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Research and teaching project

Research project

In order to complete their life cycle and produce viable offsprings, plants need to maintain an efficient balance between the development of their different organs. On the one hand, the shoot is responsible for the fixation of carbon from the atmosphere and, ultimately, for the formation of flowers and seeds. On the other hand, roots are responsible for the uptake of water and nutrients from the soil solution. The coordination of growth is particularly sensitive during critical developmental stages such as the floral transition or the flowers formation. At these stages, the plants need to finely tune the balance between water and carbon flows to be able to cope with (challenging) environmental constrains.

Despite being central in the plant development, coordination mechanisms between the root and the shoot have been seldom studied by the scientific community, especially in mature plants. In *Arabidopsis thaliana*, root and shoot developments have been shown to be intertwined not only during the plant development [5, 24] but also under abiotic stress [13] or during the floral transition [4]. In maize (*Zea mais*), QTL co-localisations suggest common regulatory pathways under- and below-ground [8]. On the other hand, some specific processes, such as the interplay between phloem (carbon) and xylem (water) flows have been know for decades [21]. But again, such processes have not been quantitatively linked to plant productivity under environmental constraints.

Computational approaches have been proven to help addressing such complex biological questions (such as in Band et al. [1]). In previous years, a handful of functional structural plant models (FSPM, Godin et al. [12]) were developed to simulate either carbon [2, 10, 11] or water [14] flows in the plant, but not for both. Some models have successfully simulated phloem and xylem interactions, but for reduced plant network only [7, 15]. Only few of the these models have explicitly taken the environment into account.

> My long-term research objective will be to understand how the plant regulates **complex developmental processes** occurring at **mature stages** in response to **heterogeneous environment**. To achieve this goal, I will develop a **functional-structural whole plant model**, initially calibrated for maize (*Zea mays*). More specifically, I will start with a focus on **carbon and water** flows in the soil-plant-atmosphere continuum.

The biological validation of the studied processes (at first, carbon and water flows) will continuously remain at the center of the model improvement. In the framework of an existing collaboration, I plan to use selected lines from new maize segregation population between B73, the maize reference genotype, and Palomero Toluqueno, a Mexican highland landrace (in collaboration with R. Rellan-Alvarez, Cinvestav, Mexico). This population presents a unique phenotypic diversity that will be used to calibrate our model. In addition, I will take advantage of the unique combination of infrastructures between the IBG3 (e.g. AGRASIM, PET-scan), the UCL (e.g. root phenotyping platform) and external institution (for instance, with J. Dinenny at Stanford for the GLO-Roots system [23]). I will use these different platforms to precisely characterise carbon and water flows in the selected maize lines (fig. 1).

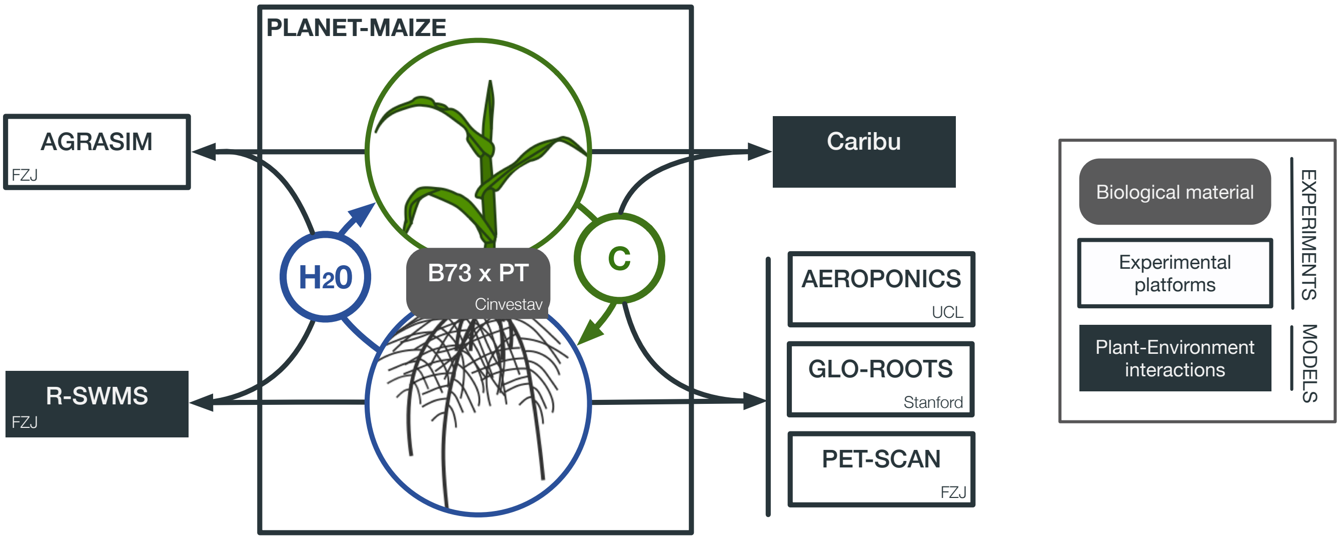

Figure 1: Overview of the research strategy for the development of PlaNet-Maize.

From a modelling point of view, I will work with an existing FSPM, PlaNet-Maize. PlaNet-Maize is a whole plant FSPM that has been used and calibrated to simulate water flows in mature maize plants [16]. I will implement an explicit carbon flow resolution in the model to understand allometric relations at critical developmental stages (on-going work). In addition, the model will be coupled to realistic soil (R-SWMS [14]) and light (Caribu [6]) models in order to assess the plant response to heterogeneous environmental conditions (fig. 1). On the medium/long term, the model will be coupled with (and take advantage of) the tools already in use at the IBG3 (RootBox, DuMuX). The integration of PlaNet-Maize with these tools will be facilitated by the fact that the same formalisms are used in the different models (1D tree in a 3D environment). On the long term, I will also explore the possibility to connect our models with lower scale (tissue) and higher scale (crop) models.

The collaboration between the Université catholique de Louvain and the Forschungszentrum Jülich opens unique research opportunities. My project aims at leveraging these opportunities and has been designed to fits perfectly within the existing research groups from both institutions. In that context, I believe my multidisciplinary expertise (at the intersection of plant physiology [3, 20], plant phenotyping [17, 18, 19, 23] and plant modelling [9, 16, 22]), as well as my international collaboration network are the key for such project to succeed[1].

[1] It is worth mentioning that I am currently involved in the writing of an ERC grant proposal (with A. Schnepf and X. Draye) that takes advantage of the same complementarities.

Teaching project

I am convinced that plant models can be of great use within the bioengineering studies. The construction of a model requires a deep understanding of the processes of interest. Modellers have to place such processes in more general, quantitative framework, which can lead to new questions and, sometimes, new paradigms. As such, plant models have to potential to be great learning tools.

Over the last decade, modelling has become an invaluable tool for plant biologists. However, only a minority of researchers have the skills to work with plant models as they require the integration of computational, mathematical, geophysical and biological knowledges. As such, a plant modelling course would perfectly fit into bioengineering studies, that naturally combines these different topics.

Plant modelling falls within the framework of two existing master classes: *Gestion intégrée du système sol-plante* and *Modélisation de systèmes biologiques*. In concertation with the courses' coordinators, I propose to integrate a plant modelling component in both programs.

The course *Gestion intégrée du système sol-plante* is divided in three parts. I plan to integrate a plant modelling module in the first one, *Interactions sol-plante*. I will discuss the utility of plant modelling in the framework of soil-plant research and how modelling could be used to answer complex bio-physical questions. The teaching module will be based on practical examples found in the scientific literature. These examples will be analysed and discussed with the students.

The course *Modélisation de systèmes biologiques* already contains a part dedicated to Functional-Structural Plant Models. In agreement with the course coordinator (Prof. Xavier Draye), I would like to take an active part in this module. Given the practical orientation of this course, I would like to propose *hands-on* sessions to the students. The course would be an opportunity for them to (i) explore and try some of the existing plant models (such as RootBox or PlaNet-Maize) and (ii) to think about the rationale between the different models. In particular, we will discuss in details the trade-off and choice that need to be made when designing a plant model. A last part of the module will be devoted to the creation of a simple plant model in R.

Working with plant models is a perfect opportunity to teach the student good practices in scientific programming and scientific collaboration. Practical exercises will be performed in groups and the tools routinely used by the scientific community will be used by the students. These tools range from collaborative report writing (Google Docs and OverLeaf) to project management (Slack) and collaborative coding (GitHub).

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