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# A simple model to predict phenology in malting barley based on cultivar thermo-photoperiodic response

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ABSTRACT

In the Pampean region of Argentina, farming systems are based on intensive land use, wheat/soybean double cropping being a key component of these agricultural systems. However, during the last years farmers have been replacing wheat for barley due to its earlier maturity date, reducing yield penalization in soybean as a consequence of delays in its sowing date, and improving the economic profits of the double cropping system. To maximize the benefits of barley/soybean double cropping system, the proper timing of key barley ontogenic stages should be easily identifiable by farmers. The objectives of the present study were to (i) characterize crop phenology through thermo-photoperiod models in response to different sowing dates, (ii) use the algorithms calculated in point (i) to generate a simple model for predicting phenology, using historical climatic series, and (iii) validate the model with independent data. Barley cultivars used in the present study did not show vernalization requirements. Variations in phenology, measured in thermal time, were mainly associated with variations in photoperiod sensitivity during the emergence-heading phase. Significant differences in photoperiodic sensitivity, from −65 °Cd h$^{-1}$ (Scarlett) to −344 °Cd h$^{-1}$ (Q. Ayelen), were observed among cultivars. However, cultivars did not show significant differences in critical photoperiod or intrinsic earliness. The slope of the relationship between heading time and date of emergence, calculated from the algorithms used to build the model, based on thermo-photoperiodic response, varied between locations and cultivars. When the model was tested with an independent data set, predictions for the sowing-flowering phase showed a root mean square error lower than 4% (similar to that observed using more complex models). The algorithms used in the model were masked into a friendly frame and outputs were shown in a simple and attractive manner for users. The model was uploaded to the web site of the University of Buenos Aires to be used by students, advisors, professionals and farmers barley.



## 1. Introduction

Ever since the no-tillage practice was introduced in the Pampean region of Argentina, farming systems have been based on an intensive use of land, wheat/soybean double cropping being a key component of these agricultural systems. Soybean – wheat double-cropping is also a common production system in other regions such as mid-southern and mid-western United States (Kyei-Boahen and Zhang, 2006; Egli, 2008), or central Europe (Basic et al., 2004). In the double-cropping system, soybean is planted immediately after wheat harvest (from late December to early January in the Pampean region) (Calviño et al., 2003). In the Southern Pampean region, each day of delay in soybean sowing after mid-December represents a soybean yield reduction of ca. 2% per day (Calviño et al., 2003). Under this scenario, barley is an alternative for replacing wheat as it normally matures earlier than wheat due to an earlier flowering (Miralles et al., 2000, 2001; Alvarez Prado et al., 2013). This barley-related benefit has been reflected in ca. 400% increase of the malting barley harvested area

*Abbreviations:* DOEm, day of year for seedling emergence; DOEmc, critical day of year for seedling emergence; DOFVN, day of year for first visible node; DOHd, day of year for heading; DOPM, day of year for physiological maturity; DOSow, day of year for sowing; Em, seedling emergence; FVN, first visible node; Hd, heading; Ie, intrinsic earliness (°Cd); N, nitrogen; P, phosphorus; PM, physiological maturity; *Ps*, photoperiod sensitivity (°Cd h$^{-1}$); RMSE, root mean square error; SD, sowing date treatments; Sow, sowing date; $T_b$, base temperature (°C); TT, thermal time units (°Cd).

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in the Pampa region during the last 10 years (MAGyP, 2011). In the same period, the introduction of new barley cultivars with similar or even higher yield potential than wheat, thus improving the economic profits of barley/soybean double cropping, contributed to expanding the malting barley harvested area. However, further opportunities to maximize benefits in this cropping system still exist if the timing of key barley ontogenic stages could be better and easily identified by farmers. Having a better knowledge of particular crop phases, such as the critical period when the number of grains is determined (Arisnabarreta and Miralles, 2008) or stages such as heading date, would help to make crop management decisions. One of the main restrictions when selecting sowing dates for winter cereals in the Rolling Pampas is the occurrence of frosts around heading. Thus, the evaluation of frost risk around heading should be considered when sowing date is brought forward to improve the benefit of early maturing. In order to turn barley into a better competitor than wheat, a "fine tune" crop management is required with a correct prediction of barley phenology.

Phenology of barley can be divided into the following phases: (i) sowing to emergence, (ii) emergence to heading, and (iii) heading to physiological maturity. Development (phenology) in barley is mainly determined by three factors: photoperiod, temperature and vernalization (Slafer and Rawson, 1994). Increases in temperature determined a reduction in the duration of the phases from sowing to physiological maturity. As temperature plays a major role in plant development from sowing to maturity, phenology is usually characterized in thermal time units (Bonhomme, 2000). In relation to its photoperiod response, barley is considered a long-day plant reaching heading more rapidly with increases in photoperiod until reaching the critical value (named optimum photoperiod); beyond optimum photoperiod, the emergence to heading phase is constant (when measured in thermal time and considering plants without vernalization requirements). Vernalization is the requirement by which extended exposure to low temperatures promotes the advance to reproductive stages (Brooking and Jamieson, 2002; Amasino, 2004). If the cultivar has strong sensitivity to vernalization, exposure to temperatures above ca. 16 °C will provoke a remarkable delay in heading date (Brooking and Jamieson, 2002). Under field conditions, changes in sowing date or location will determine changes in temperature and photoperiod to which barley crops are exposed. Thus, a delay in sowing date, associated to increases in mean photoperiod, will determine reductions in the duration of sowing-heading period due to increases in mean temperature, as well as in mean photoperiod (Hay and Ellis, 1998). However, if the cultivar has vernalization requirements, the delay in sowing date (i.e. higher temperatures) will determine a longer sowing to heading phase (Hay and Ellis, 1998). Therefore, for the same cultivar, observing longer durations of emergence to heading phase associated with delays in sowing date provides evidence of vernalization requirements (Whitechurch et al., 2007). The duration of the phase from heading to physiological maturity is only modified by temperature: an increase in mean temperature reduces the duration of the phase measured in days. However, for a particular genotype, if this phase is measured in thermal units the values should be constant (when the range of explored temperature is between the base and the optimum) independently of the occurrence of heading time.

Crop simulation models, such as those used for wheat (ARC-WHEAT1, Weir et al., 1984; CERES-Wheat, Ritchie and Otter, 1985; AFRCWHEAT2, Porter, 1993), and barley (CERES-Barley, Otter-Nacke et al., 1991; QBAR, Goyne et al., 1996) are powerful tools for predicting phenology (Goyne et al., 1996). Nevertheless, these models require several variables as inputs (i.e. crop management, soil description, climatic series and genetic coefficients) and some minimal training for users. These models are based on mathematical algorithms that describe variations in the rate of development over time, in response to environmental factors such as temperature and photoperiod (Otter-Nacke et al., 1991; Herndl et al., 2008). To develop this kind of models, it is necessary to count with a solid characterization of the cultivars response to temperature and photoperiod variations across specific locations as well as to determine the annual and inter-annual variations in crop phenology using historic climatic series. Alternatively, crop phenology could be easily simulated by simple and empirical models based on cultivar thermo-photoperiodic response in crops without vernalization requirements (McMaster and Wilhelm, 2003; Jamieson et al., 2007; He et al., 2012).

The objectives of this study were to (i) characterize the crop phenology in response to changes in temperature and photoperiod in Argentine, Brazilian and Uruguayan barley cultivars, (ii) use the adjustments (algorithms) calculated in point (i) to generate a simple model for predicting phenology in different locations of the Pampean region, and (iii) validate the model with independent data. The criteria applied for building the model might be made extensive to other cultivars or crops and to different regions.

## 2. Materials and methods

### 2.1. General conditions and experimental design

A field experiment was carried out during the 2005/2006 growing season at the experimental field of the Department of Plant Production, University of Buenos Aires (34°35′S, 58°29′W). Treatments consisted of a combination of 7 sowing dates (SD) and 8 two-rowed commercial malting barley cultivars (*Hordeum vulgare* L.). The experiment was arranged in a randomized complete block design on sites with 3 blocks per treatment, where sowing dates represented the sites and cultivars were randomized within each sowing date and block. The cultivars included in the analysis were chosen because they represent those mainly used by the malting industry in Argentina (B1215, MP 1109, Quilmes Ayelén, Quilmes Painé and Scarlett), Uruguay (Danuta and Dayman) and Brazil (BRS 195) (Aguinaga, Pers. Com.; INTA, 2011). Plots (2.1 m long, 1.4 m wide, with rows 0.175 m apart) were sown on May 20, June 7 and 30, July 21, August 4, and September 1 and 26 (named as SD1 to SD7, respectively). Sowing density was ca. 335 seeds m$^{-2}$ in all treatments for the range of sowing dates used in the experiment. Due to insufficient availability of seeds, cultivars BRS 195 and Dayman were not included on the first sowing date. The experiment was conducted without biotic limitations, since diseases and weeds were controlled. Plots were irrigated during the whole crop cycle to supplement natural rainfall with the aim of avoiding crop water stress. Soil samples were taken immediately before each sowing to determine nitrogen (N) and phosphorus (P) content within the first 0.6 and 0.2 m soil layers, respectively. Urea was applied in order to reach a soil nitrogen availability of 150 kg N ha$^{-1}$, in two different stages distributed between sowing and tillering DC 2.1 (Zadoks et al., 1974). No phosphorus fertilizer was added since P availability at sowing was high (25 mg kg$^{-1}$, Bray and Kurtz, 1945).

Maximum and minimum air temperature data were recorded hourly with a meteorological station (Vantage Pro2, Davis Instruments, CA, USA) located in the experimental field.

### 2.2. Measurements

Crop was monitored twice a week to determine phenology in all treatments. The phenological stages measured were: seedling emergence (Em, DC 1.0), first visible node (FVN, DC 3.1), heading (Hd, DC 6.0) and physiological maturity (PM, DC 9.0) (Zadoks et al., 1974). Em was recorded when 50% of the plants within each