Modelling Rice Phenotypic Plasticity in Diverse Climates Using EcoMeristem: Model Evolution and Applications to Rice Improvement

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Climate change and variability (CCV) exposes tropical crops as rice to heat and drought. Increasing atmospheric CO_2 is expected to improve plant transpiration efficiency but benefits may be more than offset by reduced transpirational cooling and accelerated phenology. Yield is generally affected by environment effects on morphogenesis, particularly to stress during reproductive sink capacity determination. Exposure of reproductive processes to heat and drought, in turn, depends on plant structural development and resulting microclimate and water availability. These highly genotype-dependent interactions make it difficulty to predict CCV impacts and design adaptations.

An important step is to model this system, particularly interactions between plant morphogenetic and phenological processes with climate and resources, and resulting microclimate within the crop stand. Models are needed that consider crop structural development at organ level, while providing sufficient phenological and physiological detail to situate stress sensitive processes within time and canopy. Such a model must be coupled with a heat balance providing accurate information on soil, floodwater, leaf and panicle temperature. Key physiological processes would thus become predictable, including:

- tillering and tiller maintenance/abortion,
- leaf area dynamics including senescence,
- spike number dimensioning and adjustments,
- stem carbohydrate accumulation and mobilization to grains,
- thermal and drought induced spike sterility determined at the sensitive microspore and anthesis stages or by panicle exertion limitation,
- and finally grain filling process.

A new type of functional–structural plant models is needed that integrates environment dynamics within soil-water-plant-atmosphere continuum.

EcoMeristem model was designed to simulate environment and genotype driven phenotypic plasticity for rice and other cereals. It simulates rice plant morphogenesis at organ, plant and canopy levels in response to drought and climatic (excluding CO2) factors. The key concept is the feedback of trophic status (source-sink and competition among sinks) on organ initiation and (pre-)dimensioning processes, through signals to the meristem. A state variable quantifying internal competition for assimilates constitutes this signal (Ic: supply-demand ratio), which also governs resource and stress feedbacks on senescence processes. Water deficit is described by Fraction of Transpirable Soil Water (FTSW) and derived physiological coefficients. The sensitivity of development vs. trophic feedbacks is set by genotypic parameters (threshold and slope parameters, e.g. for tillering response to Ic or leaf expansion, assimilation and transpiration rates to FTSW).

EcoMeristem was developed to

- explore phenotypic plasticity concepts as affected by abiotic factors (drought, T…),
- explore ideotype concepts for specific environments, and
- measure heuristically hidden (process based) traits/parameters within phenotyping context.

A new objective is to study rice varietal response to CCV (CIRAD, NIAES, IRRI, WUR collaboration). EcoMeristem was therefore recently linked with 3D visualization tool (OpenAlea), opening the way to spatial micrometeorological computations within the canopy. Further model developments are needed:

- Completing the model for all developmental stages,
- Extending the water balance to flooded and mixed flooded/aerobic systems,
- Introducing CO2 effects on plant gas exchange,
- Introducing a stratified heat balance for the soil-water-plant-atmosphere continuum.

This paper presents the current state of model development and applications, and future improvements for research on rice crop adaptation to CCV.