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

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L-GrassF : a new FSPM to simulate the phenology of perennial grasses

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Context

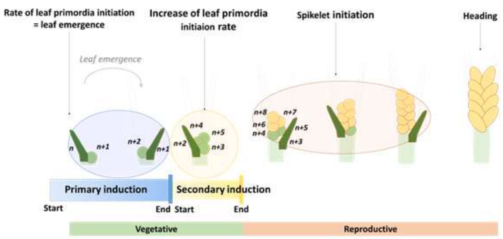
- Predicting the reproductive phenology of perennial grasses is a major concern because it determines plant perenniality and the quantity and quality of forage[1].
- The heading date (HD, date of spike appearance) is one of the major phenological stages used to manage grasslands and rank cultivars' earliness.
- HD is under high genetic and environmental control, making HD hard to predict.
- Projections of future climates suggest changes in seasonal temperature patterns whose consequences on perennial grass phenology are unknown.
- The FSPM approach can help to:
  - Integrate the genetic diversity of plant responses to their environment
  - Predict changes in composition and production of grasslands
  - Design new ideotypes adapted to future climate conditions

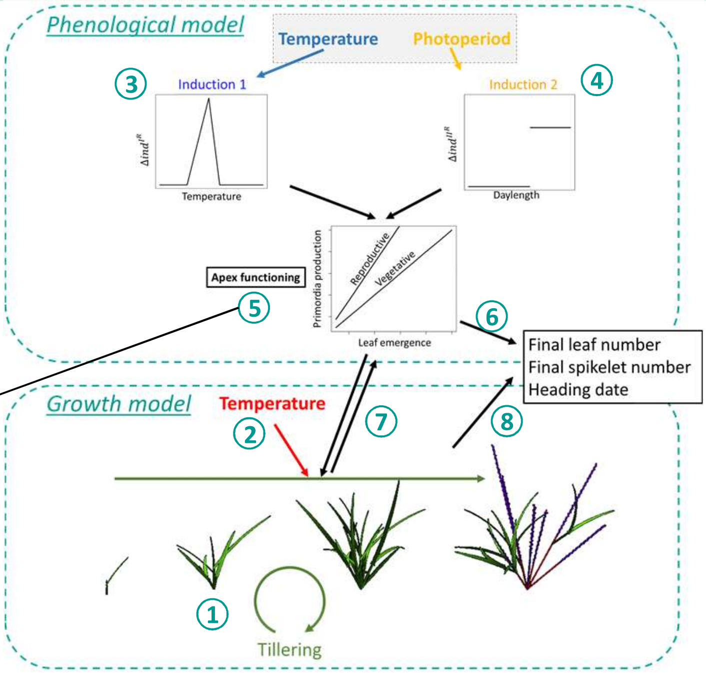
We present a new FSPM, L-GrassF[2], that simulates the phenological changes occurring for each tiller of a plant in response to its local environment

Model description

L-GrassF simulates the 3D vegetative development of ryegrass plants (leaf appearance and growth, tiller onset). The kinetics of leaf elongation is coordinated with its appearance to light and also determines the initiation of the next leaf (1). The model also accounts for the effect of temperature on leaf elongation rate (2).

Floral induction is modelled as two successive phases at tiller scale. The primary induction corresponds to an accumulation of low temperatures (3). The secondary induction increases with the accumulation of long days (4).
The state of floral induction of each apex affects the plastochron (5) and the final number leaves and spikelets (6).





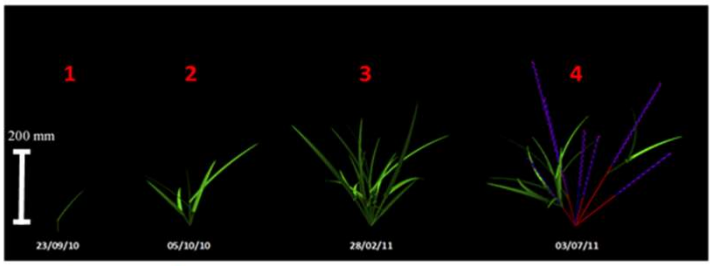
In addition, the beginning of the secondary induction triggers an increase of the rate of leaf elongation and hence tillering (7).

The heading date is defined from the ligulation of the last leaf (8).

Simulations

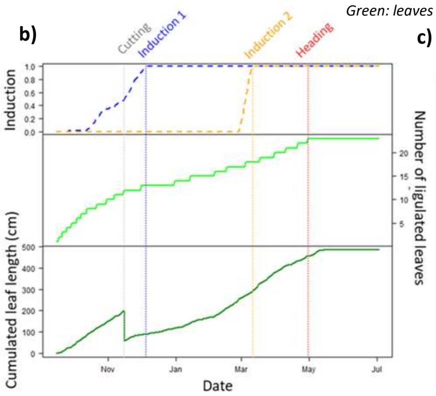
- The geometrical interpretation of the L-system provided 3D views of the plant architecture at different stages of development (a).
- L-GrassF also produced original insights in the dynamics of floral induction and leaf ligulation (b)
- A sensitivity analysis of the model revealed that HD was mainly determined by three parameters related to leaf elongation and the maximal rate of secondary induction. These three parameters were then calibrated for 6 ryegrass cultivars using a subset of a dataset describing HD in 6 French locations between 2011 and 2017 (GEVES).
- The variation of HD was about 30 days on average. The validation of the model against an independent dataset showed that the range of HD precocity was well simulated by the model (c).
- Considering all cultivars together highlighted an overall efficient prediction of HD (RMSE <10 days) and a good representation of cultivar earliness (R^2 = 0.48).

a)

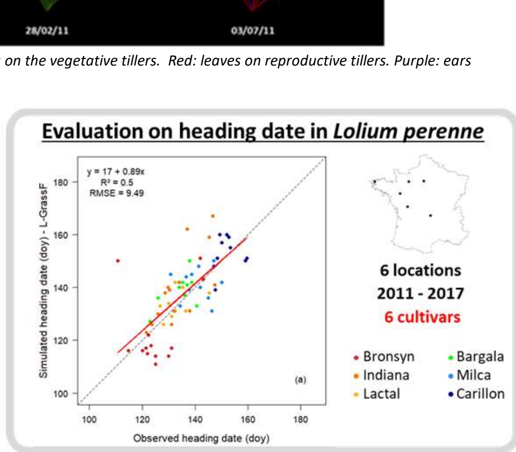


Green: leaves on the vegetative tillers. Red: leaves on reproductive tillers. Purple: ears

b)



c)



Conclusion and perspectives

- While the current models of grassland phenology are based on empiric relations to temperature, L-GrassF uses a mechanistic approach considering the complex interactions between primary induction, secondary induction and vegetative morphogenesis.
- The first quantitative assessment of the prediction of genetic x environment interactions, proved L-GrassF to perform well.
- Further developments will be made to test the ability of L-GrassF to simulate the proportion of reproductive tillers in spring and subsequent regrowth potential.

[1]Rouet, S., Barillot, R., Leclercq, D., Bernicot, M. H., Combes, D., Escobar-Gutiérrez, A., & Durand, J. L. 2021. Interactions Between Environment and Genetic Diversity in Perennial Grass Phenology: A Review of Processes at Plant Scale and Modeling. Front plant sci, 12, 672156-672156.
[2]Rouet, S., Durand, J. L., Leclercq, D., Bernicot, M. H., Combes, D., Escobar-Gutiérrez, A., & Barillot, R. 2022. L-GrassF: a functional–structural and phenological model of Lolium perenne integrating plant morphogenesis and reproductive development. *in Silico Plants*, 4(2), diac012.