankeb (1993) stated that The P coefficients are well estimated and acceptable for the rice varieties. Similarly Jintrawet (1991) indicated that the rule of thump in model is to achieve reliability in phenology prediction before attempting to develop accuracy in predicting growth and yield. This is because maize plant phenology is the factor that influences the growth as well as grain yield and yield components. Thus, the model was able to simulated phenology satisfactory for all genotypes and was eligible for further testing for accuracy in predicting growth of the maize plant.

Table 24. Simulated and observed silking and maturity dates for 3 maize varieties.

| Varieties | Sowing dates | Silking date | | | Maturity date | | |
|---|---|---|---|---|---|---|---|
| | | Sim. | Obs. | Diff. | Sim. | Obs. | Diff. |
| NS 1 | Nov 28(332) | 63 | 59 | 4 | 104 | 104 | 0 |
| | Jan 28(28) | 57 | 56 | 1 | 93 | 93 | 0 |
| | Mar 28(87) | 55 | 56 | -1 | 92 | 93 | -1 |
| | May 29(149) | 57 | 56 | 1 | 95 | 96 | -1 |
| | Jul 29(210) | 58 | 55 | 3 | 97 | 93 | 4 |
| | Bias | | | 1.33 | | | 0.33 |
| | RMSE | | | 2.13 | | | 1.73 |
| NSX 9210 | Nov 28(332) | 63 | 60 | 3 | 105 | 104 | 1 |
| | Jan 28(28) | 57 | 58 | -1 | 94 | 96 | -2 |
| | Mar 28(87) | 55 | 56 | -1 | 92 | 94 | -2 |
| | May 29(149) | 57 | 57 | 0 | 96 | 97 | -1 |
| | Jul 29(210) | 59 | 55 | 4 | 100 | 94 | 6 |
| | Bias | | | 0.83 | | | 0.66 |
| | RMSE | | | 2.12 | | | 2.64 |
| SW 3601 | Nov 28(332) | 61 | 57 | 4 | 102 | 101 | 1 |
| | Jan 28(28) | 55 | 55 | 0 | 92 | 92 | 0 |
| | Mar 28(87) | 53 | 55 | -2 | 90 | 93 | -2 |
| | May 29(149) | 54 | 56 | -2 | 96 | 96 | -3 |
| | Jul 29(210) | 58 | 54 | 4 | 97 | 93 | 4 |
| | Bias | | | 0.66 | | | 0.0 |
| | RMSE | | | 2.58 | | | 2.23 |

## 2. Growth and Yield Simulation

### Above Ground Biomass

The simulated and observed stalk, leaf and kernel dry weight of three maize varieties differing in planting dates are presented in Figure 29-31. The model overestimated stalk and leaf dry weights of all three genotypes across planting dates. This is probably because the model greatly overestimates the number of total leaves of all maize varieties compared to the observed field data. However, the simulated kernel dry weight of three maize genotypes are overestimated for PD3, PD4 and PD5 while the model underestimated those at PD1 and PD2.

### Yield and Yield Components

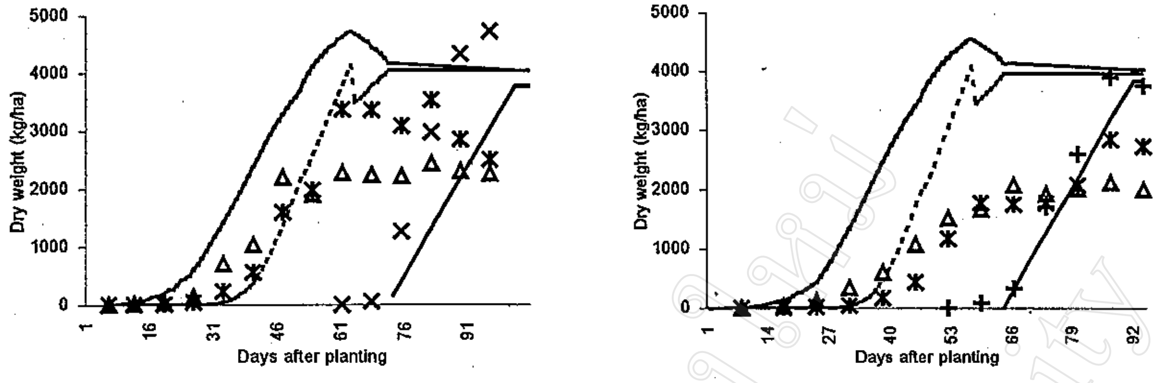
The comparison between simulated and observed kernel yield and yield components of NS 1, NSX 9210 and SW 3601 are presented in Table 25. Generally, the grain yield particularly maize is considered in its simplest components of kernel numbers per unit area x kernel size (Fisher and Palmer, 1983). The results show that the simulated kernel numbers $m^{-2}$ of NS 1 and SW 3601 are overestimated by an average of 2201 and 2552 numbers $m^{-2}$, respectively, while NSX 9210 is underestimated by an average of 2394 numbers $m^{-2}$ compared with observed data. In general, the simulated and observed kernel numbers $m^{-2}$ of SW 3601 were found greater than NSX 9210 and NS 1. The lowest simulated kernel numbers $m^{-2}$ among planting date of all varieties was obtained at PD1, in contrast, the lowest observed grain numbers $m^{-2}$ was found when planted at PD3 in all varieties.

The simulated kernel weight of all genotypes is greatly overestimated by an average of 0.1744, 0.1816 and 0.1794 g as compared to observed data. The simulated data of NSX 9210 produced the greatest kernel weight (0.1816 g) while SW 3601 was found the most observed kernel weight (0.1670 g).

The model overestimated kernel yield of all varieties across planting dates (except at PD1). The simulated maximum kernel yield are 4072, 4594 and 4937 kg /ha for NS1, NSX9210 and SW3601, respectively. This corresponded to July and May planting dates, respectively. The observed maximum kernel yield of NS1, NSX9210 and SW3601 are 4569, 4534 and 5333 kg/ha which correspond to November planting date, respectively.

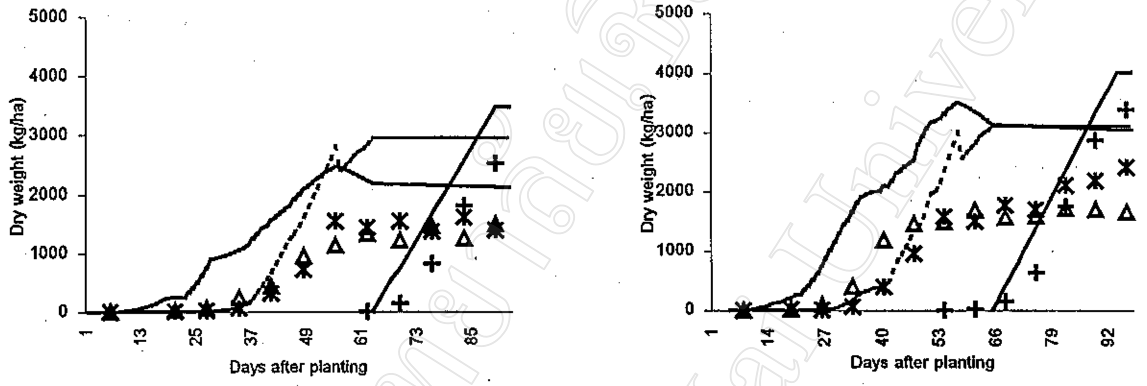
The observed kernel yields when tested statistically in terms of analysis of variance are presented in Table 26. The results indicate that there is significant difference among planting data treatments and varieties, however, no significant difference was detected among variety and planting dates interaction.

The model greatly overestimates grain yield across varieties and planting dates except for PD1 and PD2. This could be due to the positive relationship between LAI and grain yield. Generally, LAI is closely related to grain production because physiologically active leaves contribute to the photosysthesis of the plant (Ritchie *et al.*, 1986). The large discrepancy between simulated and observed kernel yield is mainly due to: i) great overestimate of kernel number m$^{-2}$ and kernel weight; ii) the model assumes that all spikes formed will develop into kernel which will eventually be harvested. This implies that the naturally occurring percentage of unfilled spikes is not taken into account iii) There is also yield loss due to pest, rats, birds, diseases and harvesting (Mankeb, 1993); iv) Field observation shows that leaf senescence in maize was found while the model assumes that all leaves number will become stray green through the growing season.



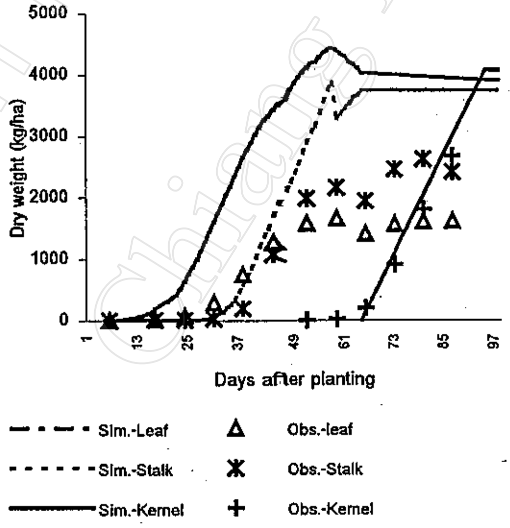
(a) November

(b) January



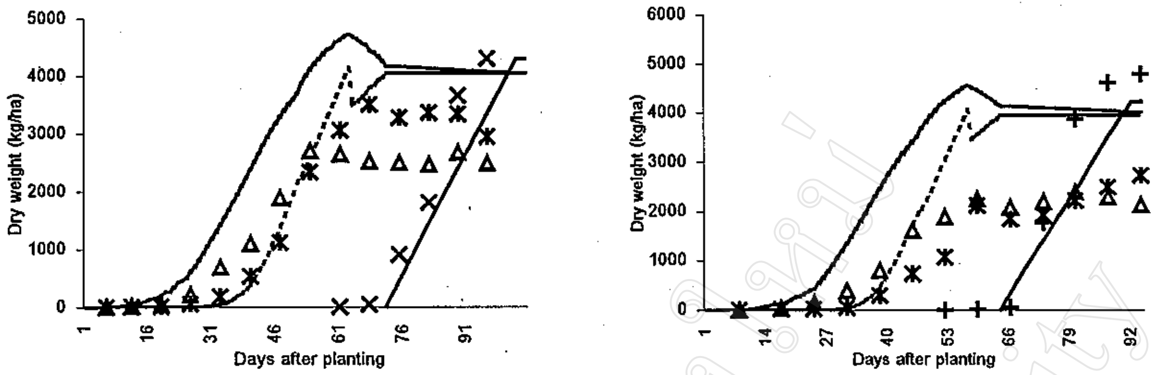
(c ) March

(d) May



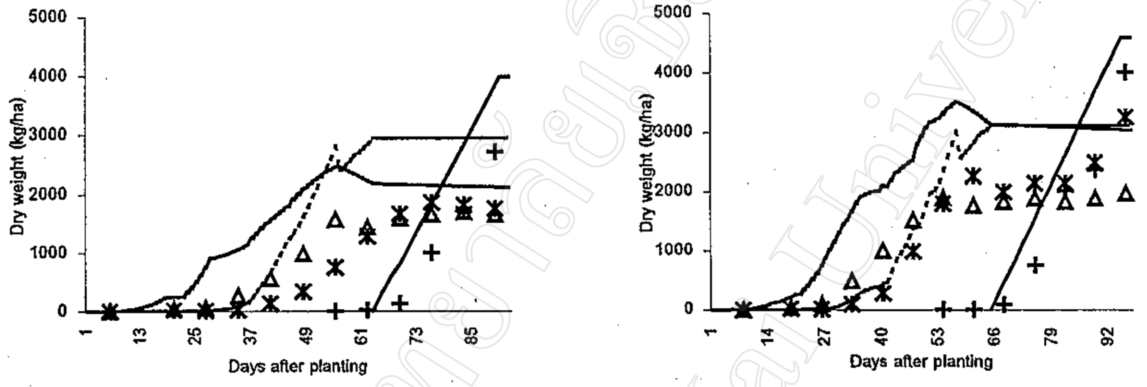
(e) July

Figure 29 Comparison between simulated and observed leaf, stalk and kernel dry weights of NS 1 at five planting dates; (a) November, (b) January, (c ) March, (d) May, and (e) July.



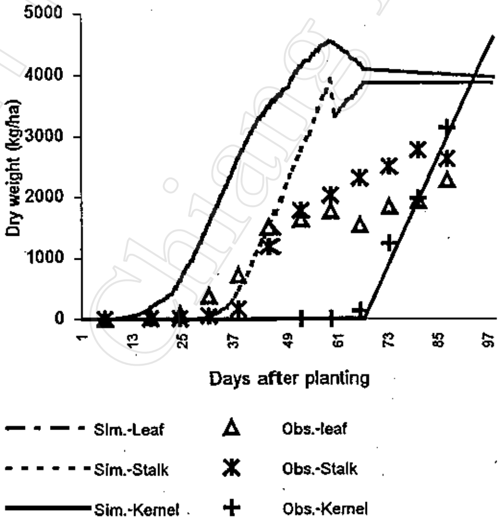
(a) November

(b) January



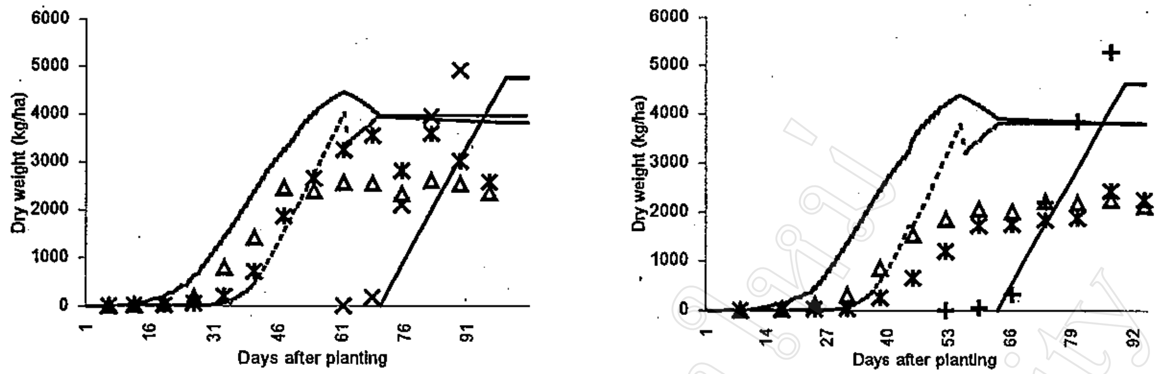
(c ) March

(d) May

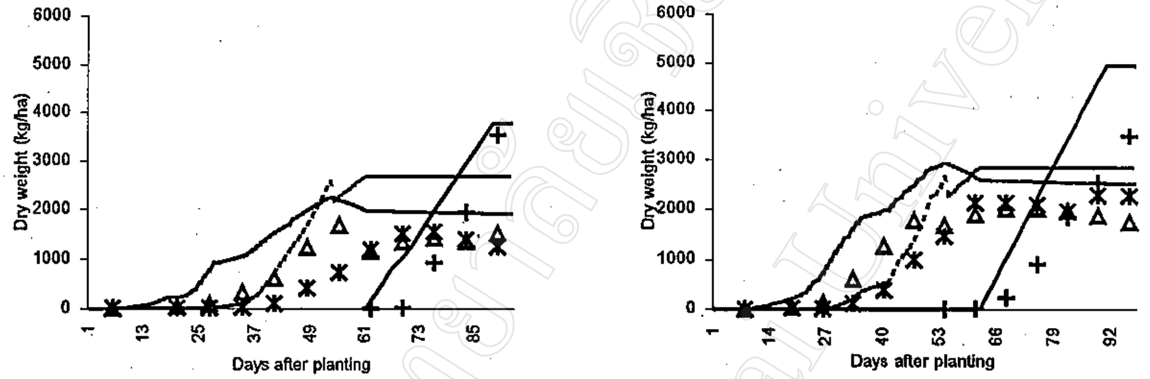


(e) July

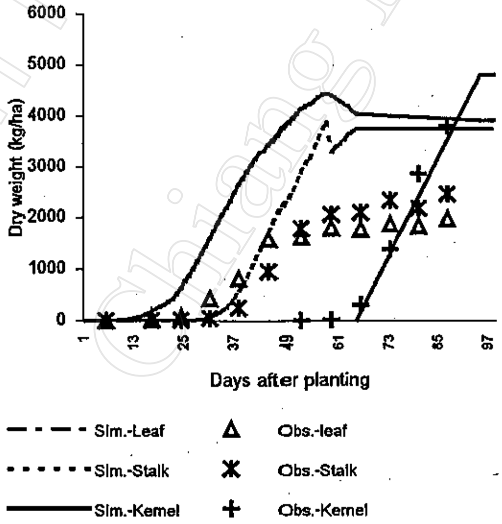
Figure 30 Comparison between simulated and observed leaf, stalk and kernel dry weights of NSX 9210 at five planting dates; (a) November, (b) January, (c ) March, (d) May, and (e) July.



(a) November (b) January



(c ) March (d) May



(e) July

Figure 31 Comparison between simulated and observed leaf, stalk and kernel dry weights of SW 3601 at five planting dates; (a) November, (b) January, (c ) March, (d) May, and (e) July.

Table 25. Simulated and observed kernel yield and yield components of three maize varieties at five different planting dates.

| Planting dates | Kernel yield (kg/ha) | | Kernel no. m$^{-2}$ | | Kernel weight (g) | |
|---|---|---|---|---|---|---|
| | Simulated | Observed | Simulated | Observed | Simulated | Observed |
| NS 1 | | | | | | |
| PD1 | 3772 | 4569 | 2065 | 2456 | 0.1827 | 0.1860 |
| PD2 | 3830 | 3324 | 2388 | 2249 | 0.1604 | 0.1480 |
| PD3 | 3470 | 2615 | 2199 | 1960 | 0.1578 | 0.1330 |
| PD4 | 4012 | 3174 | 2201 | 1953 | 0.1823 | 0.1620 |
| PD5 | 4072 | 2451 | 2154 | 2085 | 0.1890 | 0.1170 |
| Mean | 3831 | 3226 | 2201 | 2140 | 0.1744 | 0.1492 |
| V | | 0.0902 | | 0.0128 | | 0.0558 |
| NSX 9210 | | | | | | |
| PD1 | 4290 | 4534 | 2243 | 2693 | 0.1913 | 0.1680 |
| PD2 | 4226 | 4172 | 2599 | 2684 | 0.1626 | 0.1550 |
| PD3 | 3978 | 3153 | 2401 | 2035 | 0.1910 | 0.1550 |
| PD4 | 4591 | 3788 | 2404 | 2276 | 0.197 | 0.1660 |
| PD5 | 4594 | 3370 | 2324 | 2424 | 0.1816 | 0.1390 |
| Mean | 4335 | 3803 | 2394 | 2422 | 0.1816 | 0.1566 |
| V | | 0.0392 | | 0.0125 | | 0.0388 |
| SW 3601 | | | | | | |
| PD1 | 4754 | 5333 | 2512 | 2965 | 0.1892 | 0.1800 |
| PD2 | 4619 | 4567 | 2889 | 2681 | 0.1599 | 0.1700 |
| PD3 | 4755 | 3755 | 2281 | 2291 | 0.1646 | 0.1640 |
| PD4 | 4937 | 3863 | 2620 | 2328 | 0.1884 | 0.1660 |
| PD5 | 4793 | 3796 | 2458 | 2453 | 0.1950 | 0.1550 |
| Mean | 4571 | 4262.8 | 2552 | 2543 | 0.1794 | 0.1670 |
| V | | 0.0268 | | 0.0102 | | 0.0163 |

Table 26. Analysis of variance for observed kernel yield.

| Source of variance | df | MS | F-value |
|---|---|---|---|
| Replication | 3 | 2,973,659 | $11.9^{**}$ |
| Planting date | 4 | 7,432,046 | $29.6^{**}$ |
| Error (a) | 12 | 250,870 | |
| | | | |
| Variety | 2 | 5,436,990 | $27.8^{**}$ |
| Planting date x Variety | 8 | 257,126 | $1.3^{ns}$ |
| Error (b) | 30 | 195,880 | |

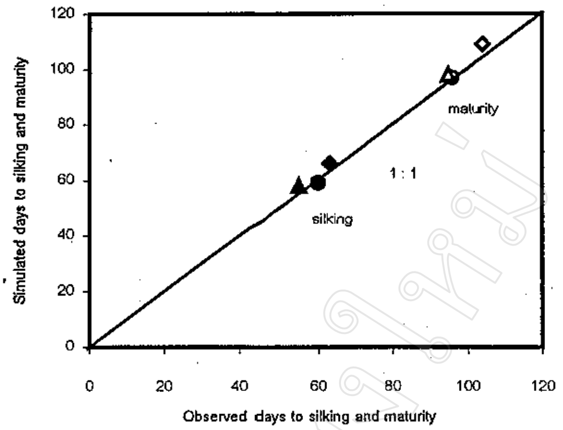
CV. (a) = 13.1 %, CV. (b) = 11.6 %

## II. Model Validation

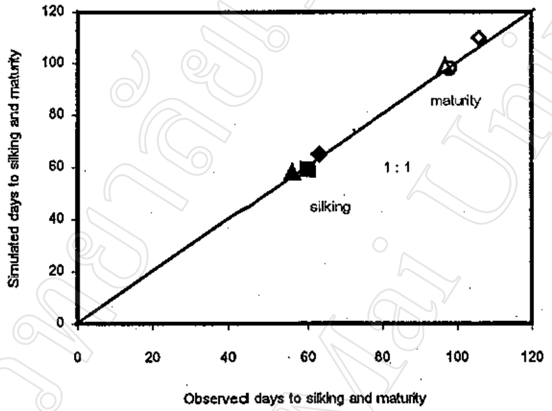
### 1. Phenological Simulation

Silking and Maturity Dates

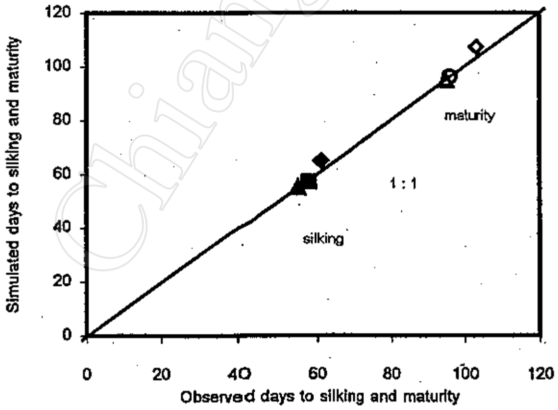
The comparison between observed and simulated silking and maturity dates of NS1, NSX 9210 and SW 3601 differing in planting dates during 1998-1999 experiment at Phitsanulok Field Crops Experiment Station are presented in Figure 32. Results show that the model simulated reasonably both silking and maturity dates across planting dates and varieties. The simulated silking and maturity dates of NS 1 are both consistently overestimated by an average of 1 days (RMSE 2 days) compared with the observed data (Table 27). The model also overestimates silking and maturity dates for both NSX 9210 and SW 3601 by an average of 1 days (RMSE 2 days). Results from the validation of the Ceres-Maize model show that the model is capable of simulating the phenological events, both silking and maturity dates relatively well across varieties and planting dates.



(a) NS 1.



(b) NSX 9210



(c) SW 3601

Figure 32 Comparison between simulated and observed days to silking and maturity three maize genotypes in 1998-1999.

Table 27. Simulated and observed silking and maturity dates (days) for 3 maize genotypes.

| Varieties | Sowing dates | Silking date |  |  | Maturity date |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Simulated | Observed | Diff. | Simulated | Observed | Diff. |
| NS 1 | PD1 | 66 | 63 | 3 | 109 | 104 | 5 |
|  | PD2 | 59 | 60 | -1 | 97 | 96 | 1 |
|  | PD3 | 58 | 55 | 3 | 98 | 95 | 3 |
|  | Bias |  |  | 0.83 |  |  | 1.83 |
|  | RMSE |  |  | 1.78 |  |  | 2.97 |
| NSX 9210 | PD1 | 65 | 63 | 3 | 110 | 106 | 4 |
|  | PD2 | 59 | 60 | -1 | 98 | 98 | 0 |
|  | PD3 | 58 | 56 | 2 | 99 | 97 | 2 |
|  | Bias |  |  | 0.67 |  |  | 1.16 |
|  | RMSE |  |  | 1.52 |  |  | 2.41 |
| SW 3601 | PD1 | 65 | 61 | 4 | 107 | 103 | 4 |
|  | PD2 | 57 | 58 | -1 | 96 | 96 | 0 |
|  | PD3 | 55 | 55 | 0 | 95 | 95 | 0 |
|  | Bias |  |  | 0.50 |  |  | 1.0 |
|  | RMSE |  |  | 1.68 |  |  | 2.08 |

## 2. Growth and Yield Simulation

### Above Ground Biomass

The simulated and observed stalk, leaf and kernel dry weight of three maize varieties differing in planting dates are presented in Figure 33-35. The model overestimated stalk and leaf dry weights of all three varieties across planting dates. This is probably because the model greatly overestimates the number of total leaves of all maize varieties compared to the observed field data. In addition, the observed leaf and stalk dry weight greatly reduced compared to the simulated data due to waterlogging occurred during the active vegetative growth period in 1999 (Figure 2). However, the simulated results of the model for kernel dry weight are more accurate in all three varieties across planting dates as compared to observed data.

### Yield and Yield Components

Table 28 shows the simulated kernel numbers m$^{-2}$ of NS 1, NSX 9210 and SW 3601 are overestimated by an average of 2328, 2533 and 2824 numbers m$^{-2}$, respectively compared with observed data. The simulated and observed maximum numbers m$^{-2}$ of NS 1, NSX 9210 and SW 3601 are 2513, 2735 and 3123 kg /ha and 2504, 2596 and 2708 kg/ha, respectively which correspond to February planting dates. The lowest observed and simulated kernel numbers m$^{-2}$ among planting date of all genotypes were obtained at PD2. This is probably due to suitable climatic condition for producing kernel number. It is also clear that the simulation model of kernel numbers m$^{-2}$ is quite accurate due to less standardized mean square error value (0.0047-0.0189).

The simulated kernel weight of all genotypes is also greatly overestimated by an average of 0.1889, 0.1965 and 0.1955 g compared with observed data. The simulated and observed maximum kernel weight of all genotypes are also correspond to February planting dates. While the lowest observed and simulated kernel numbers m$^{-2}$ among planting date of all genotypes were obtained at PD2. The simulated data of NSX 9210 produced the greatest kernel weight (0.1965 g) while SW 3601 was found the most observed kernel weight (0.1673 g). The simulated kernel weight is also quite accurate due to less standardized mean square error value (0.0420-0.1746).

Figure 36 shows the simulated and observed kernel yield for 3 maize varieties. The model overestimated kernel yield of all genotypes across planting dates. The simulated and observed maximum kernel yield of NS1, NSX9210 and SW3601 are 4801, 5472 and 6336 kg /ha and 4686, 4618 and 5457 kg/ha, respectively which correspond to February planting dates (Table 27). It is also indicate that the simulation model of kernel yield for all varieties is relatively accurate due to less standardized mean square error value (0.0956-0.2207).

This indicates that the calculated genetic coefficients resulted the model consistency perform for the varieties studies.

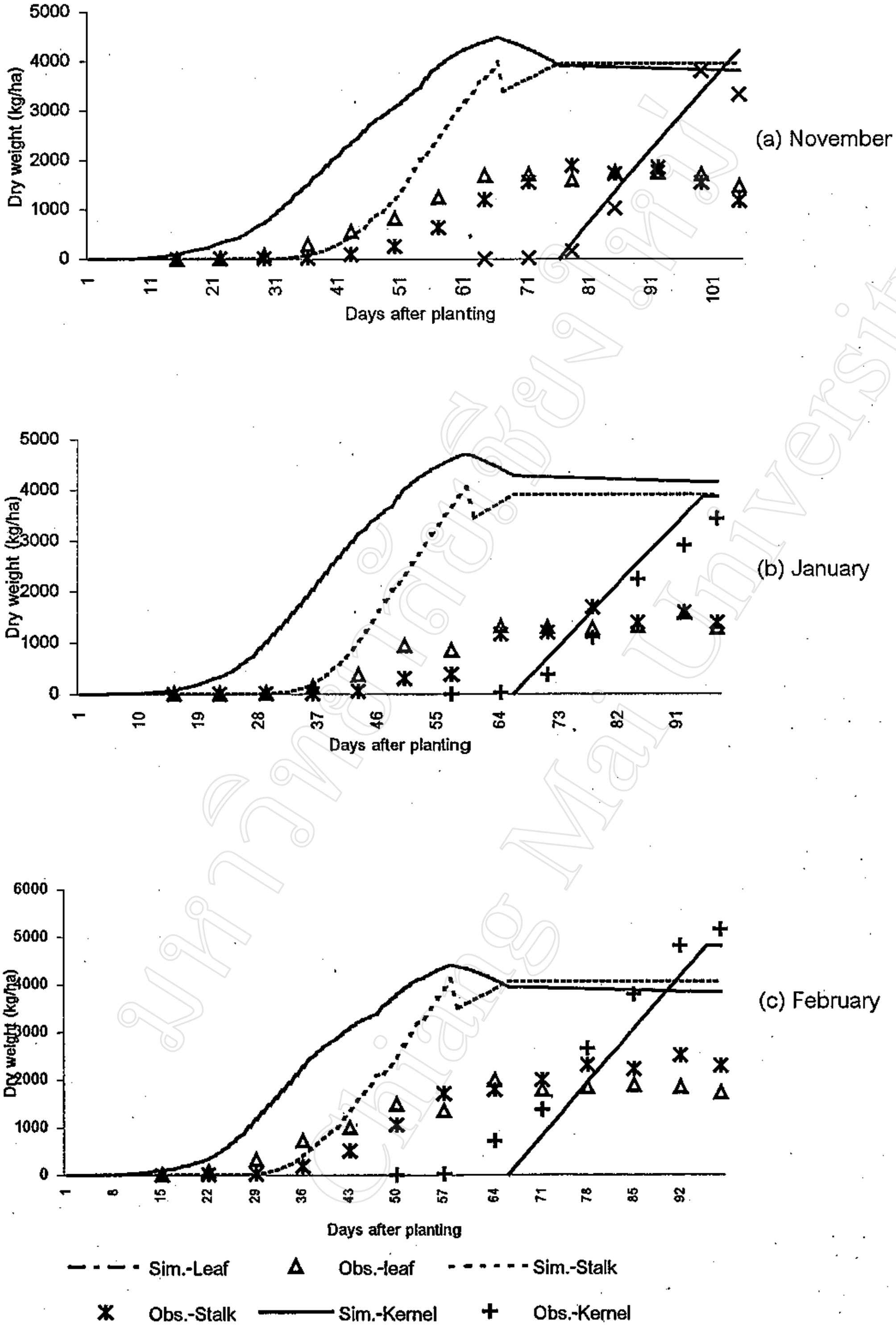


Figure 33 Comparison between simulated and observed leaf, stalk and kernel dry weights of NS 1 at three planting dates; (a) November, (b) January and (c ) February.

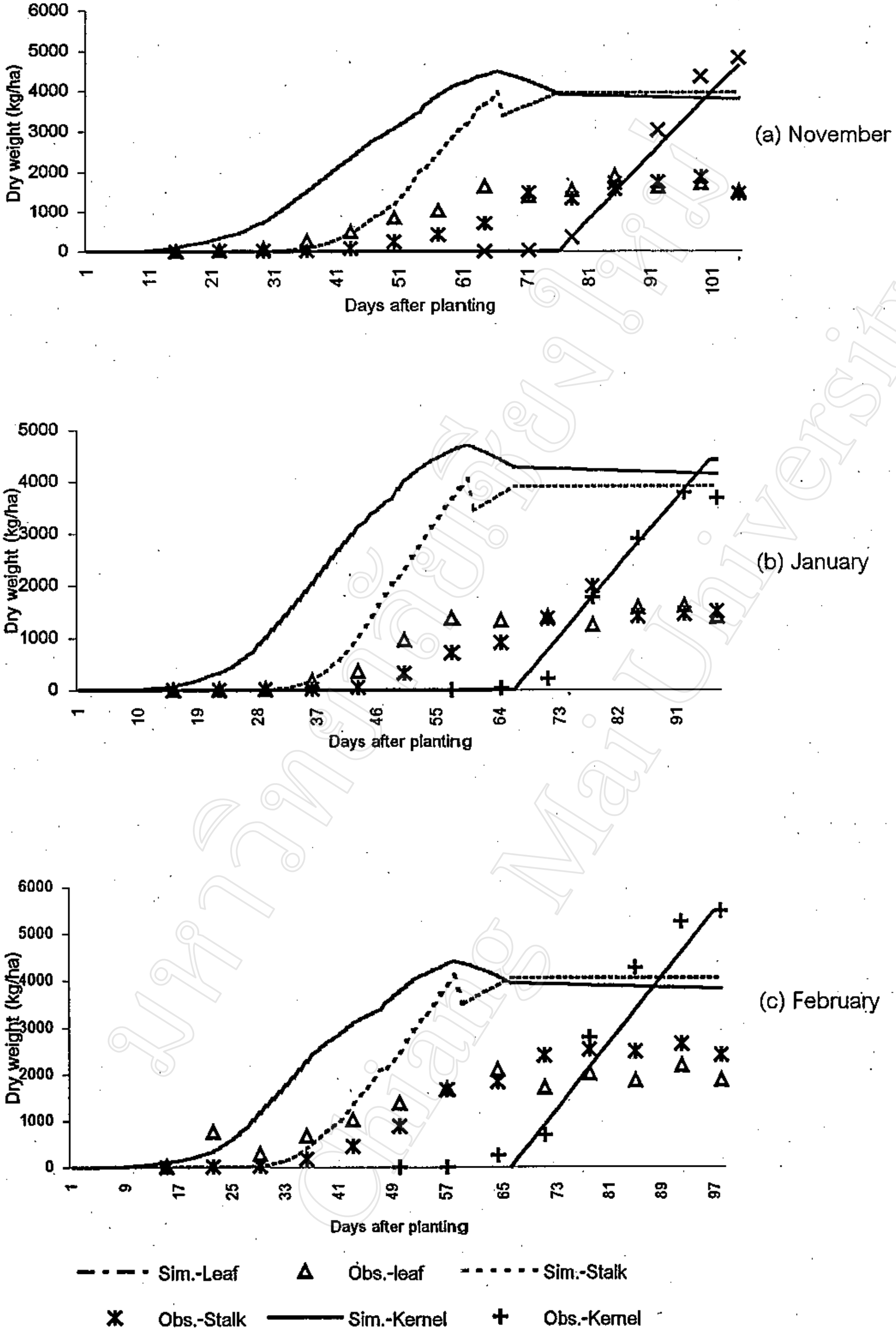


Figure 34 Comparison between simulated and observed leaf, stalk and kernel dry weights of NSX 9210 at three planting dates; (a) November, (b) January and (c ) February.

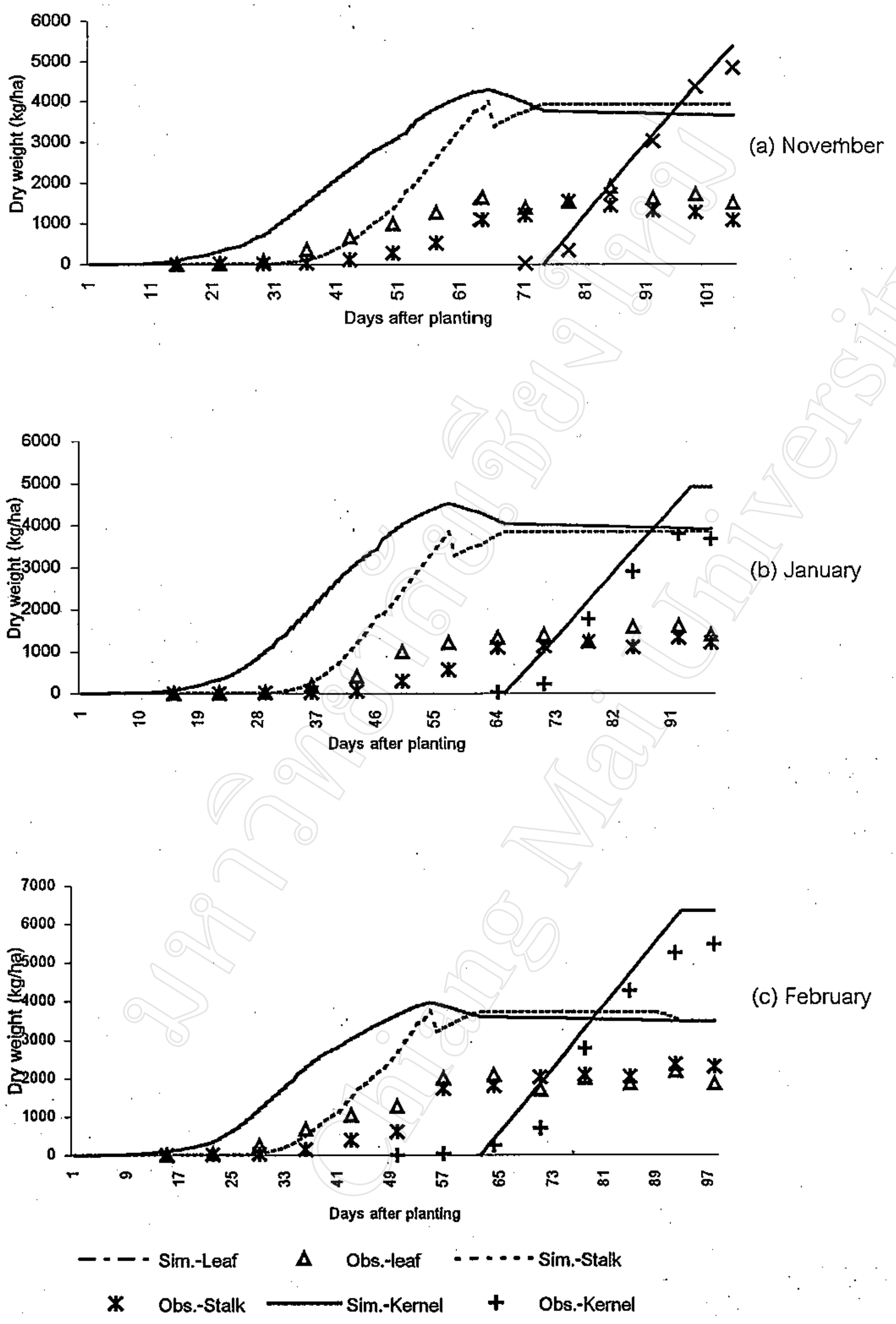


Figure 35 Comparison between simulated and observed leaf, stalk and kernel dry weights of SW 3601 at three planting dates; (a) November, (b) January and (c ) February.

Table 28. Simulated and observed kernel yield and yield components of three maize genotypes at three different planting dates.

| Planting dates | Kernel yield (kg/ha) | | Kernel no. m$^{-2}$ | | Kernel weight (g) | |
|---|---|---|---|---|---|---|
| | Simulated | Observed | Simulated | Observed | Simulated | Observed |
| NS 1 | | | | | | |
| PD1 | 4463 | 3257 | 2320 | 2322 | 0.1924 | 0.1400 |
| PD2 | 3874 | 2392 | 2151 | 1882 | 0.1800 | 0.1270 |
| PD3 | 4801 | 4686 | 2513 | 2504 | 0.1944 | 0.1870 |
| Mean | 4379 | 3445 | 2328 | 2236 | 0.1889 | 0.1513 |
| V | | 0.0956 | | 0.0047 | | 0.0793 |
| NSX 9210 | | | | | | |
| PD1 | 5068 | 3291 | 2523 | 2438 | 0.2009 | 0.1350 |
| PD2 | 4421 | 2323 | 2343 | 2093 | 0.1887 | 0.1110 |
| PD3 | 5472 | 4618 | 2735 | 2596 | 0.2001 | 0.1780 |
| Mean | 4987 | 3410.6 | 2533 | 2375 | 0.1965 | 0.1413 |
| V | | 0.2207 | | 0.0052 | | 0.1746 |
| SW 3601 | | | | | | |
| PD1 | 5358 | 4020 | 2688 | 2430 | 0.1993 | 0.1650 |
| PD2 | 4909 | 3236 | 2661 | 2324 | 0.1845 | 0.1350 |
| PD3 | 6336 | 5457 | 3123 | 2708 | 0.2029 | 0.2020 |
| Mean | 5534.3 | 4238 | 2824 | 2487 | 0.1955 | 0.1673 |
| V | | 0.0950 | | 0.0189 | | 0.0420 |

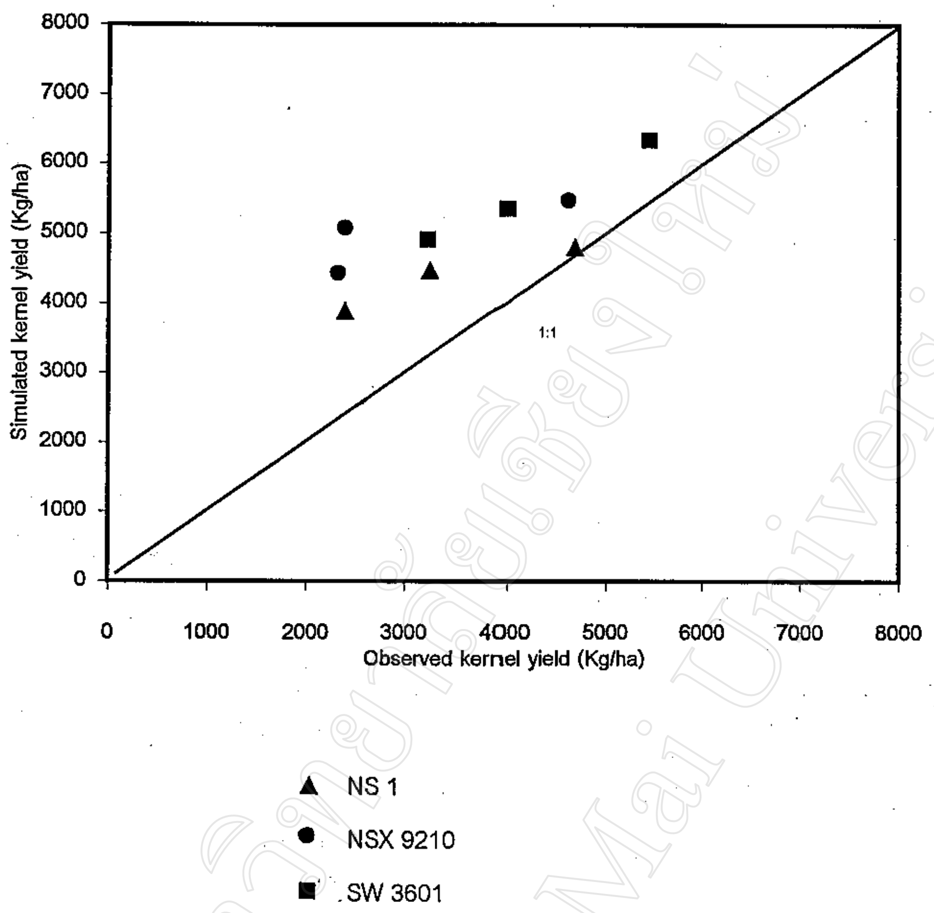


Figure 36 Comparison between simulated and observed kernel yield of NS 1, NSX 9 and SW 3601 at three planting dates.