

# Sowing date and fertiliser effects on sweet corn phenological development

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## Abstract

Phenology is important in crop production as it determines the synchrony of the crop with its environment. Therefore, phenology is important in crop mechanistic growth models, and when scheduling process crops such as sweet corn. Temperature is the main driver of sweet corn development, however the effects of factors such as nutrient stress have not been quantified. The aim of these experiments was to determine a base temperature ( $T_b$ ) for sweet corn in Canterbury, and then use thermal time to quantify the effect of nitrogen (N) and phosphorus (P) on phenology.

'Challenger' sweet corn was sown on five dates. By minimising the coefficient of variation (CV%) in thermal time between emergence and silking, or maturity, a  $T_b$  of 8 °C was selected. Two separate experiments with either 5 N (0, 45, 90, 180, 300 kg N/ha), or 5 P (0, 50, 100, 150, 200 kg P/ha) rates were conducted on a low P site. When N was not applied maturity was from 997 (300 ha/ha) to 967 °Cd (0 kg N/ha). P deficiency delayed maturity from 957 (200 kg P/ha) to 1018 °Cd (0 kg P/ha), due solely to an increase in the duration between emergence and silking (588 to 693 °Cd), with 351 °Cd between silking and maturity.

These results suggested that P can markedly alter sweet corn phenology. Ensuring that crops are not P deficient is important for both crop scheduling and quantifying the risk of crop failure in a marginal climate like Canterbury. Furthermore, the response of development to P supply should be included in models of sweet corn response to fertiliser.

**Additional key words:** base temperature, maturity, nitrogen, phenology, phosphorus, silking, thermal time, *Zea mays*.

## Introduction

A mechanistic description of crop development is an important component of crop production. In particular, the timing of events in the crop life cycle determines its synchronicity with the environment. For a process vegetable crop, such as sweet corn (*Zea mays*), quantifying phenology is also important for crop scheduling, whereby the timing and management of operations, such as sowing, are manipulated to produce an even sequence of production for factory requirements (Wurr *et al.*, 2002). Furthermore, in mechanistic crop growth models accurate predictions of crop phenology are required to ensure other processes are simulated to occur at the appropriate time and therefore respond to the prevailing environmental stimuli (Hodges, 1991).

Quantification of phenology is also useful to indicate the risks of crop production in a marginal environment. New Zealand sweet corn production is expanding into marginal environments such as Canterbury. In 2000, 1160 ha or 18 % of the total New Zealand production was in Canterbury (Anon, 2000). However, previous analysis of crop

phenology and climatic variation has indicated that Canterbury is the most southern latitude where sweet corn can be reliably grown (Wilson and Salinger, 1994). These predictions indicated there was a significant risk that sweet corn would fail to mature due to cool temperatures (slow development) and a short frost-free period (growing season). These risks can be minimised by using early maturing cultivars and early planting dates.

In a well-managed crop (adequate water and nutrients) crop development is determined by temperature and photoperiod. For example, in a winter wheat simulation model, Weir *et al.* (1984) used daily temperature data and photoperiod to simulate phenological development. Temperature is the key factor in determining the development rate of a crop, so thermal time ( $T_t$ ) is used to quantify the accumulation of temperature between development stages. Thermal time, or heat units (°Cd) is simply the sum of mean daily temperatures ( $T_{mean}$ ) minus a base temperature ( $T_b$ ) that varies with crop type (Equation 1). When  $T_{mean}$  is below  $T_b$  when development is set at 0.

$$T_t = \sum (T_{mean} - T_b) \quad (\text{Equation 1})$$

This method assumes a linear increase in development rate with increasing  $T_{\text{mean}}$ , and assumes that this development ceases at or below  $T_b$ . The determination of the correct  $T_b$  for development is an important step in determining  $T_t$  for a crop (Shaykewich, 1995). This is particularly important for C4 crops such as *Zea mays*, which are likely to have a high  $T_b$ , when they are grown in a cool climate, such as Canterbury, where  $T_{\text{mean}}$  is sometimes close to or below  $T_b$ . In such a case an inaccurate  $T_b$  will lead to great disparity in thermal time accumulation with development rate. Furthermore,  $T_t$  time is central to the development of phenological sub models in mechanistic crop growth models. For example, Muchow *et al.* (1990) used  $T_t$  with a  $T_b$  of 8 °C to predict leaf appearance, silking (start of grain growth period), and crop maturity of grain maize in their model. However, in their model Wilson *et al.* (1995) used a broken stick function to account for development at low temperatures in a cool climate. Thermal time is also the basis of crop scheduling. However, deficiencies of certain nutrients may have marked effects on the development of the crop. These effects have not been adequately quantified, particularly in sweet corn.

In the current experiment the time taken to reach silking and then crop canning maturity were examined. Silking is an important event in the crop's life, because it occurs at the same time as leaf growth stops, and signals the start of grain filling (Brooking and McPherson, 1989). Silking represents a stage in the crop phenology when there is a shift from vegetative to reproductive priority. It is an easily definable growth stage, which can be used to give an intermediate (during the season) measure of crop development. Canning maturity is defined as 72 % kernel moisture content and is important for scheduling for producers.

Thus, the aim of the three experiments reported in this paper was to quantify the effects of sowing date, and mineral nutrition on sweet corn phenological development. In the first experiment data from five sowing dates was used to determine the most appropriate base temperature ( $T_b$ ) to use for calculating thermal time for sweet corn development. In the second and third experiments the effect of varying rates of nitrogen (N) and phosphorus (P) fertiliser on sweet corn phenology were examined.

## Methods

### Site and crop agronomy

All three experiments used 'Challenger' sweet corn, hand sown at a rate of 71,000 plants/ha in 0.7m into low phosphorus site (Olsen P = 6 µg/ml) at Lincoln, Canterbury, New Zealand in the 2001-2002 growing season. A full description of the site and crop management has been given previously (Fletcher *et al.*, 2002). However, a range of sowing dates, N and P fertiliser regimes were applied to the crops in each of the three experiments (Table 1).

### Experiment 1 (sowing date)

In experiment 1 crops were established on three sowing dates (18 October, 8 November, 15 November) in three replicates of a completely randomised design. All treatments received basal dressings of 300 kg N/ha (as Calcium ammonium nitrate CAN; 26, 0, 0, 0), 200 kg P/ha as triple superphosphate TSP; 0, 21, 0, 0) and 35 kg S/ha (as Potassium sulphate  $K_2SO_4$ ; 0, 0, 40, 7). Plots were 4.9 m wide (7 rows at 0.7 m spacing) and 5 m long. In the analysis of this experiment additional data from the equivalent fully fertilised plots from Experiments 2 and 3 were included, which gave five sowing dates sown at 7 day intervals (Table 1). N and P fertiliser in all experiments were applied in split applications (N on 15 October, 20 December 2001, and 16 January 2002; P on 5 October and 14 October).

### Experiment 2 (Phosphorus)

Experiment 2 was sown on 25 October in a randomised complete block design with five rates of P (0, 50, 100, 150, and 200 kg P/ha as TSP) replicated three times (Table 1). All plots received basal dressings of 300 kg N/ha (as CAN) and 35 kg S/ha (as  $K_2SO_4$ ). Plots were 4.9 m wide (7 rows at 0.7 m spacing) and 10 m long.

### Experiment 3 (Nitrogen)

Experiment 3 was sown on 1 November in a randomised complete block design with five rates of N (0, 45, 90, 180, and 300 kg N/ha as CAN) replicated three times (Table 1). All plots received basal dressings of 200 kg P/ha (as TSP) and 35 kg S/ha (as  $K_2SO_4$ ). Plots were 4.9 m wide (7 rows at 0.7 m spacing) and 10 m long.

**Table 1. Outline of treatments for three experiments with 'Challenger' sweet corn grown at Lincoln, Canterbury, New Zealand in 2001-2002.**

Treatment	Sowing Date (2001)	N applied kg/ha	P applied kg/ha	Kernel Moisture % at final harvest
<b>Experiment 1</b>				
SD1	18 October	300	200	76.6
SD2	8 November	300	200	74.2
SD3	15 November	300	200	76.1
* P200	25 October	300	200	76.6
* N300	1 November	300	200	74.8
<b>Experiment 2</b>				
P0	25 October	300	0	75.2
P50	25 October	300	50	76.6
P100	25 October	300	100	74.7
P150	25 October	300	150	75.6
P200	25 October	300	200	76.6
<b>Experiment 3</b>				
N0	1 November	0	200	76.6
N45	1 November	45	200	74.1
N90	1 November	90	200	74.9
N180	1 November	180	200	74.6
N300	1 November	300	200	74.8

\* P200 and N300 treatments included in the analysis of Experiment 1. So that five sowing dates were included.

## Measurements

Crop emergence was monitored for all plots in Experiment 1. In Experiments 2 and 3 the low, medium and high plots were all monitored. Two, 1 metre lengths of row were monitored daily and visible coleoptiles counted. In Experiments 2 and 3 there were no differences between treatments, therefore, in the final analysis a mean date was used for all plots.

In each plot of all three experiments 20 contiguous plants were marked and monitored daily to estimate the time of 50 % silking. To determine harvest maturity (72 % moisture in kernels) the kernels were stripped, using a knife, from three randomly selected cobs and a 70-200 g sub-sample was taken. This sub-sample was dried rapidly overnight at 105 ( $\pm$  5) ° C for approximately 12 hours. The dry matter of the sub-sample was determined, and the fraction of moisture in the fresh sample calculated. Data indicated a mean water loss rate of 0.6 % per day during this period, which was used to estimate the date of harvest, 1 day in advance of the 72 % moisture content in kernels. At harvest maturity the 20 marked plants were hand harvested and their kernel moisture content determined (Table 1).

The above method gave a mean of 75-76 % moisture for the three experiments with no significant differences between treatments (Table 1).

However, there was a clear trend in Experiment 3 for the N0 plots to have greater moisture content than the other treatments. There was also a trend in Experiment 1 for SD2 and the N300 treatment to have lower moisture contents than the other three treatments.

## Analysis

### Experiment 1

Data from Experiment 1 were used to quantify the phenological development of a sweet corn crop without nutrient stress. An appropriate base temperature ( $T_b$ ) for accumulating thermal time was determined. Cumulative thermal time (Equation 1) from emergence to silking and from emergence to maturity was determined for each plot using a range of  $T_b$  from 0 to 10 ° C in 1 ° C steps. For each  $T_b$  a mean  $T_t$  and standard deviation (SD) for the 15 plots were calculated. Using these parameters a coefficient of variation (CV %) was calculated for each base temperature. The most appropriate  $T_b$  was selected as that giving the minimum CV %.

### Experiments 2 and 3

For each plot in both experiments  $T_t$  (Equation 1) cumulated thermal time for the periods from emergence to maturity, emergence to silking, and silking to maturity, was calculated using the  $T_b$  defined in Experiment 1. These were then compared

between fertility treatments using analysis of variance in GENSTAT 5, release 4.2 (Lawes Agricultural Trust, Rothamsted experimental station, UK, 2001). Means separation was based on Fishers protected least significant difference.

## Results

### Experiment 1

The CV % for Tt from emergence to silking was always higher than from emergence to maturity. Up to silking the CV % showed a steady decline as the T<sub>b</sub> increased from 0 °C and reached a minimum of 3.03 % at T<sub>b</sub>=7 °C. Higher values for T<sub>b</sub> lead to a large increase in CV % (Figure 1a). A similar pattern was found for the Tt from emergence to maturity but the minimum CV of 1.69 % was at T<sub>b</sub>=8 °C (Figure 1b).

Based on these results, and previous literature a T<sub>b</sub>=8 °C was selected for all further analysis. Using this the mean Tt from emergence to maturity was 968 °Cd, with 602 °Cd from emergence to silking and a further 364 °Cd from silking to maturity.

### Experiment 2

The addition of P fertiliser to sweet corn accelerated development to crop maturity (p<0.05). The Tt from emergence to maturity was 1018 °Cd with no P fertiliser but 957 °Cd when 200 kg P/ha was supplied (Table 2). This equated to a 9 day difference in maturity.

The period from emergence to silking was the major component of this difference with Tt reduced

from 693 °Cd with no P fertiliser to 588 °Cd (p<0.01) with 200 kg P/ha (Table 2). In contrast the duration of the period from silking to maturity was unchanged by fertiliser at 351 (± 11 s.e.) °Cd.

### Experiment 3

The addition of N fertiliser delayed maturity from 967 °Cd with no N, to 997 °Cd (p<0.05) when 300 kg N/ha was supplied (Table 3). This equated to 6 days difference.

Despite this difference between emergence to maturity, there was no systematic difference in the Tt from emergence to silking (614±8 °Cd) or from silking to maturity with a mean of 368±9 °Cd (Table 3).

## Discussion

### Experiment 1

It was concluded from Experiment 1 that the most appropriate T<sub>b</sub> for modelling sweet corn phenological development was 8 °C (Figure 1). The statistically most appropriate T<sub>b</sub> for the period between emergence and silking was 7 °C, but there was only a minor increase in CV % when a T<sub>b</sub> of 8 °C (as was found for the emergence to maturity period) was used. A value of 8 °C is the same as that used previously in a maize crop model (Muchow *et al.*, 1990), and for a previous study of sweet corn development by Stone *et al.* (1999). However, 8 °C varies from other reported T<sub>b</sub>s calculated for sweet corn, such as 5.4 - 6.4 °C (Olsen *et al.*, 1993), and in New Zealand 6 °C (Brooking and McPherson, 1989).

**Table 2. Effect of five rates of applied fertiliser P (0, 50, 100, 150, and 200 kg P/ha) on Tt (°Cd) from emergence to maturity, emergence to silking, and silking to maturity in 'Challenger' sweet corn grown in Lincoln, Canterbury, New Zealand, in 2001-2002.**

Applied Phosphorus (kg/ha)	Emergence - Maturity (°Cd)	Emergence - Silking (°Cd)	Silking - Maturity (°Cd)
0	1018	693	325
50	982	637	345
100	991	634	357
150	962	603	359
200	957	588	369
p value	0.019	0.001	0.124
s.e.	10.4	15.7	10.7

**Table 3. Effect of five rates of applied fertiliser N (0, 45, 90, 180, and 300 kg N/ha) on Tt (°Cd) from emergence to maturity, emergence to silking, and silking to maturity in 'Challenger' sweet corn grown in Lincoln, Canterbury, New Zealand, in 2001-2002.**

Applied Nitrogen (kg/ha)	Emergence – Maturity (°Cd)	Emergence – Silking (°Cd)	Silking – Maturity (°Cd)
0	967	622	345
45	976	599	377
90	985	615	370
180	989	609	380
300	999	627	370
p value	0.025	0.212	0.173
s.e.	5.42	7.86	9.41

The method for calculating a  $T_b$  used here seems appropriate as it was based on minimising the variation in Tt for predicting development, but this method is only one of many possibilities. Each of these other methods yields different solutions. With the same data set Yang *et al.* (1995) calculated a  $T_b$  ranging from 6.3 to 10 °C, for sweet corn, depending on the method used. The method of minimising the CV %, such as in the current experiment, has been used previously for maize, where a  $T_b$  of 6 °C was found to be the optimum (Bonhomme *et al.* 1994).

A key problem with using a range of sowing dates to calculate a  $T_b$  is that it ignores the effect of photoperiod. However, in addition to defining a  $T_b$  for maize, Bonhomme *et al.* (1994) demonstrated that development of temperate cultivars was virtually photoperiod insensitive. Furthermore, in a climate such as Canterbury's most sweet corn crops will be sown close together while the environmental conditions are optimum, therefore photoperiods are similar. In a study of development in commercial sweet corn crops in Feilding and Gisborne, Brooking and McPherson (1989) indicated that the effect of photoperiod on crop durations was likely to be minimal.

Previous research has indicated that early development of *Zea mays* is mainly driven by soil temperature (Stone *et al.*, 1999). However, for the purposes of crop scheduling and in the current experiment air temperatures are used, because they are more readily available and usually adequate. Normally soil temperature and air temperature are coupled with each other. Therefore, in the current experiment this is unlikely to have significantly affected the results.

The CV % at each base temperature for the period between emergence and crop maturity were much lower than the CV % for the period between

emergence and silking (Figure 1). This was because there was similar variation (SD) in both periods, but a much larger mean in the period between emergence and maturation. Therefore, the variation as a proportion of the mean (CV %) was reduced.

### Experiments 2 and 3

From Experiment 2 it was concluded that severe P deficiency markedly delayed the maturity of sweet corn (Table 2). The delay was caused by an increase in the emergence to silking period. Silking was probably delayed by a reduction in the appearance of individual leaves (Fletcher *et al.*, 2002). The period from silking to maturity was not altered.

The delay in silking with P deficiency has been reported previously for maize (Arya and Singh, 2001). However, this was not quantified in Tt but the number of days to 50 % flowering was reported to differ from 57.9 days in the 0 kg P/ha treatment to 55.8 days in the 40 kg P/ha treatment. In sweet corn starter fertiliser (both N and P) has been shown to reduce the number of days to silking (Swiader and Shoemaker, 1998). This reduction in days was related to early seedling dry mass, indicating that the early plant growth was limiting development.

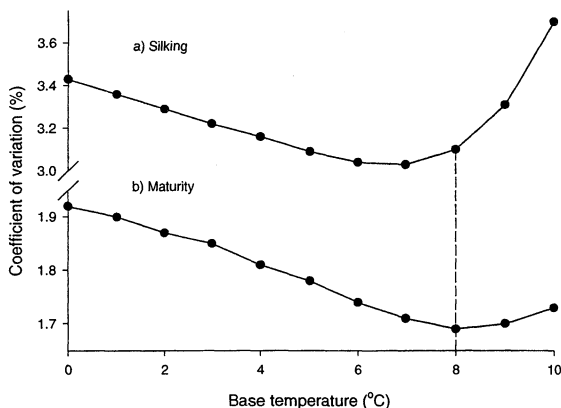
Biological reasons for the delay in development are not immediately obvious. It is possible that P deficiency limited photosynthesis (Usuda and Shimogawara, 1992), so that there was insufficient photo assimilate available for leaf expansion. In this case a lack of crop growth contributes to the perceived delay in development. Alternatively, the lack of P may have had important implications for energy transfers within the plant. Inorganic P may be lacking so that ADP/ATP are limited, leading to decreased enzyme kinetics. Jacob and Lawlor (1993), showed that levels of ATP and

ADP were markedly reduced in phosphate deficient maize and sunflower (*Helianthus annuus*) leaves.

A delay in maturity with a P limitation indicates the need to include a P response in crop models. Without this models will give poor simulations of crop and environment synchronies in low P environments. For crop scheduling the effect must also be included. Consequences of any P deficiency can be anticipated or avoided by the addition of adequate P to commercial crops.

Sweet corn is a 'risky' crop to grow in Canterbury (Wilson and Salinger, 1994) due to the

short growing season. Any delay in maturity will further increase the risk of crops failing to mature. This issue is likely to be most apparent for 'organic' crops where P stress may be a problem. In such circumstances risks can be reduced by early planting and the use of high P (Olsen P >20 µg/ml) sites. Rock phosphate can also be used in 'organic' systems. However, it will take longer to become plant available than traditional P sources (McLaren and Cameron, 1998). Therefore careful attention must be paid to maintaining P status in these situations.



**Figure 1.** Effect of varying  $T_b$  on the CV% in  $T_t$  from emergence to silking (a) and emergence to maturity (b) in 'Challenger' sweet corn grown in Lincoln, Canterbury, New Zealand in 2001-2002. The dotted line indicates  $T_b$  of 8 °C selected for further analyses.

Results from Experiment 3 showed that applying N delayed crop maturity (Table 3). This was due to the combination of small increases in both the time from emergence to silking and silking to maturity. However, much of the effect was probably caused by the error in predicting harvest date accurately, with clear differences in moisture content between the treatments (Table 1). In this experiment the low N plots were at a higher moisture content (76.6 %), with the other plots being approximately 74.6 %. Given a moisture loss rate of approximately 0.6 % per day this equates to about a 3 days, accounting for half this difference. Alternatively, the addition of N may have increased leaf area index, leading to an increase in evaporative

cooling and hence a slight canopy temperature drop. This may have caused a small delay in maturity. The magnitude of this delay was biologically and agronomically insignificant. The slight delay contrasts with previous results, where N stress delayed development in *Zea mays* (Singh and Wilkins, 1999). Perhaps in the current experiment soil N levels too high for such a response. Francis *et al.*, (1992) showed that a spring wheat crop, without N fertiliser, following July cultivated pasture was able to accumulate 170 kg N/ha. While, a sweet corn crop yielding 16 t/ha will take up 174 kg N/ha (Clarke *et al.*, 1986).

The results indicate that the effect of P on sweet corn maturity was more important than the

effect of N, but this is likely to depend on the specifics of an experiment e.g. crop, soil and climatic effects. Previous research has indicated that N stress can lead to delays in phenological development in maize (Uhart and Andrade, 1995) and other C4 crops such as Sorghum (*sorghum bicolor*) (van Oosterom *et al.*, 2001).

The next step with these results is to determine a mechanistic basis for the observed changes. The results from Experiment 2 could be related to soil P levels (Olsen P) or even plant uptake of P to develop a functional relationship that could be integrated into previous models for maize (Muchow *et al.*, 1990; Wilson *et al.*, 1995). Data reported previously (Fletcher *et al.*, 2001) also can be used to create a mechanistic leaf appearance scale for predicting silking, and then assuming a constant duration from silking until maturity (Table 2).

In conclusion, the most appropriate  $T_b$  for quantifying sweet corn phenology in this experiment was 8 °C. P deficiency delayed maturity in sweet corn but N had a minimal effect on maturity.

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