Quantification of Stem Elongation Rate in Response to Temperature and Photoperiod by 24 Multiplicative Models

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ABSTRACT

The first step to quantify crop phenology is to precisely estimate the parameters which affect it. These main parameters are temperature and photoperiod. Therefore we aimed to formulate and validate 24 mathematical functions that can be used to determine cardinal temperatures, critical photoperiod (below which development rate decreases due to short photoperiods) and the effect of temperature and photoperiod on biological days required from emergence to stem elongation for wheat (cv. ‘Koochdaash’). For this purpose, 24 multiplicative non-linear regression models (including flat, logistic, quadratic, cubic, dent-like, segmented, curvilinear and beta) for response to temperature, and quadratic, dent-like and negative exponential, to assess the response to photoperiod, were used. Also, the phenological data obtained from an independent experiment were used for independent model evaluation. A multiplicative model that included a quadratic function for response to both temperature and photoperiod was the most adequate to describe the response of stem elongation rate to temperature and photoperiod. Using this function, a base temperature of 7.62°C, a ceiling temperature of 37.60°C, a critical photoperiod of 14.006 h and a photoperiod sensitivity coefficient of 0.11 h−1 were obtained. This function and its parameters can be used in wheat simulation models to predict the duration of emergence to stem elongation based on a thermal time concept. Also, the required number of biological days from seedling to stem elongation using this model was 26.90.

Keywords: cardinal temperatures, non-linear fitting, photoperiod, stem elongation rate, wheat
Abbreviations: F: flat; S: segmented; Q: quadratic; C: cubic; V: curvilinear; D: dent-like; B: beta; L: logistic; Ne, negative-exponential

INTRODUCTION

A portion of a crop model is devoted to predicting the timing of crop development processes (phenology) (Hodges 1991). In a crop model, the simulation of crop phenology is generally divided into several growth stages to mark sequential turning points in crop development and biomass partitioning. Without accurate prediction of phenology, the model will simulate growth processes as occurs at different times and under different conditions that they actually do, and conditions during each growth stage affect the ability of the crop to respond to conditions during later stages (Jame and Cutforth 2004). The simple concept of constant thermal time is most commonly used for predicting the time required from emergence to stem elongation (thermal time has the unit of degree-days (°C days) and is defined as (Eq. 1) (Hodges 1991).

\[ TT = \sum_{n=1}^{N} (T - T_b) \]  

where T, Tb and n are mean daily temperature, base temperature and number of days until a given stage, respectively.

Temperature is the most important driving force influencing crop development rate and its function is linear at a wide range of temperatures (Forcella 1993). The main environmental variables that affect wheat development (when expressed in thermal time units) are temperature and photoperiod (Slafar and Rawson 1994). Many studies have demonstrated that photoperiod influences the rate of development well beyond the end of the vegetative phase (Slafar and Rawson 1994).

The stem elongation phase in wheat [Triticum aestivum (L.)] is considered to be critical for yield determination. A longer duration of this phase could hypothetically increase grain set and therefore yield (Whitechurch et al. 2007). Wheat development from seedling emergence to flowering can be divided into three sub-phases (Slafar and Rawson 1994): (i) vegetative (when all leaf primordia on the main shoot are initiated until floral initiation, i.e. the formation of the first reproductive primordium or collar); (ii) early reproductive (from floral initiation to the formation of the terminal spikelet when all spikelets and few florets within them are differentated); (iii) late reproductive (from terminal spikelet initiation to flowering, a stem elongation phase when most florets are differentiated to reach a maximum number of floret primordia that then experience a drastic reduction to end up with a number of fertile florets as flowering).

The correct timing of phenological events is generally considered to be the most important factor for adaptation and maximum yield in individual environments (Syme 1968; Fischer 1979; Richards 1991). The time from sowing to anthesis is dependent on the cumulative durations of three phenological phases, vegetative from sowing (S) to double ridge (DR), spikelet initiation from DR to terminal spikelet (TS) and stem elongation from TS to anthesis (A) (Davidson and Christian 1984). The three phases contribute differently to yield; thus, their relative durations must be balanced within the time available from sowing to anthesis. Early sowing increases the number of days or thermal units to anthesis (Stapper and Fischer 1990), but the effects on the duration of the three component phases are not known. Knowledge of the effect of sowing date on development is also necessary to improve wheat crop models (Manupetipan and Pearson 1993).

Non-linear regression models have been extensively used to quantify stem elongation of many crops. Ritchie

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