Feedbacks between plant microclimate and morphogenesis in fluctuating environment: analysis for rice using *Ecomeristem* model coupled with 3D plant and energy balance computation tools in OpenAlea platform

[a]Soulié Jean Christophe, [b]Pradal Christophe, [c]Fournier Christian and [a]Luquet Delphine

[a]CIRAD, UR AIVA, Montpellier, France, 34398
[b]CIRAD, UMR DAP, Montpellier, France, 34398
[c]INRA UMR LEPSE, Montpellier, France, 34060
luquet@cirad.fr

Keywords: rice morphogenesis, plasticity, source-sink regulation, microclimate,

Introduction

During the last decades, crop growth models largely demonstrated their relevance for supporting cropping system management. Today, these models are more and more asked to support breeding by accounting for the Genotype X Environment interactions (GxE) that regulate crop performance under increasingly fluctuating environments (*i.e.* climate change and variability, CCV). They thus need to be implemented with modules formalizing underlying biological processes. Ongoing studies on plant response to CCV (temperature, CO_2, drought) suggest that these processes are organ based and depend on organ phenology and micro-environment. A key example are processes regulating inflorescence morphogenesis and sink strength in response to temperature or drought; though crucial to predict CCV impact on crop performance, in particular for tropical cereals' as rice, such mechanisms can hardly be formalized into classical models representing crop growth as a source-driven, "big leaf" process. More recently, a category of models gave rise that aims to take advantage of FSPM advances in crop growth modeling. Among them is GreenLab (Yan *et al.* 2004), a mathematical model implemented rather for analyzing plant growth and architecture in response to climatic fluctuations to understand crop performance, than for predicting crop performance in various environmental conditions.

Ecomeristem: modeling concepts and programming environment

Meanwhile, *Ecomeristem* (Luquet *et al.* 2006) is a crop growth, eco-physiological model that was designed for rice (model plant for cereals) to account for plant morphogenesis and its plasticity depending on G potential and sensitivity to E (water, temperature, radiation). It was initially created to address the vegetative morphogenesis and its concepts are currently extended to the whole plant cycle. It formalizes in a simple way the functioning of apical meristem, i.e. the GxE regulation of organ initiation, pre-sizing and/or abortion. An average plant in its stand is daily simulated in terms of topology, organ size and dry weight. Plant geometry is not considered and resource acquisition is, until now, simulated by a 'big leaf' approach. Roots are considered as a bulk compartment with a daily resource demand for growth. E is sensed by the plant through two key state variables of plant water and carbohydrate (C) status, daily computed as the ratio between plant supply (from big leaf approach at crop level) and organ demands (sum of organ demand relative to their daily expansion). The plant responds to these state variables based on G parameters defining i) potential morphogenesis (*eg.* leaf appearance rate, size, tillering) and ii) sensitivity to E (*eg.* tillering response to C, leaf transpiration, expansion response to drought).

EcoMeristem model is hosted by the *EcoPhen* platform. It is entirely written using the Delphi language. Conceptually, it relies on the Discrete Event Specification (DEVS) formalism (Zeigler, 1976) and in particular the Dynamic Structure DEVS (DS-DEVS) formalism (Barros, 1995). Consequently, *EcoPhen* can be defined as DEVS simulator. This approach allows to dynamically building the simulated plant by adding or deleting new organs (leaves, tillers, etc.) depending on the internal status of the simulated plant.

The model was validated in various climatic conditions and for contrasted rice genotypes, in particular recently regarding the phenotypic plasticity or rice vegetative morphogenesis under drought (Luquet *et al.* 2008); it is currently used in this context to explore the impact of plant developmental rate in the regulation of water and carbon source-sink relationships and finally on crop performance under drought (Luquet *et al.* 2010c). This model is novel as it formalizes the GxE regulation of organ sink strength, their feedback with plant morphogenesis and resource acquisition and, finally, with crop performance. In this sense, it can be considered as a FSPM and as a key step to make crop models account for G variability and integrate genetic information. However, to deal with rice plant response to CCV and resulting impact on crop performance, the feedbacks between plant, organ microclimate and morphogenesis must be further accounted for.

Ecomeristem coupling with 3D and microclimate computation tools in OpenAlea

For this purpose, *Ecomeristem* has been integrated in the OpenAlea platform (Pradal *et al.* 2008) to reuse existing simulation pipelines implemented for other poaceae (*eg.* maize, wheat). At each step of the simulation (1 day), *Ecomeristem* is run and its outputs (i.e. plant topology and organ size) are converted into a MTG (Godin *et al.*, 1999). The geometry is then computed using the PlantGL library (Pradal and Bourdon 2009) using a node provided by Adel (Fournier and Andrieu 1998) and stored in the MTG. Finally, daily computation of plant microclimate and energy balance and, accordingly, of the state variables regulating plant morphogenesis in *Ecomeristem is* provided by Caribu (Chelle and Andrieu 1998).

Figure 1 shows the preliminary results. The top two quadrants of Figure 1 are a 3D representation by plantGL and leaf growth modules of a rice plant simulated by *Ecomeristem* without and with water stress. The lower quadrants are the resulting computation of radiation interception on the two previous mock-ups using a density of 20 plants per m².

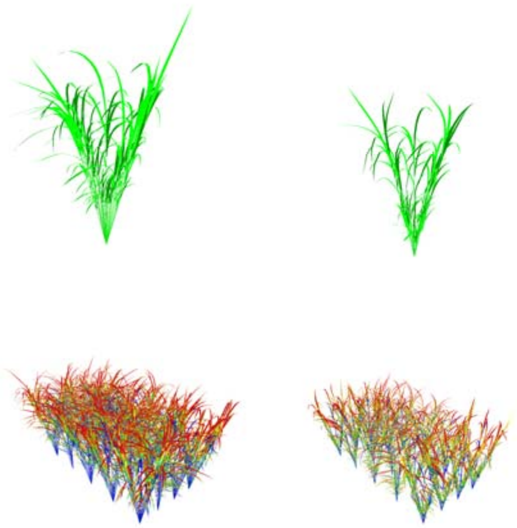

Figure 1. Top: 3D representation of *EcoMeristem* topological output after a 30 day long simulation, using the same plant parameterization, with (left) non limiting growth conditions and (right) after a dry-down period of 17 weeks. Bottom: resulting computation of radiation interception on the corresponding plant stand with a density of 20 plants per m²

Objectives, expected outputs and perspectives of the studies

The present work is the first step in this ongoing project aiming at implementing a FSPM environment to deal with the GxE regulation of rice plant morphogenesis and crop performance under increasingly fluctuating climate (considering temperature, drought and ultimately, CO_2). It aims to quantify, based on the model coupling described above, the impact of considering plant/crop 3D architecture instead a ‘big leaf’ approach on the simulation of light resource acquisition and finally of plant and crop vegetative morphogenesis in fluctuating environments. A simulation experiment was designed to consider genotypes with a contrasted morphogenesis and architecture (leaf angle, size, thickness, tillering and developmental rates), in contrasted E (photo-thermal x drought).

Based on the results obtained in the present work (analysis underway) dealing only with the radiation component of energy balance, the importance of considering the feedbacks between plant morphogenesis and microclimate to study plant response and adaptation to CCV is discussed and, by there, the role FSPM has to play in this context.

References

Barros, F. J. (1995) Dynamic structure discrete event system specification: A new modeling and simulation formalism for dynamic structure systems. In *Proceedings of the 1995 Winter Simulation Conference*, pp. 781-785. International Society for Computer Simulation

Chelle M, Andrieu B (1998) The nested radiosity model for the distribution of light within plant canopies. *Ecological Modelling* **111**, 75-91.

Fournier C, Andrieu B (1998) A 3D architectural and process-based model of maize development. *Annals of botany* **81**, 233-250.

Godin C., Costes E., Sinoquet H. (1999) A method for describing plant architecture which integrates topology and geometry. *Annals of Botany*, **84**, 343-357

Luquet D, Dingkuhn M, Clément-Vidal A (2008) Modeling drought effects on rice with EcoMeristem : feedbacks of water and carbohydrate relations on phenotypic plasticity. In 'Whole plant physiology modelling project. Final meeting '. Johnston, Iowa (USA). (Ed. Luquet D.)

Luquet D, Dingkuhn M, Kim HK, Tambour L, Clément-Vidal A (2006) EcoMeristem, a Model of Morphogenesis and Competition among Sinks in Rice. 1. Concept, Validation and Sensitivity analysis. *Functional Plant Biology* **33**, 309-323.

Rebolledo MC, Dingkuhn M., Soulié JC, Rouan L, Luquet D (2010) Developmental dynamics and early growth vigour in rice 3. Model based and experimental exploration under drought conditions. *in preparation*.

Pradal C, Boudon F (2009) PlantGL : a Python-based geometric library for 3D plant modelling at different scales. *Graphical Models* **71**, 1-21.

Pradal C, Dufour-Kowalski S, Boudon F, Fournier C, Godin C (2008) OpenAlea: a visual programming and component-based software platform for plant modelling. *Functional Plant Biology* **35**, 751-760.

Yan HP, Kang MZ, Reffye PD, Dingkuhn M (2004) A Dynamic, Architectural Plant Model Simulating Resource-dependent Growth. *Annals of Botany* **93**, 591-602.

Zeigler B. (1976) Theory of Modeling and Simulation. Wiley Interscience.