Modeling drought effects on rice with *EcoMeristem*: Feedbacks of water and carbohydrate relations on phenotypic plasticity

Luquet D., Dingkuhn M., Clément-Vidal A.
CIRAD, Centre de Cooperation Internationale pour la Recherche Agronomique et le Développement
TA A 59/01, Av. Agropolis Lavalette, 34398 Montpellier Cedex 5.

Introduction

Technologies created by molecular biologists for accelerating crop improvement are permanently progressing. The challenge today is to provide to geneticist traits of interest as well as related phenotyping methodologies, in order to find out underlying genes and alleles through association or QTL mapping approaches. Phenotyping methods are needed that enable addressing physiological, process based traits that are closer to gene action than conventional, descriptive methods that are subject to large GxE effects. This is particularly the case regarding plant response to abiotic stresses such as drought, involving adaptive biological processes that constitute phenotypic plasticity. Most of these processes are difficult and expensive to access experimentally. Modelling has an important role to play here: if a model formalizes correctly biological processes to simulate the phenotype, then it is possible to use the model as a phenotype analyzer (heuristic approach; Dingkuhn *et al.* 2005; Hammer *et al.* 2002). The model thereby serves to provide genotypic parameter values obtained by model optimization against observed data. If observations used to parameterize the model are easy to measure, this permits high throughput applications within genetic studies.

The objective of this study was to adapt *EcoMeristem*, a crop model simulating rice morphogenesis and phenotypic plasticity during vegetative stage, to the case of drought. This paper describes and tests the new model formalisms based on experimental data.

Material and methods

Experiment: Two experiments (Exp1, 2) were carried out on one rice genotype, IR64 (Oryza sativa L., indica group), to analyse rice morphogenesis, sugar metabolism and water status variations under drought. The setup was based on a replicated dry-down design using potted plants in a phytotron, with gravimetric monitoring of soil moisture and plant transpiration, to compute FTSW (Fraction of Transpirable Soil Water: FTSW=AWS/TTSW, with AWS, available soil water content and TTSW, total transpirable soil water content). Stressed plants were re-watered after a severe stress level was attained.

Observed dynamics in stressed and control plants of transpiration and leaf expansion rates, plant morphogenesis, sugar content, leaf rolling and senescence, were used to develop and test algorithms implemented in *EcoMeristem*.

Model presentation: *Ecomeristem* (Dingkuhn *et al.* 2006; Luquet *et al.* 2006; Luquet *et al.* 2007) simulates rice morphogenesis based on (i) algorithms and parameters controlling leaf initiation rate (*phyllochron*) and pre-dimensioning (*MGR*, Meristem Growth Rate and *SLAp*, slope of the relation computing structural specific leaf area vs. leaf rank), tillering (*Ict*), radiation use efficiency (RUE) and, as a proportional consequence, root growth; and (ii) daily carbon sink to source balance estimation based on a plant internal competition index, Ic, (C supply/demand ratio, demand being the sum of assumed organ daily growth and supply, daily assimilation). Depending on genotypic parameters, plant responds to Ic by adjusting organ size and number (phenotypic plasticity). The model is specifically dedicated to model assisted phenotyping, i.e. for optimizing parameters as a means to quantify genotypic, process based traits. For this purpose the model was recently implemented in modelling software, named EcotropV4 (developed in Delphi language), facilitating model development or modification and implementing optimization and sensitivity analysis tools.

Results

Main experimental results: Water stress reduced transpiration and leaf expansion rates when FTSW dropped below 0.69 and 0.56, respectively (Figure 1). Plant growth and development were slowed (Figure 2). Sugar metabolism was differently affected regarding sink (young leaves, root) and source (mature leaves) organs: starch and sucrose increased in sink organs with and hexoses decreased, while the opposite was observed in source organs (not shown). However, bulk, whole plant carbohydrate concentration was not affected (Figure 1, middle graph).

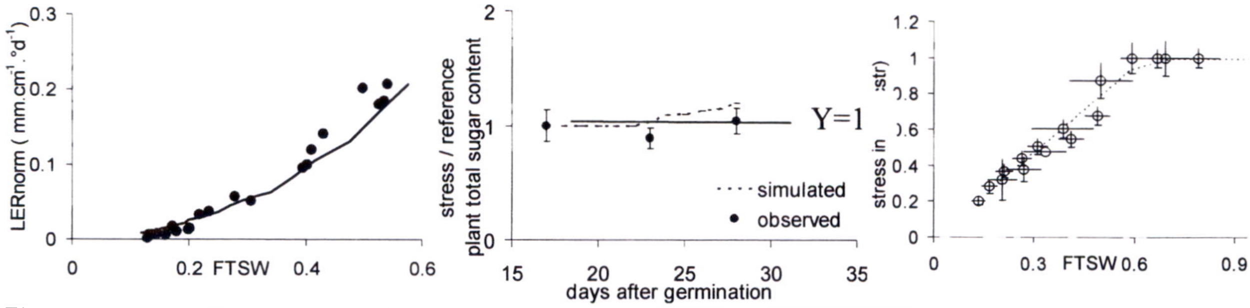

Figure 1 : comparison between observed and simulated (left) RLER (leaf expansion rate normalized by final potential length), (middle) plant total sugar content (stress by reference ratio) and (right) cstr (actual by potential transpiration rate) response to drought in Exp2.

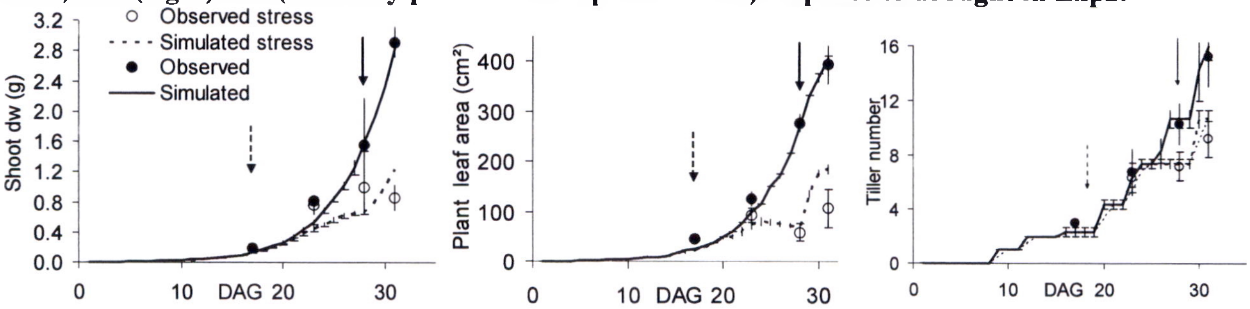

Figure 2 : comparison between observed and simulated shoot dry weight, plant leaf area and tilering dynamics in Exp2. Arrows indicate stress set up (dashed) and re-watering date (plain).

<u>Model adaptation and modeling results:</u> the new formalisms implemented in Ecomeristem consisted first of a water stress index, cstr, equal to the ratio between actual and potential transpiration, function of FTSW and a genotype dependent threshold parameter defined experimentally. Based on cstr as state variable, a set of equations formalizing water stress impact on transpiration, potential carbon assimilation, LER and leaf rolling were implemented.

The improved model simulated well growth response to drought, water use, organogenetic and morphological dynamics while using a common set of model parameters for both drought and control treatments in Exp1 and 2 (Figure 1, 2, results for Exp2). Source-sink relationships between mature and developing organs, tillering and leaf senescence were accurately simulated. The model also reproduced correctly whole plant carbohydrate balance stability from control to stressed treatment, indicating carbon non-limiting conditions of rice plants under drought (Figure 1). However, details metabolic dynamics in source and sink organs were not implemented in the model.

Conclusion

EcoMeristem model adaptations to drought have been successfully implemented. The model is now being applied to a large range of genotypes, to assist in QTL analyses and association mapping for rice.

References

Dingkuhn M, Luquet D, Kim HK, Tambour L, Clément-Vidal A (2006) Ecomeristem, a Model of Morphogenesis and Competition among Sinks in Rice: 2. Simulating Genotype Responses to Phosphorus Deficiency. *Functional Plant Biology* **33**, 325-337.

Dingkuhn M, Luquet D, Quilot B, Reffye PD (2005) Environmental and genetic control of morphogenesis in crops: Towards models simulating phenotypic plasticity. *Australian Journal of Agricultural Research* **56**, 1-14.

Hammer GL, Kropff MJ, Sinclair TR, Porter JR (2002) Future contributions of crop modelling - from heuristics and supporting decision making to understanding genetic regulation and aiding crop improvement. *European Journal of Agronomy* **18**, 15-31.