

## 4

## Maize Phasic Development

J. R. KINIRY

USDA-ARS  
Temple, Texas

Grain yields of maize (*Zea mays* L.) vary greatly across locations and among years within locations. Mathematical modeling of maize yield has been popular because of the desire to predict grain yields across these variable environments. Maize production models include the Runge-Benci Model (Runge & Benci, 1975), the Splinter Model (Splinter, 1974), SIMAIZ (Duncan, 1975), the Bio-photo-thermal Model (Coligado and Brown, 1975), the Energy-Crop Growth Model (Coelho & Dale, 1980), CORNF (Stapper & Arkin, 1980), and CERES-Maize (Jones & Kiniry, 1986).

Most maize production models are designed to predict grain yield response to environment, but they differ in the types and complexity of biological processes involved. These differences are especially evident in techniques of predicting phenology. The Runge-Benci Model makes no attempt at predicting development. The Splinter Model and SIMAIZ both predict growth stages by accumulating degree-days. When the number of degree-days reaches a specified value, the plant is assumed to have reached the next growth stage. No attempt is made to quantify photoperiod sensitivity. The Energy-Crop Growth Model also predicts phenology based solely on temperature. The temperature function is a series of four lines fit to growth rate data. The Bio-photo-thermal Model combines genetic, photoperiodic, and thermal factors to predict number of days to tassel initiation. The CORNF and CERES-Maize Models both use photoperiod and temperature to predict development. In both, photoperiods > 12.5 h delay tassel initiation in sensitive genotypes and increase the final number of leaves. However, CERES-Maize provides a more detailed system of predicting stages and number of leaves, and its components can be more easily tested and validated. Recently, a phenology model was described in Japan (Torigoe, 1986; Torigoe et al., 1986) that includes leaf initiation, leaf-collar appearance, and developmental stages similar to CERES-Maize. In this model, development rates are temperature dependent and photoperiod sensitivity is ignored.

The objective of this chapter is to describe a model for predicting maize phenology based on photoperiod and temperature. Tassel and leaf primordia initiation are simulated to predict total number of leaves (TLNO). Rate of leaf-tip appearance is simulated to predict when the last leaf will emerge. Silking is predicted to occur soon thereafter. Three phases between silking

and physiological maturity are simulated. Two processes involved in phenology, which are not included, are the dependence of seed germination on soil water and the dependence of physiological maturity on assimilate supply. By omitting these, neither soil water balance nor assimilate allocation are required.

## I. MODEL DESCRIPTIONS

### A. Model Inputs and Operation Details

The model described in this chapter is designed to run with a minimal amount of weather data and input variables. The model is written in FORTRAN. The only required climatic data are daily minimum and maximum air temperatures (TEMPMN, TEMPMX). The latitude (LAT) and the day of the year of sowing (ISOW) are also required. There are three parameters that describe a cultivar: (i) the daily thermal time from seedling emergence to the end of the juvenile phase (P1); (ii) photoperiod sensitivity measured in days of tassel initiation delay per hour of photoperiod increase (P2); and (iii) the daily thermal time from silking to physiological maturity (P5). These can be independently derived as described in the text or can be estimated from values for similar cultivars for the location. The average computer time required to execute the model for one cultivar and one season on a large main-frame computer is 3 s. Simulations involving several years of weather data can be run with the same cultivar and planting date.

Phenological phases described in the model represent plant growth intervals delineated by distinct physiological events. The system of numbering these phases is circular as described in Table 4-1. An identifying integer (ISTAGE) is given for all phases, including the phase between physiological maturity and sowing (ISTAGE = 7) when the soil is fallow.

The model operates with a daily incrementing loop, which is executed until the end of the weather data is reached (Fig. 4-1). First the daily temperatures are read. Next, variables pertinent to the present phase are calculated. Finally, the decision is made as to whether the next phenological phase has been reached. This design is efficient and makes the model easy to understand and test.

Table 4-1. Description of the phenological phases used in the model.

Phase no.	Phase description
7	Prior to sowing (fallow)
8	Sowing to germination
9	Germination to seedling emergence
1	Seedling emergence to end of juvenile phase
2	End of juvenile phase to tassel initiation (photoperiod-sensitive phase)
3	Tassel initiation to silking
4	Silking to beginning of effective filling period of grain (lag phase)
5	Effective filling period of grain
6	End of effective filling period to physiological maturity (black layer)

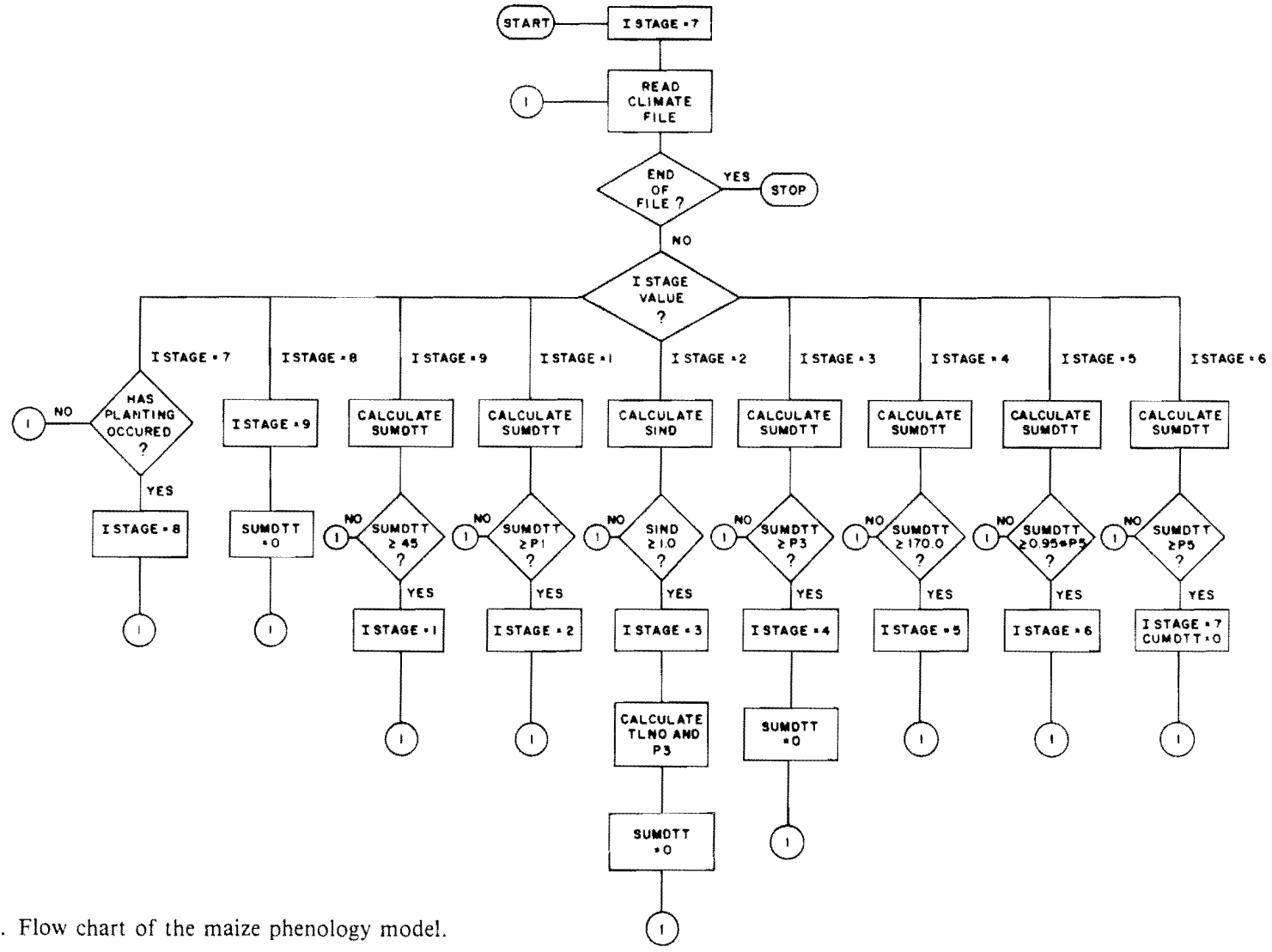


Fig. 4-1. Flow chart of the maize phenology model.

## B. Model Assumptions Concerning Maize Phenology

The critical assumptions, as described in detail in the following sections, relate to the development response to temperature for the apical meristem and leaves, and the rate of photoperiodic induction. The model assumes that the rate of development in various stages increases linearly above the base temperature up to 34°C, and then decreases linearly to zero as temperatures increase from 34 to 44°C. Similarly, rates of leaf initiation and leaf-tip appearance are assumed to change linearly in these two ranges of temperature. Photoperiodic induction is assumed to decrease with increasing photoperiod for photoperiods greater than 12.5 h. The number of days of tassel initiation delay for each hour increase in photoperiod is assumed to be a constant for any given photoperiod-sensitive cultivar.

## C. Maize Development

### 1. Thermal Response of Maize Development Rates

A growing degree-day or daily thermal time (DTT) system is used to simulate all processes except photoperiodic induction. Daily thermal time, calculated in the present model, is similar to the heat stress equation (Gilmore & Rogers, 1958), except that a base temperature of 8°C is used for most processes, a high temperature cutoff is activated at 34°C, and values are decreased linearly from their maximum at 34°C to zero at 44°C. Using the symbolism  $DTT_{TBASE}$  as the DTT for base temperature (TBASE), DTT is calculated from the mean daily temperature (TEMPM) as

$$DTT_{TBASE} = TEMPM - TBASE, \quad TEMPM > TBASE \quad [1]$$

The  $DTT_{TBASE}$  is set to zero if daily maximum temperature (TEMPMX) is less than TBASE. This approach is altered if one of two conditions exist:

1. TEMPMX is greater than and daily minimum temperature (TEMPMN) is less than TBASE, or
2. TEMPMX exceeds 34°C.

In such cases, eight values between TEMPMX and TEMPMN are interpolated with a zero-to-one factor (TMFAC) calculated with a polynomial fit to a sine wave curve. These values are substituted for TEMPM in Eq. [1] for temperatures between TBASE and 34°C and in Eq. [2] for temperatures between 34 and 44°C.

$$DTT_{TBASE} = [(44 - TEMPM)/10](34 - TBASE) \quad [2]$$

The mean of these interpolated values is the value for DTT.

**a. Base Temperatures of Development.** The base temperature of 8°C is used for all phenological phases except seedling emergence. This value came from a linear fit to rates of leaf tip appearance measured in controlled-

temperature growth chambers (Tollenaar et al., 1979; Kiniry & Ritchie, 1983, unpublished data; Fig. 4-2). A linear fit to predictions of leaf initiation rate (Warrington & Kanemasu, 1983) in the midrange of temperature also had a TBASE close to 8 °C (Fig. 4-3). The decrease in DTT above 34 °C, down to zero at 44 °C, was derived from the leaf-tip appearance rate data in Fig. 4-2.

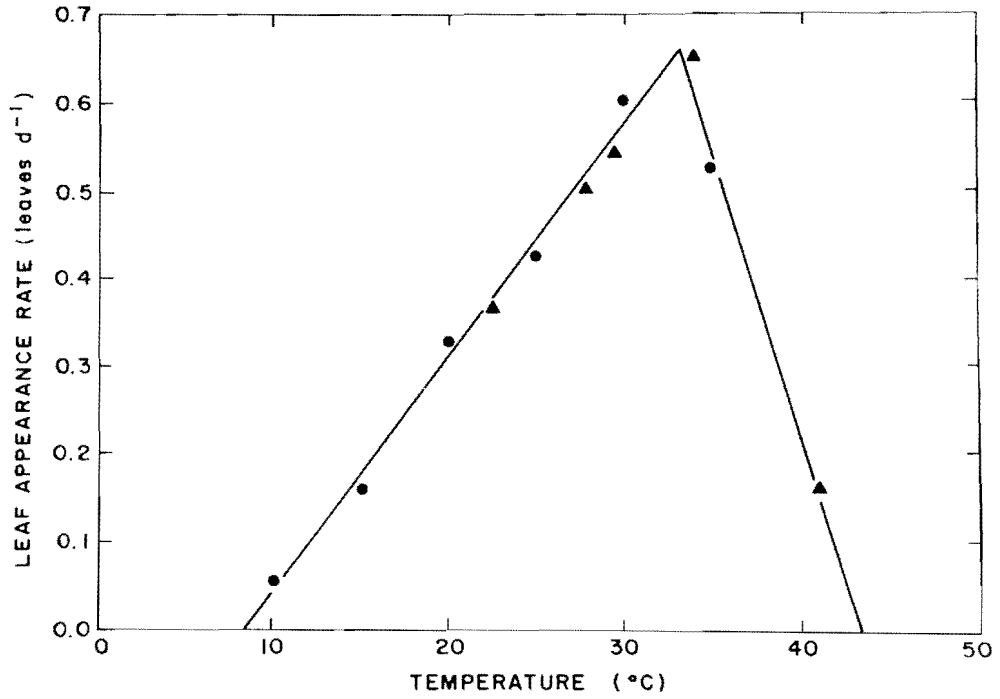


Fig. 4-2. Leaf-tip appearance rate of maize as a function of temperature. (● Tollenaar et al., 1979; ▲ Kiniry & Ritchie, 1983, unpublished data.)

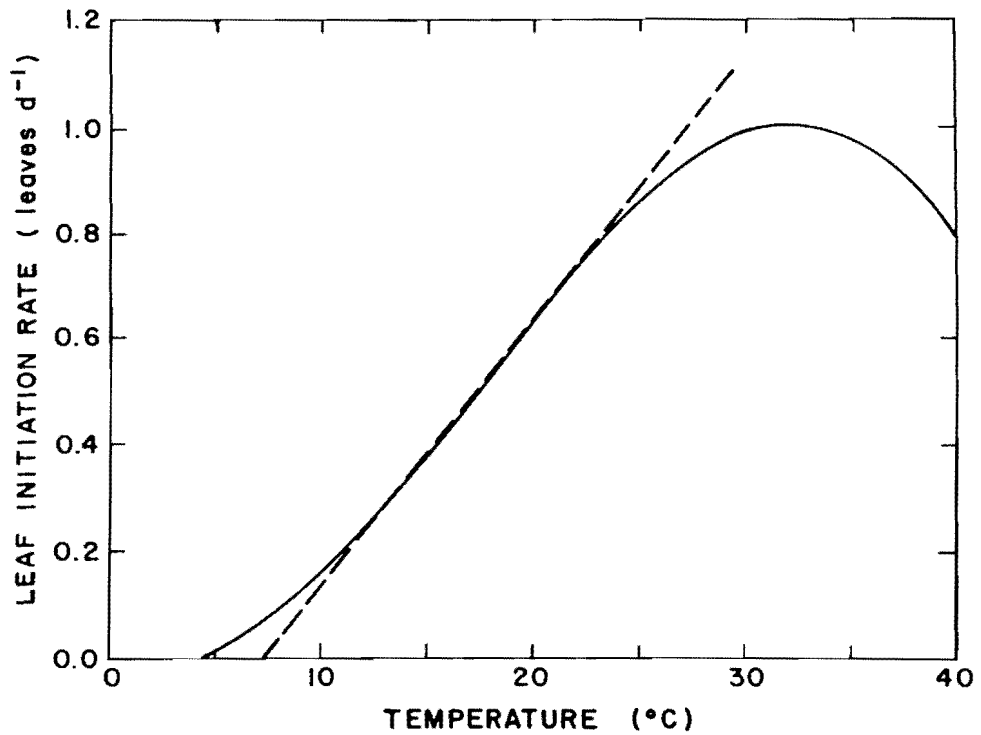


Fig. 4-3. Function for leaf primordium initiation rate of maize as a function of temperature (Warrington & Kanemasu, 1983).

The DTT from germination to seedling emergence has a TBASE value of 10°C. Coleoptile elongation rate has been shown to linearly increase from a value near zero at 10°C to a maximum value at 30°C (Blacklow, 1972).

## 2. Planting to Seedling Emergence Interval

In the model, planting to seedling emergence requires one day for germination and then 45 DTT<sub>10</sub> for coleoptile elongation. This assumes adequate soil moisture for germination at the time of planting. Results from unpublished field experiments conducted by the author have shown that there was an average of 45 DTT<sub>10</sub> in the interval from one day after planting to seedling emergence when planting depth was 5 cm.

## 3. Seedling Emergence to Silking Interval

The period from seedling emergence to silking involves three separate but related systems. The total number of leaves (TLNO) is determined from the number of leaf primordia initiated between seedling emergence and tassel initiation. Date of tassel initiation is determined using both DTT<sub>8</sub> and photoperiod. Silking, or end of leaf growth, is determined from TLNO and the rate of leaf-tip appearance. These three systems, leaf initiation, leaf-tip appearance, and the induction of tassel initiation, were developed independently and can be tested separately. They not only provide a framework for this model, but also one for further research in maize phenology.

The same DTT system described above with a base of 8°C is used to predict both leaf primordia initiation and leaf-tip appearance. The difference between the two rates is in the DTT<sub>8</sub> required per leaf tip or primordium. A field experiment at Temple, TX, (Kiniry and Ritchie, 1981 unpublished data) which used destructive sampling to count leaf primordia, showed that 21 DTT<sub>8</sub> were required for each leaf primordium to initiate and 38.9 DTT<sub>8</sub> for each leaf tip to appear. These values allow for prediction of leaf development, but date of tassel initiation is also required to determine TLNO.

Tassel initiation is the stage when leaf primordia initiation ends and branches of the tassel begin to develop. Work in the field at Temple, TX has shown that there are six primordia present at seedling emergence. Dividing the DTT<sub>8</sub> total from seedling emergence to tassel initiation by 21 DTT<sub>8</sub> allows prediction of the number of new primordia that were initiated.

Prediction of tassel initiation is critical to the system. The method used is based on work by Rood and Major (1980), and Kiniry et al. (1983a, b). While the plant is in the juvenile phase immediately following seedling emergence, the plant's development rate is dependent on temperature and independent of photoperiod. After a genotype-specific sum of DTT<sub>8</sub> (P1) has been reached, the plant's apical development is assumed to be independent of temperature and in the photoperiod-sensitive phase. In the model, all genotypes initiate their tassel 4 d after the start of this phase in photoperiods ≤ 12.5 h. For photoperiods > 12.5 h, the rate of induction (RATEIN) is:

$$\text{RATEIN} = 1/(4 + P2 \times (\text{HRLT} - 12.5)) \quad [3]$$

where HRLT is the number of daylight hours including civil twilight and P2 is a genotype-specific parameter for sensitivity. In the model, plants reach the tassel initiation stage when the total of daily values of RATEIN is  $\geq 1.0$ . Values for P1 and P2 have been determined for a wide range of genotypes (Table 4-2). Values for other cultivars can be calculated from controlled-environment experiments. The P1 value is the  $\text{DTT}_8$  total from seedling emergence to 4 d prior to tassel initiation in photoperiods of  $\leq 12.5$  h. The P2 value is the number of days delay in tassel initiation for each hour increase in photoperiod  $> 12.5$  h.

This system of predicting date of tassel initiation provides a method whereby high temperatures on different dates prior to tassel initiation can have variable effects on the final number of leaves (TLNO). Tollenaar and Hunter (1983) found that high temperatures immediately prior to tassel initiation increased TLNO. In the present model, duration of the inductive phase is strictly photoperiod dependent. However, initiation of leaf primordia is still temperature dependent. High temperatures during this phase will increase the rate of leaf initiation, but will not increase the rate of development of the apex. This results in a greater TLNO and delayed silking. Likewise, in the juvenile phase, both leaf initiation and phase duration are temperature dependent. High temperatures during this phase will increase both development rates and cause no change in TLNO.

In this model, silking and the end of leaf growth are assumed to occur on the same day. To determine the  $\text{DTT}_8$  from seedling emergence to the end of growth of the last leaf, two factors must be taken into account. The second leaf tip emerges from the leaf whorl about 20  $\text{DTT}_8$  after seedling emergence. There are about 76  $\text{DTT}_8$  from last leaf-tip appearance to the ligule appearance of that leaf. Thus, the total  $\text{DTT}_8$  from seedling emergence to emergence of the last leaf ligule is

$$(\text{TLNO} - 2) \times 38.9 + 96.0. \quad [4]$$

Subtracting the  $\text{DTT}_8$  at tassel initiation yields P3; the  $\text{DTT}_8$  total from tassel initiation to the end of leaf growth. Analysis of the data of Kiniry (1979) shows that, across three hybrids, four planting dates, two locations, and two years, the mean  $\text{DTT}_8$  from tassel emergence to silking was 62  $\text{DTT}_8$ . Assuming the last leaf tip emerges at tassel emergence, there are 14  $\text{DTT}_8$ , or about 1 d between silking and collaring of the last leaf.

#### 4. Silking to Maturity Interval

Grain development is the major phenomenon in the period from silking to physiological maturity. The three phases defined in the present system are those described by Johnson and Tanner (1972). These phases include a lag phase, a period of nearly linear grain filling called the effective fill period, and the period from the end of the effective fill period to physiological maturity (black layer).

Table 4-2. Genotype-specific values for the daily thermal time with an 8°C base temperature (DTT<sub>8</sub>) from seedling emergence to the end of the juvenile phase (P1), the days delay in tassel initiation for each hour increase in photoperiod (P2), and the DTT<sub>8</sub> from silking to physiological maturity (P5).

Cultivar	P1 DTT <sub>8</sub>	P2 d delay h <sup>-1</sup>	P5 DTT <sub>8</sub>
<u>Southern Canada</u>			
CORN281	110	0.30	--
CP170	120	0.00	680†
F7 × F2	125	0.00	732†
LG11	125	0.00	737†
PIO 3995	130	0.30	--
<u>Northern USA</u>			
INRA 260	135	0.00	739†
EDO	135	0.30	--
A654 × F2	135	0.00	751†
DEKALB XL71	140	0.30	--
F478 × W705A	140	0.00	670†
PIO 3901	144	0.30	--
<u>Northern Nebraska, N. Iowa, N. Illinois, and N. Indiana</u>			
PIO 3720	180	0.80	685
A632 × W117	187	0.00	730†
PIO 3382	200	0.70	--
PIO 3780	200	0.76	685
C281	202	0.30	685
<u>Southern Nebraska, S. Iowa, S. Illinois, and S. Indiana</u>			
PIO 511A	220	0.30	685
PIO 3183	260	0.50	750
W69A × F546	240	0.30	--
A632 × VA26	240	0.30	--
W64A × W117	245	0.00	--
NEB 611	260	0.30	720
B14 × OH43	265	0.80	665
B8 × 153R	218	0.30	760
<u>Central Missouri and Kansas to North Carolina and Southward</u>			
PIO 3147	255	0.76	685
WF9 × B37	260	0.80	710
PV82S	280	0.50	750
PV76S	260	0.50	750
B56 × C131A	318	0.50	700
B73 × Mo17	220	0.52	880
NC + 59	280	0.30	750
McCurdy 67-14	265	0.30	825
<u>Tropical Cultivars</u>			
H610	340	0.52	840
PIO X304C	390	0.52	940

† Values (Derieux & Bonhomme, 1982) assume maturity occurs at 30% grain moisture.

Kiniry and Keener (1982) found that the summed DTT<sub>10</sub> were less variable than days for the interval between silking and physiological maturity for various planting dates. The present model assumes a genotype-specific number of DTT<sub>8</sub> from silking to maturity. Future experimental work may indicate a different base temperature.



Work by Cross (1975) shows that the DTT for the lag phase did not differ significantly among genotypes. In the present model, this was determined to be 170 DTT<sub>g</sub> (Kiniry, 1985). The effective fill period begins at the end of the lag phase and ends when 95% of the total DTT<sub>g</sub> from silking to physiological maturity have been accumulated. The final developmental phase, from the end of the effective fill period to physiological maturity, requires the remaining 5%. A statement has been added to the model to prevent delayed maturity if cool temperatures prevent DTT accumulation during this final, short stage. If the DTT is  $\leq 2.0$  on a day during this last stage, maturity is assumed to occur.

Values for P5, the required summation of DTT<sub>g</sub> from silking to maturity, ranged from 665 for 'B14 × OH43' to 940 for 'PIO X304C' (Table 4-2). These values were derived from field data that included both silking and maturity measurements.

## II. MODEL VALIDATION

### A. Planting to Silking Interval

Predictions of interval lengths were tested for planting to silking and silking to physiological maturity. Testing for the first interval was done on four hybrids, Pioneer 3780, B73 × Mo17, H610, and McCurdy 67-14, each with several measured dates of silking. Another test was performed using 10 entries grown at eight locations in Europe (Derieux & Bonhomme, 1982).

Locations for Pioneer 3780 ranged from as far north as University Park, PA to as far south as Temple, TX (Table 4-3). The mean error in prediction of silking was 0.1 d early, with a standard deviation (SD) of 7.3 d. The greatest error occurred for data from Greeley, CO, with date of silking underestimated by 17 d. This could have been due to dry soil conditions delaying germination or because soil temperatures were cooler than air temperatures early in the season, causing delayed emergence. Deleting this one observation, the mean error was 2.0 d early with an SD of 3.8 d.

The hybrid with the most extensive test data was B73 × Mo 17 (Table 4-4). It was grown in nine plantings at Columbia, MO in 1978 and 1979 (Kiniry, 1979; Griffin, 1980), and was included in a multilocation study (Stapper & Arkin, 1980). There were plantings in 1982, 1983, and 1984 in Temple, TX (Kiniry, 1985) and a multilocation study in Europe in 1977 and 1978 (Derieux & Bonhomme, 1982).

Errors were similar in magnitude to those for Pioneer 3780. When large errors occurred, they were underpredictions of the days to silking. This may have been due to errors in dates of germination or seedling emergence. The mean error was -2.7 d and the SD was 5.6 d. Deleting the three data sets with large negative errors, the mean error was -1.2 d and the SD was 4.2 d.

The hybrid H610 was planted on several dates and locations in Hawaii (Table 4-5). It failed to have the large negative errors associated with some of the data sets of the previous two hybrids. This may have been due to the lack of cool soil temperatures. The mean error was 2.2 d and the SD was 4.3 d.

Table 4-3. Predicted and measured dates of silking of maize hybrid Pioneer 3780.

Location	Year	Silking	Date	Difference
		predicted	measured	
		— day of year —		d
Pennsylvania State Univ.†	1979	217	214	3
		222	222	0
		240	232	8
		250	243	7
Greeley, CO‡	1976	197	214	-17
Tyron, NE§	1978	211	211	0
Temple, TX¶	1982	149	151	-2
	1983	160	158	2
	1984	158	160	-2
$\bar{x}$				-0.1
SD				7.3

† Yao (1980).

§ Clawson (1980).

‡ Cuany et al. (1977).

¶ Kiniry (1985).

Table 4-4. Predicted and measured dates of silking of maize hybrid B73 × Mo17.

Location	Year	Silking	Date	Difference
		predicted	measured	
		— day of year —		d
Columbia, MO	1978	194	203	-9
		202	207	-5
		197	195	2
		210	211	-1
Location 2†	1978	224	221	3
		228	226	2
		198	205	-7
		220	223	-3
Location 3‡	1979	210	207	3
		233	246	-13
Swift Current, Saskatchewan§	1979	205	209	-4
Bloomington, IL§	1979	187	198	-11
		150	157	-7
		161	164	-3
Temple, TX¶	1982	150	157	-7
		161	164	-3
Europe#	1977-1978	155	157	-2
		235	248	-13
		215	220	-5
		204	202	2
Martonvasar, Hungary		223	220	3
Debrecen, Hungary		220	219	1
Zajecar, Yugoslavia		215	209	6
Radzikow, Poland		238	236	2
$\bar{x}$				-2.7
SD				5.6

† Kiniry and Keener (1982).

‡ Griffin (1980).

§ Stapper and Arkin (1980). Cooperators included H.R. Davidson, Canadian Dep. Agric., Swift Current, Saskatchewan and J.L. Malcolm, Funk Seeds Int., Bloomington, IL.

¶ Kiniry (1985).

# Derieux and Bonhomme (1982).

Table 4-5. Predicted and measured dates of silking of maize hybrid H610 in Hawaii. †

Location	Year	Silking	Date	Difference
		predicted	measured	
		Day of year		d
Waipio, HI	1983	43	43	0
Iole, HI	1982	218	208	10
Iole, HI	1979	134	130	4
Iole, HI	1978	114	110	4
Iole, HI	1978	239	235	4
Kukaiau, HI	1978	125	123	2
Kukaiau, HI	1979	206	209	-3
Kukaiau, HI	1978	91	87	4
Kukaiau, HI	1979	113	118	-5
Kukaiau, HI	1979	97	94	3
Halawa, HI	1978	265	259	6
Kukaiau, HI	1978	240	243	-3
$\bar{x}$				2.2
SD				4.3

† U. Sing and G. Uehara (1983, unpublished data).

Table 4-6. Predicted and measured dates of silking of maize hybrid McCurdy 67-14.

Location	Year	Silking	Date	Difference
		predicted	measured	
		Day of year		d
Columbia, MO†				
Location 1	1978	200	207	-7
	1978	206	210	-4
	1979	202	199	3
	1979	213	214	-1
Location 2	1978	227	225	2
	1978	229	231	-2
	1979	206	208	-2
	1979	225	225	0
Temple, TX‡	1981	179	174	5
	1982	140	145	-5
$\bar{x}$				-1.1
SD				3.7

† Kiniry and Keener (1982).

‡ C.A. Jones, 1982, unpublished data.

The final hybrid tested was McCurdy 67-14 (Table 4-6). There were eight plantings in Columbia, MO and two in Temple, TX. The mean error of these predictions was -1.1 d and the SD was 3.7 d.

Considering all four hybrids, the average mean error was -0.4 d and the average SD was 5.2 d. Large errors were usually underpredictions of the days to silking.

Another analysis was done with data from Europe consisting of 10 entries grown at eight locations (Derieux & Bonhomme, 1982; Table 4-7). Genetic parameters for all entries were derived using data from Fuchs, France. Data from this location were not included in the testing. Mean errors ranged

Table 4-7. Measured subtracted from predicted silking dates for 10 entries grown at seven locations in Europe in 1977 and 1978.†

Location	Year	Cultivar									
		Inra 260	F7 × F2	CP170	LG11	A654 × F2	F478 × W705A	A632 × W117	F16 × F19	W69A × F546	A632 × Va 26
Aubia, France	1977	4	--	6	4	6	3	0	4	--	--
Mons, France	1978	-1	-3	-6	-5	-2	-3	-1	-2	-3	-4
Rome, Italy	1978	2	2	3	2	4	3	4	5	7	6
Martonvasar, Hungary	1978	6	5	6	5	--	5	0	--	--	13
Debrecen, Hungary	1978	7	6	6	5	--	8	6	--	--	9
Zajecar, Yugoslavia	1978	6	6	4	6	7	7	6	9	15	15
Radzikow, Poland	1978	-4	0	1	-3	-5	-9	4	-3	6	6
$\bar{x}$		2.9	2.7	2.9	2.0	2.0	2.0	2.7	2.6	6.25	9.2
SD		4.1	3.7	4.3	4.3	5.2	6.0	3.0	5.0	7.4	7.5

† All data from Derieux and Bonhomme (1982).

from 2.0 d for cultivars LGH, A654 × F2, and F478 × W705A to 9.2 d for A632 × Va26. Standard deviations ranged from 3.0 d for A632 × W1117 to 7.5 d for A632 × Va26. Pooling all entries in all locations, the mean error was 3.2 d and the SD was 4.9 d. This SD was comparable to the mean SD for the previous tests. It appears that errors in this model's predictions can be expected to have a SD of 4 to 5 d.

### B. Silking to Maturity Interval

Tests on the growth phase from silking to physiological maturity were conducted with B73 × Mo17 and McCurdy 67-14. Both hybrids were grown with multiple plantings in Missouri and Texas. The required  $DTT_8$  to complete this growth interval was determined using a subset of the data. All the data were included in the test results. Errors for B73 × Mo17 (Table 4-8) had a SD of 8.0 d. This was comparable to errors for the planting to silking interval of the same hybrid. The two greatest errors overpredicted the interval duration. By deleting the two plantings with large errors, the mean error became  $-0.1$  d and the SD was 3.3 d. These two plantings did not appear to be stressed; kernel dry weights were 0.32 and 0.34 g kernel<sup>-1</sup> and grain yields were 8220 and 8370 kg ha<sup>-1</sup>, respectively.

McCurdy 67-14 (Table 4-9) had a SD of 8.3 d, which was greater than the SD associated with the errors in silking date prediction. For this hybrid, the three largest error values underpredicted the duration of the growth phase. This hybrid, when grown in Missouri, experienced low temperatures when approaching physiological maturity. The present system of using  $DTT_8$  may be too simple to predict physiological maturity as temperatures approach freezing. It is possible that photosynthetic rate or carbohydrate availability may influence the time of maturity under cool conditions.

Table 4-8. Predicted and measured days from silking to physiological maturity for hybrid B73 × Mo17.

Location	Year	Interval		Difference
		Predicted	Measured	
		d		
Columbia, MO				
Location 1†	1978	52	52	0
	1978	53	53	0
	1979	53	55	-2
	1979	59	66	-7
Location 2†	1978	64	47	17
	1978	69	51	18
	1979	57	56	1
	1979	76	74	2
Temple, TX‡	1979	46	45	1
Temple, TX§	1984	47	43	4
$\bar{x}$				3.4
SD				8.0

† Kiniry and Keener (1982).

‡ Stapper and Arkin (1980).

§ Kiniry (1985).

Table 4-9. Predicted and measured days from silking to physiological maturity for hybrid McCurdy 67-14.

Location	Year	Interval		Difference
		Predicted	Measured	
d				
Columbia, MO				
Location 1†	1978	50	53	-3
	1978	50	52	-2
	1979	50	66	-16
	1979	56	71	-15
Location 2†	1978	61	52	9
	1978	68	68	0
	1979	71	72	-1
	1979	56	72	-16
Temple, TX‡	1981	41	41	0
	1982	44	50	-6
$\bar{x}$				-5.0
SD				8.3

† Kiniry and Keener (1982).

‡ C.A. Jones (1982, unpublished data).

### III. RESEARCH NEEDS

A possible source of uncertainty in the model is inconsistency in the  $DTT_8$  per leaf primordium or leaf tip. Warrington and Kanemasu (1983) reported the leaf initiation rate in a 12 h photoperiod at 28 °C was 95% as great as in a 14 or 16 h photoperiod at the same temperature. In contrast, Gmelig-Meyling (1973) found that the rate of leaf appearance was not photoperiod dependent for plants grown in photoperiods ranging from 9 to 17 h. Also, in contrast with our findings in the field, Tollenaar et al. (1984) found that leaf appearance rates of different hybrids varied by as much as 14%. Another deviation occurred in a field experiment planted in October in Temple, TX, when leaf primordia required 27 instead of 21  $DTT_8$ .

Rate of daylength change has been proposed as one factor that alters the rate of leaf appearance (Baker et al., 1980). These two rates were shown to be correlated in wheat (*Triticum aestivum* L.) grown in the field. However, in growth chambers with controlled temperatures, leaf appearance rate was not affected by rate of daylength change for the first 2 wk after seedling emergence (Kiniry & Ritchie, 1983, unpublished data). In this experiment, two wheat and two maize cultivars were grown in a constant-temperature environment with either + 5, - 5, or zero minutes of change in photoperiod per day.

The silking to maturity interval also needs further research. An obstacle to defining the  $DTT$  system for this interval lies in the problems associated with growing large maize plants in growth cabinets. Maize grain development is seldom normal in such controlled environments. Likewise, problems with light quality and temperature control make work in greenhouses equally difficult. At the present time, the author believes a  $DTT_8$  with the required sum calculated from field data for each cultivar is sufficient.

## IV. SUMMARY

The model presented here was shown to function in a wide range of environments and with a wide range of genotypes. Similar to the traditional  $GDD_{10}$  sums that are widely used, it requires only daily maximum and minimum temperatures. The model's advantage is its ability to account for photoperiod sensitivity and the effects of high temperatures on final leaf number. In addition, three components of vegetative development, leaf initiation, leaf-tip appearance, and tassel initiation, can be independently tested.

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