

Simulating phenology in perennial grasses using a morphogenetic model: L-GrassF

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Introduction

Predicting the reproductive phenology and in particular the heading date (HD, appearance of the spike) in perennial grasses is a major concern for farmers because it determines the quantity and quality of forage. This event exhibits a high genetic variability within species, reaching more than 30 days for European cultivars. To date, prediction methods of HD are empiric and do not address the consequences of reproductive phenology on grassland perenniality, *i.e.* the productivity of grassland over several years without resowing. Indeed, the reproduction of perennial grasses in grazed or harvested grasslands is mostly vegetative because spikes are removed before seed maturity. During the spring, some tillers become reproductive, produce a spike and finally die, while other tillers remain vegetative until the next season, depending on their ontogenic status. The tiller population is thus largely modified by phenology. The phenology of perennial grasses is controlled by the seasonal variations of temperature and photoperiod (Heide, 1994, Rouet, 2021). Predictions of climate change suggest significant changes in seasonal temperature pattern, which will create new combinations of temperature and photoperiod whose consequences on the floral induction of perennial grasses are unknown. Here, we present L-GrassF, a new FSPM simulating the genetic variability of the phenology of perennial ryegrass in order to better understand the perenniality of grasslands and better anticipate the effects of climate change.

Materials and method

L-GrassF extends the previous leaf growth model L-Grass (Verdenal et al., 2008) to the reproductive stages by integrating the interactions between vegetative growth and the processes of floral induction and reproductive organ development. The model is detailed in Rouet *et al.*, 2022 and is in open access on GitHub (<https://github.com/openalea-incubator/lgrass>). L-GrassF simulates the production of tillers in *Lolium perenne* as well as their growth according to self-organization rules between successive leaves. The model simulates floral induction, growth of reproductive organs and mortality for each individual tiller according to the environmental conditions to which they were exposed. The floral induction is modelled by two successive phases: the primary induction, controlled by temperature and the secondary induction, controlled by photoperiod. Leaf elongation, the rate of primordia production and their differentiation into leaves or spikelets are modulated by the state of floral induction. In the model, HD results from the interaction between floral induction and leaf morphogenesis.

The model was calibrated and validated on two independent datasets from the French Variety and Seed Study and Control Group (GEVES), which include the observations of HD for seven cultivars of *Lolium perenne* grown in six French locations between 2001 and 2017. The

calibration of the model was performed on the three most sensitive parameters identified by a sensitivity analysis. These parameters (Y_m^0 , kY_m^0 and $PPRM$), control leaf elongation during the vegetative phase, leaf elongation during the reproductive phase and the maximal daily rate of secondary induction. The calibration consisted in the identification of the set of parameters with the lowest RMSE between observed and simulated HD for each cultivar. Finally, the model was validated for HD predictions against the second independent dataset.

Results and discussion

For cultivars Bronsyn, Indiana, Lactal, Carillon and Escal, the model provided good overall estimates of HD (RMSE < 10 days) but the coefficients of determination were low. This could be explained by the narrow range of observed HD for these cultivars, especially for Carillon. For Milca, the elevated RMSE was partly explained by one environment for which the model clearly overestimated HD (Figure 1e). For Bargala, the RMSE was higher and the determination coefficient was very close to zero, meaning that the model was not able to give better prediction than the mean observed HD (Figure 1d). We did not find any clear explanation for the model's behavior in this situation which was not characterized by unusual environmental conditions. Considering all cultivars together (Figure 1h) highlighted an overall efficient prediction of HD (RMSE ~ 10 days) and a good representation of cultivar earliness ($R^2 = 0.48$). The functional-structural approach used in L-GrassF made it possible to account for the interactions between vegetative morphogenesis and floral induction of the apex as a function of the environment experienced by each individual tiller.

L-GrassF showed promising performances in predicting HD of *Lolium perenne* cultivars. The model is now intended to be used to study the determination of the proportion of reproductive tillers as well as the impact of future climatic conditions on perennial grass phenology.

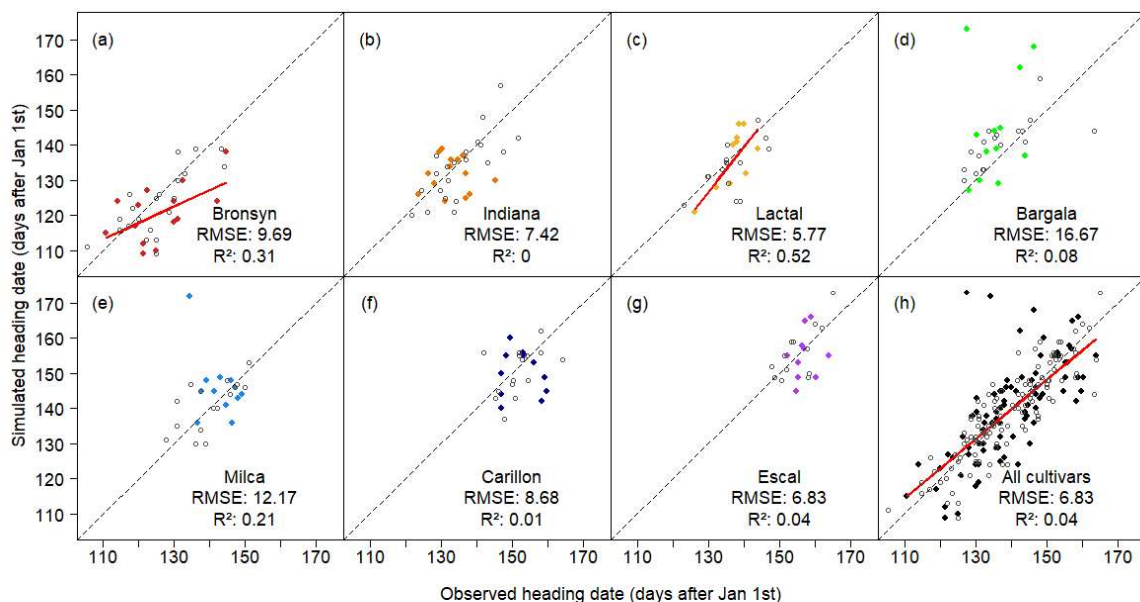


Figure 1: Comparison of observed and predicted values of heading date obtained with L-GrassF for seven cultivars. (a) Bronsyn, (b) Indiana, (c) Lactal, (d) Bargala, (e) Milca and (f) Carillon, (g) Escal. Grey and colored points represent the sub-datasets used for model calibration and validation, respectively. Reprinted from Rouet *et al.* (2022). *isP*, 4 (2), 1-17. Copyright © 2022, Oxford University Press

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