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# Re-parametrisation of Adel-wheat allows reducing the experimental effort to simulate the 3D development of winter wheat

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**Highlights:** A parameterisation of wheat architecture was developed, having high flexibility to simulate contrasted genotypes and growth conditions with a reasonably low number of parameters. Field measurements at 4-5 dates allowed to simulate crops from emergence to maturity with a good agreement between simulated and measured ground cover and GAI. Dynamics of leaf angles were shown to impact strongly ground cover.

**Keywords:** 3D modelling, parameterisation, tillering, architecture, phyllochron, geometry

## INTRODUCTION

Functional-structural plant models (FSPM) simulate plant development and growth, by combining models of physiological and developmental processes within a representation of the three-dimensional (3D) structure of plants. Structural 3D plant models rather aim at mimicking the dynamics of plant and crop structure based on experimental data. Structural 3D plant models, interfaced with physical models, can be used as tool to investigate how plant structure modulates various processes such as emission, deposition and transfer of biotic (e.g. fungal spores) and abiotic entities (e.g. water, light, pesticides) in the canopy. In this paper, we focus on improvement and validation of Adel-wheat (Fournier *et al*., 2003), which is a structural model of winter wheat. Adel-wheat is based on a small set of coordination rules relating organ extension patterns with leaf emergence patterns, and a rather detailed and extensive set of parameters describing plant architecture at the individual organ level. It allows simulating the dynamics of wheat architecture over time, with flexibility allowing to represent morphological differences between genotypes and plasticity in response to growth conditions. Still the model requires intensive field data acquisition and had not been carefully assessed for the properties of the simulated canopies. In this work we: (i) set up a new parameterisation to improve the compromise between flexibility and complexity, (ii) assessed the quality of the model (iii) defined a protocol for acquisition of experimental data and (iv) implemented a routine to estimate model parameters and input variables from experimental data.

## METHODOLOGY

### *Developing and improving Adel-wheat parameterisation*

Adel-wheat uses a coordination scheme of organ extension, senescence and disappearance in which the beginning and the end of events for each botanical module (lamina, sheath, and internode) are determined by the Haun Stage dynamic (HS) and the shoot senescence index (SSI). The dynamics for HS and SSI for each axis need to be provided as input in the model; just like functions representing dimensions of the fully developed organs depending on their position on the axis. Based on a set of experiments representing various cultivars, cultural practices (sowing date, planting density, and fertilization) and climatic conditions, we defined more synthetic parameterisations of the HS, the SSI, the dynamic of tiller population, the axis final leaf number and the final organ dimensions. For tillers, the dynamics of organ extension and senescence and dimensions of mature organs are derived from those simulated on the main stem. All dynamics are expressed in thermal time, which can be calculated taking into account either a linear or a non-linear temperature response. The objective of the new parameterisation was to keep sufficient flexibility to be fitted in a large range of plasticity whilst keeping the number of parameters reasonably low (3-6 for each aspect). We also seek at proposing parameters that have simple interpretation and are easy to derive from field measurements.

The Haun Stage dynamic HS(τ) over the growth cycle was either linear with a constant phyllochron or bilinear with a break-point. The HS sub-model allows for these two possible behaviours (Fig.1). Depending on HS behaviour, either four or five parameters are required to calibrate the model, taking into account both main stem and tillers.

The Shoot Senescence Index (SSI) describes the number of senescent leaves on an axis. We defined a simple empirical description of leaf senescence in which the SSI dynamic is derived from the number of green leaves GL(τ) and the Haun Stage: SSI(τ)= HS(τ) - GL(τ). As a prerequisite, we need to know HS(τ) and 6 parameters have to be measured to calibrate GL(τ). Fig.1 illustrates this parameterisation.

Tillers are divided into cohorts according to their date of emergence, which is synchronized with MS leaf emergence. When a primary tiller exists, the conditional probability of emergence of a secondary tiller is taken equal to those of a primary tiller of the same cohort. The number of active tillers decreases linearly during the phase of fast internode elongation: the youngest tillers stop first. Consequently, the number of active axes follows a curve with 4 phases. The parameters to calibrate this sub-model are: the emergence probabilities of primary tillers, the number of elongated internodes and the number of ear-bearing tillers.

Dimensions of mature organs on tillers are derived from those on the main stem. For this, we defined correspondence functions based on to the date of phytomer emergence and/or the position of the phytomer along the axis (Fig.2). The variables required as input are the dimension of main stem organs (laminas, sheath, internode, peduncle, and ear).

Leaf curvature is not parameterised with a mathematical function: the model select leaf curvatures in a database of measured ones. The function used for this could however be re-parameterised. In the previous version, selection within the leaf curvature database, depended only of the phytomer position along the axis. In this work, we showed that leaf curvature varies significantly not only with leaf position but also with phytomer age. In the new version, both leaf position and leaf age are considered in the selection function (Fig.3).

***A reference experiment for model evaluation***

The winter wheat cultivar *T. aestivum* 'Maxwell' was sown with typical agronomic conditions (220 plants/m², sowing on October, 26th of 2010). Plants were grown under non limiting conditions of water and nutrients and kept free of disease and weeds. The layout includes four blocs treated as repetitions. Two types of data were collected: data at plant scale that were used as input in the model, and data at crop scale used to evaluate the model by comparing them with simulations. Data collection included 3 parts: First, sixty tagged plants were followed weekly to estimate: (i) kinetics of laminas leaf extension and senescence, (ii) organ final size (laminas, sheath, internode, peduncle and ear) (iii) evolution of active axes number. Second, destructive samplings were carried out at 6 dates in order to complement the dataset of dimension and to calculate variables at crop level (leaf and global area index: GAI and LAI). Geometric data (leaf shape and curvature) are also collected for each date. Third ground cover (GC) photographs were taken weekly with two angle of view: vertical (0°) and oblique (57.5°).

***The simplified experimental protocol***

We (i) defined an experimental protocol that minimizes the measurement effort and allow estimating the required parameters and (ii) developed an application that generates Adel-wheat detailed input based on the parameters values. Finally the procedure allows for simulating the 3D crop dynamics from emergence to grain maturity by only performing detailed measurements at four dates: HS=4~5, 1 node, 2 nodes and flowering, plus simple measurements of green leaf number at one or two dates during grain filling. Measured data consist in: HS, SSI and organ dimension of MS, probability of primary tiller appearance, final axis number and the moment of start elongation and flowering. Detailed evaluation of this application will be presented in the oral communication.

RESULTS

The parameterisations that had been defined with the large set of experimental conditions could be fitted to represent with a high degree of accuracy the plant behaviour observed in the reference experiment. The figures below illustrate results relative to parameterisation of: the dynamic of Shoot Senescence Index (Fig.1) and the length of laminas (Fig.2).

When comparing simulated GAI and gap fraction dynamics with field measurements, differences were within the range of experimental errors. Figure 3 illustrates the importance of leaf curvature dynamic. Pooling leaf curvature data independently of leaf age resulted in significant deviations between model and simulations that vanished when data of leaf curvature were separated according to leaf age.

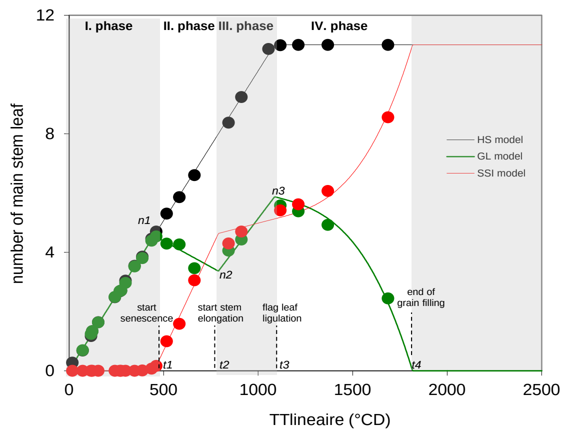


Fig.1. Dynamic of leaf number vs. thermal time for a main stem. Lines represent the parameterisation: total (HS, black), green (GL; green), senescent (SSI; red). Background (white/grey) shows the phases of senescence. I: No senescence. II: linear decrease of GL until stem elongation. III: linear increase in GL until flag leaf ligulation. IV: polynomial function for kinetics of GL after flowering. Dots show measurements in the reference experiment; each dot is a median calculated over 60 plants.

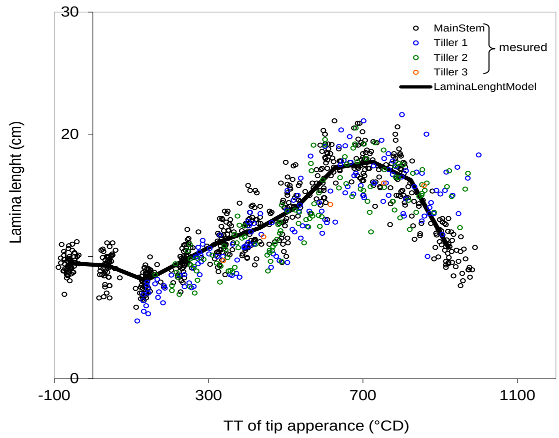


Fig.2. Length of fully developed laminas vs. thermal time of tip appearance; black line represents the function fitted to main stem data and symbols represent length of individual laminas of main stem (black), tiller 1 (blue) and tiller 2 (red) measured during the reference experiment. A same curve could be used for the main stem and tillers.

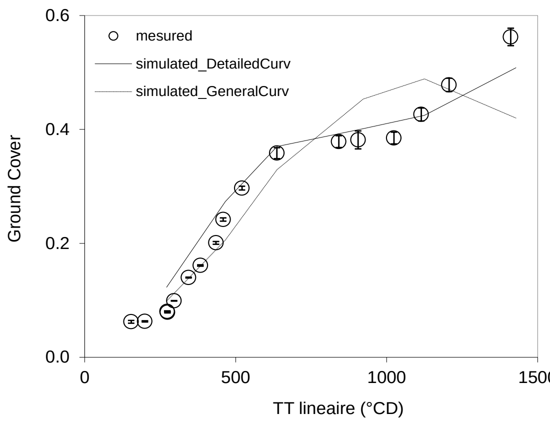


Fig.3. Ground cover vs. thermal time in the reference experiment; symbols represent measurements. Lines represent model simulation using (i) collections for leaf curvature depending on position and age of the leaf (solid line) or (ii) collections of leaf curvature depending on leaf position but pooled independently of time after ligulation (dashed line).

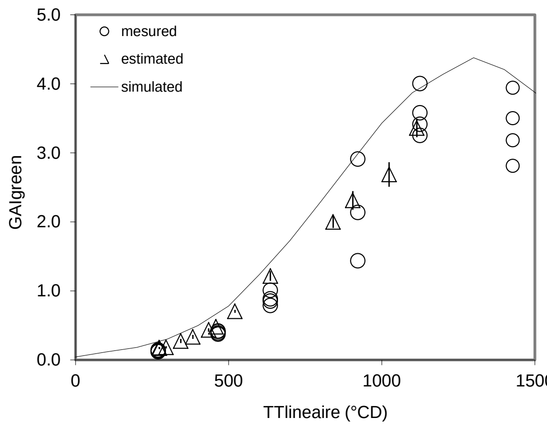


Fig.4. Global green area index vs. thermal time in the reference experiment; "o" represent direct measurements and "Δ"represent estimates from photographs at 57°. The line shows simulation with Adel-wheat virtual cover.

## CONCLUSION

The major outcomes of this work are: (i) 3D reconstruction is now possible for the full cycle, from sowing to maturity; (ii) the protocol for data acquisition has been simplified and a routine was developed so that 3D simulations can be done in applied projects (Fournier et al 2013); (iii) the parameterization, while having the flexibility to be fitted to a wide range of conditions, was shown to be able to adjust a specific condition with a high accuracy; (iv) the leaf curvature dynamics after ligulation was shown to be an important variable that deserves further attention.

## LITERATURE CITED

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