Exploring carbon allocation with a multi-scale model: the case of apple

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Understanding the allocation of carbohydrates among organs is necessary to predict plant growth in relation to climatic conditions and agronomic practices. Despite the large number of studies on the subject of carbon allocation, no clear consensus exists on (i) the most appropriate topological scale (organ, metamer, compartment...) to represent this process on complex plant structures, and (ii) the importance of distances between organs in carbon transport.

In this study, we implemented a generic source-sink based carbon allocation model, following the equation of the SIMWAL model, that takes into account the distances between sources and sinks, the sink strength and the availability of carbohydrates from photosynthesis. Our model makes use of multi-scale tree graph (MTG) to represent geometry and topology of a tree structure at different scales. Starting from the description of a plant at a given scale (e.g. metamer and growing unit scales), we defined additional grouping criteria (fruiting branches and main axis) that were used to represent the plant structure, and the process of carbon allocation at different spatial resolutions. Generic functions to determine the biomass and carbon demand of the individual organs described in an MTG were implemented and calibrated for apple trees (Fuji variety) by means of age and organ type dependent allometric equations and maximum potential Relative Growth Rate curves (RGR) obtained in a field experiment. Photosynthesis for individual leaves of the input MTG was estimated by means of a radiative model (RATP). The model was then applied to architectural mock-ups in the MTG format produced by the MappleT model, representing trees with high and low fruit loads.

Simulations on simplified plant structures qualitatively showed the influence of the scale of representation and of the distance parameter on the predicted carbon allocation. In order to test assumptions regarding the effect of distance, the source-sink behavior and the suitability of the alternative scales of representation for predicting carbon allocation, the variability and spatial distribution of the simulated RGR were compared to field observations. Finally, a benchmarking was performed to compare the computational efficiency of the model when running at different scales.

The presented multiscale model provides a framework to re-interpret the plant topology in order to test the influence of some assumptions at the basis of the carbon allocation process, such as branch autonomy or the effect of distance. It is also a mean to investigate the trade-offs between the detail at which a plant is described, and the accuracy and computational efficiency in predicting carbon allocation. The present work was developed on the OpenAlea platform, and will provide existing Functional Structural Plant Models with a new generic model to simulate carbon allocation in plants.