



# The effect of planting date on maize: Phenology, thermal time durations and growth rates in a cool temperate climate



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## ABSTRACT

Field experiments were established in the Waikato and Manawatu regions of New Zealand over two cropping seasons (2006–2007), differing primarily in rainfall and soil type, to establish how planting date (PD) influenced maize phenology and growth processes across a range of environmental conditions. Though not significantly different to 8 °C, a base temperature of 8.6–9.4 °C ( $T_b$  8.6– $T_b$  9.4) adequately estimated thermal time (TT) durations for the emergence–flowering phase while  $T_b$  0 was more satisfactory for estimating grain filling duration.

Delayed planting either reduced (Waikato) or increased (Manawatu) the emergence–flowering duration and this was associated with changes in leaf number and phyllochron length. The phyllochron averaged 47 °Cd, but increased to 51 °Cd when soil temperature, radiation and precipitation between emergence and tassel initiation were respectively >22 °C,  $\leq 17 \text{ MJ m}^{-2} \text{ d}^{-1}$  and  $\leq 30 \text{ mm}$ . Sub-optimal temperatures and radiation under late plantings triggered a source limitation, leading to assimilate remobilization, reduced grain filling duration and resulted in higher grain moistures at physiological maturity (36% vs. 30%). When rainfall between emergence and flowering was  $\geq 234 \text{ mm}$ , increases in average daily irradiance ( $19.5\text{--}21.4 \text{ MJ m}^{-2} \text{ d}^{-1}$ ) and mean temperature (15–18 °C) increased pre-flowering crop growth rate (CGR) by  $1 \text{ g m}^{-2} (\text{°Cd})^{-1}$ . With late planting, higher pre-flowering radiation ( $\geq 21 \text{ MJ m}^{-2} \text{ d}^{-1}$ ) and temperatures ( $\geq 17 \text{ °C}$ ) increased CGR while low post-flowering radiation ( $13 \text{ MJ m}^{-2} \text{ d}^{-1}$ ) and temperature (15.7 °C) reduced CGR. Kernel growth rate (KGR) was more stable across PDs and hybrids when TT was used ( $0.36\text{--}0.38 \text{ mg } (\text{°Cd})^{-1}$ ). Provided temperature was  $\geq 19 \text{ °C}$ , low daily irradiance ( $11 \text{ MJ m}^{-2} \text{ d}^{-1}$ ) did not significantly reduce KGR. More rapid leaf senescence occurred for early and late plantings, and this was attributed to source–sink imbalances caused by assimilate accumulation or shortage. Leaf senescence rates in the absence of water stress were  $0.03\% (\text{°Cd})^{-1}$  between anthesis and mid grain-fill, and increased to  $0.2\% (\text{°Cd})^{-1}$  towards the end of grain filling.

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## 1. Introduction

Provided nutrients are non-limiting, maize (*Zea mays* L.) growth and development in the field are mainly influenced by temperature, radiation, photoperiod and water availability. These factors vary in time and space and hence crops planted on different dates

experience dissimilar environmental conditions. Of these factors, temperature has the largest influence on development of modern maize hybrids as it determines the rate and duration of developmental phases.

Understanding the environmental parameters and physiological processes that affect time to maturity is key to determining hybrid suitability to a previously untested environment. In order to appropriately position a maize hybrid within a target environment, its maturity must be known. Additionally, ability to estimate timing of crop development stages helps with critical decisions in crop husbandry such as irrigation timing and in harvest prediction.

In New Zealand maize hybrids are generally rated for relative maturity using the Wisconsin Comparative Relative Maturity (CRM) system. The system is not fully standardized across different maize seed companies (Lauer, 1998). Even though the CRM rating system has units of days, it does not denote calendar days to maturity, and lacks predictive accuracy in environments that are cooler

**Abbreviations:** CGR, crop growth rate;  $\text{CGR}_{\text{ES}}$ , crop growth rate between emergence and silking;  $\text{CGR}_{\text{SS}}$ , crop growth rate between silking and silage harvest; CRM, comparative relative maturity; ENV, environment; GY, grain yield; HI, harvest index; IPAR, intercepted photosynthetically active radiation; KGR, kernel growth rate; KN, kernel number; KW, kernel weight; LA, leaf area; PD, planting date; PM, physiological maturity;  $T_b$ , base temperature; TI, tassel initiation;  $T_{\text{max}}$ , maximum daily temperature;  $T_{\text{min}}$ , minimum daily temperature;  $T_{\text{ml}}$ , maximum lethal temperature;  $T_{\text{opt}}$ , optimum temperature; TT, thermal time.

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or warmer than the US Corn Belt. A procedure that considers thermal time (TT) requirement to reach specific developmental stages such as silking or maturity alleviates these shortcomings of the CRM system.

Growth and development occur between two cardinal temperatures, a base temperature ( $T_b$ ) and a maximum lethal temperature ( $T_{ml}$ ). At  $T_b$  growth and development are assumed to be zero, and development reaches a maximum at an optimum temperature ( $T_{opt}$ ), before falling again to zero at  $T_{ml}$ . Temperatures of the vast majority of field environments fall between  $T_b$  and  $T_{opt}$ , where there is a linear relationship between temperature and rate of development. This has allowed the advent of the “TT” concept, also known as “heat units”, to describe and predict crop development. Thermal time can be used to predict crop development more reliably than calendar days since it is independent of the temperature regime in which the crop is grown provided temperatures lie between  $T_b$  and  $T_{opt}$ . For maize, TT is usually calculated as:  $TT = [(T_{max} + T_{min})/2] - T_b$ , where  $T_{max}$  and  $T_{min}$  are, respectively, daily maximum and minimum temperature. If  $T_{max}$  or  $T_{min} < T_b$ , then  $T_{max}$  or  $T_{min} = T_b$  and if  $T_{max}$  or  $T_{min} > T_{opt}$ , then  $T_{max}$  or  $T_{min} = T_{opt}$  (McMaster and Wilhelm, 1997). Most field-based thermal time systems use  $T_{opt} = 30^\circ\text{C}$ , but crop models often use  $T_{opt} = 34^\circ\text{C}$  and reduce rates of development at supraoptimal temperatures in proportion to the difference  $T_{max} - T_{opt}$  (Ritchie and NeSmith, 1991).

While the advent of TT has been a significant development in predicting timing of key developmental stages, choice of  $T_b$  is critical. Base and optimum temperatures of  $10^\circ\text{C}$  and  $30^\circ\text{C}$  are widely used for maize in the US, with  $41^\circ\text{C}$  considered as  $T_{ml}$  (Ritchie and NeSmith, 1991). Other investigations of  $T_b$  for maize have resulted in a value of  $6\text{--}8^\circ\text{C}$  (Derieux and Bonhomme, 1982; Ritchie and NeSmith, 1991; Vinocur and Ritchie, 2001) and  $T_b 10$  may lead to a significant underprediction of TT to specific developmental stages in areas of low average temperatures such as New Zealand.

The main objectives of this research are:

1. To establish whether  $T_b$  varies across different maize developmental stages.
2. To quantify the thermal time requirements to flowering and maturity among hybrids of different CRM ratings.
3. To establish the effect of planting date (PD) on timing of maize crop development milestones, phyllochron duration, kernel growth rate (KGR), crop growth rate (CGR), leaf senescence and remobilization for hybrids of different CRM ratings grown in a cool temperate climate.

The study is part of a more extensive investigation that forms the basis of adapting the CERES Maize model to predict an optimal match of hybrid and environment when planting maize in a temperate climate (Tsimba, 2011).

## 2. Materials and methods

### 2.1. Site and planting details

Four field experiments, termed ENVs, were established over two cropping seasons (2006 and 2007). These were at Rukuhia Research Station in 2006 (RUK07) and 2007 (RUK08), Ngaroto Research Station in 2007 (NGA08) and Massey University Pasture and Crop Research Unit in 2007 (MAS08). The latter was situated in the Manawatu Region on a Manawatu fine sandy loam (Dystric Fluventric Eutrochrept). Both Rukuhia and Ngaroto Research Stations are situated in the Waikato Region on a Horotiu sandy loam soil (Vitric Orthic Allophanic) and an Ohaupo silt loam (Typic Orthic Allophanic), respectively.

Weather data collection, planting details and choice of hybrids are fully described elsewhere (Tsimba et al., 2013). In brief, six hybrids representing three maturity groups: short (38P05 and 38H20), mid (36M28 and 36B08) and late (34D71 and 34P88) were planted in Waikato ENVs. In Manawatu, 36M28, 36B08 (late), 38H20, 38P05 (mid) and 39G12 (early) were planted. The seven hybrids tested ranged from 78 to 110 d based on the CRM rating. Planting dates were evenly spread to include very early, typical and very late PDs (18 September to 15 December) for each ENV, resulting in four (Manawatu) or five (Waikato) PD treatments (PD1–PD5). Due to cooler springs in Manawatu (MAS08), the earliest planting was on 16 October, resulting in PD1 being considered as missing in subsequent data analyses.

Each experiment was designed as a randomized complete block design with a split-plot treatment arrangement replicated three times where planting dates were considered as the main plots and hybrids as sub-plots. For practical reasons, gross plot sizes varied across ENVs as follows: 6 rows  $\times$  9.5 m long  $\times$  0.76 m (RUK07); 6 rows  $\times$  14 m long  $\times$  0.76 m (RUK08); 4 rows  $\times$  14 m long  $\times$  0.76 m (NGA08) and 6 rows  $\times$  10 m long  $\times$  0.70 m apart (MAS08). Measurements were taken from well bordered plants in central rows.

Weather data were obtained from the nearest National Institute of Water and Atmospheric Research (NIWA) automated weather stations. Soil temperatures used in the study were collected on-site at the 5 cm soil depth recorded hourly using “WatchDog 100” (Spectrum Technologies®, Inc.) data loggers. While RUK07 experienced a normal rainfall season, MAS08, NGA08 and RUK08 were characterized by a significantly dry summer, with the latter environment experiencing the most stressful conditions. Water stress was alleviated at MAS08 by supplemental irrigation.

### 2.2. Determination of a suitable base temperature for maize crop development

To determine the best  $T_b$  for each developmental stage, the coefficient of variation (CV) of estimates for TT durations across different PD treatments was minimized by systematically changing the value for  $T_b$  using methods similar to those described by Bonhomme et al. (1994) and Stewart et al. (1998). Only ENVs with a full complement of phenology data (RUK07, RUK08 and NGA08) were used in this exercise. Values ranging from  $T_b - 1^\circ\text{C}$  to  $T_b + 11^\circ\text{C}$  were used to calculate TT from planting to maturity in steps of  $0.1^\circ\text{C}$  for planting to emergence, emergence to tassel initiation (TI) and flowering, and for flowering to black layer for each of the five PD treatments. The most stable value for each developmental stage was considered to be the one resulting in a minimum CV for TT values across PD treatments. Standard errors of estimated  $T_b$  values were calculated and used to determine the 95% confidence interval for  $T_b$  using the three ENVs as replicates.

### 2.3. Seedling emergence and tassel initiation

Time to emergence was considered as the date when the coleoptiles of 50% of planted seeds had emerged above the soil surface. Time required to reach TI stage at RUK07 and RUK08 was determined for each plot by dissecting 3–4 randomly selected border row plants under a stereoscopic microscope every 2–3 d, starting immediately after the sixth leaf tip became visible in the whorl. Border rows were initially left unthinned to allow these measurements to be conducted on spare plants. Tassel initiation was defined as the stage when the growing point on at least 50% of the plants was  $\geq 0.4$  mm in length. Due to the time-consuming nature of the dissection procedure, TI measurements for MAS08 and NGA08 were obtained indirectly using the equation determined from RUK07 manual dissection data: *Visible leaf number at TI* =  $0.54 \times \text{final leaf number} - 1.01$  ( $r^2 = 0.67^{***}$ ;  $n = 90$ ). This relationship was estimated

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