HydroShoot: a new FSPM model for simulating hydraulic structure and gas-exchange dynamics of complex plants canopies under water deficit

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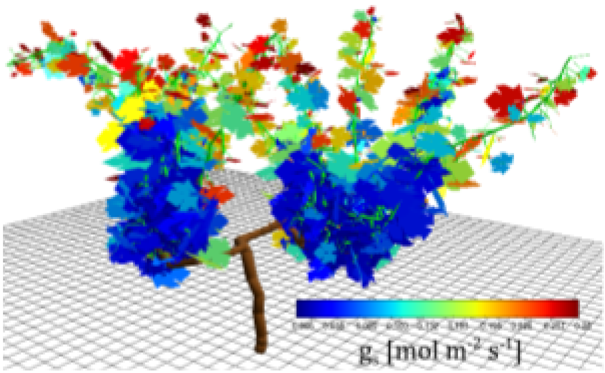
Individual leaves positioning within a plant canopy is a major determinant of the spatial distribution pattern of gas-exchange rates and energy budget within that canopy. Under water deficit, this distribution may be altered since soil drying affects stem hydraulic conductivity (K_s) and, consequently, leaves stomatal conductance (g_s), suggesting that the hydraulic structure (HS) of the shoot may shape the intra-canopy variability of gas-exchange rates under water deficit. Nonetheless, few FSPM models has evaluated the impact of HS on gas-exchange fluxes while others assume that g_s varies directly in relation to soil water status.

In this paper, we present HydroShoot, a functional-structural plant model which allows simulating the hydraulic structure, energy budget and gas-exchange fluxes of complex plant canopies under water deficit. Model parameters are calibrated and validated using sapflow and entire plant gas exchange data collected in 2009 and 2012 from grapevine (*Vitis vinifera* L. cv. Syrah) experiments under three training systems (Lyre, GDC and VSP) having contrasted canopy structures. The model is then used to evaluate the role of the hydraulic structure in predicting the intra-canopy variability of temperature and intrinsic water use efficiency of trained grapevines.

HydroShoot is composed of 4 modules used i) to construct plant architecture, ii) to estimate radiation interception by shoot elements, iii) to estimate temperature (T), foliar net CO_2 assimilation rate (A_n) and g_s and iv) to calculate the HS of the shoot.



Leaf-scale stomatal conductance (g_s) of a grapevine under a Lyre training system

Shoot architecture is constructed and its topological connections are informed according to the Multiscale Tree Graph (MTG) approach. Shoot architecture may be either generated stochastically from experimentally-established probability laws, or supplied from digitalization data. The constructed shoot mock-up is then used to estimate radiative balance for individual leaves based on the nested radiosity method implemented in the Caribu light model. Intercepted radiation per leaf surface area is used to calculate the potential values of A_n, g_s and T at the leaf-scale. The reduction of g_s due to soil-water deficit is then estimated, either by considering g_s as a function of soil water potential (Ψ_{soil}) or as a function of petiolar water potential (Ψ_{petiol}), calculated from the HS. HS, T and A_n-g_s are then solved iteratively, whereby the status variable is xylem water potential (Ψ_{xylem}) at each element of the HS.

The resulting HydroShoot model allows to capture the effect of the different training systems on the spatial distribution of A_n-g_s and T within the canopy. We show that the intra-canopy variability of the A_n-g_s couple were mainly explained, however, by the variability of local climate conditions, while the role of the hydraulic structure appeared only as secondary.

Finally, the proposed HydroShoot model was implemented for grapevine in the OpenAlea platform. However, it may readily be used for other plants as it operates on the generic MTG central data-structure provided by OpenAlea. This MTG-structure may further be useful for coupling root to shoot hydraulic structures in future studies.