# GRAAL-CN: a model of GRowth, Architecture and ALlocation for Carbon and Nitrogen dynamics within whole plants formalized at the organ level

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The functional-structural plant model GRAAL-CN has been developed to analyze the dynamics between morphogenetic processes and assimilate (carbon and nitrogen) management processes, the dynamics between carbon and nitrogen metabolism (acquisition and allocation) as well as the regulation of those processes during the vegetative development of individual plants. GRAAL-CN follows up and generalizes the work of Drouet and Pagès (2003), which considered carbon assimilates alone. It associates models of plant morphogenesis and models simulating the growth of plant compartments as related to assimilate availability. Using object-oriented modeling methods, knowledge is formalized at the organ level (local rules of development and resource management), and the behavior of the plant arises from interactions between those organs and the integration of the processes into the whole plant. Shoot and root organs are initiated as a function of temperature. Using the source-sink concept, organ growth is calculated from its individual potential growth and assimilate availability within the plant. Both assimilates, carbon and nitrogen, interact symmetrically and regulate both resource acquisition and developmental processes. Simulations using maize illustrate the capacity of the model to mimic the main features of plants in relation to development and resource allocation (e.g., dynamics of root:shoot ratio for carbon and nitrogen, changes in priority between organs as well as plant plasticity to assimilate availability). GRAAL-CN has been designed to be coupled with three-dimensional (3D) models of the shoot (Drouet, 2003) and root (Pagès et al., 1989) systems. Then, this coupled model can be associated with a model of light transfer and a model of nitrogen transfer within the soil to investigate the exchanges between plant and environment at the organ level. Conceptually, the model constitutes a generic framework with concepts and structure transposable to various species. It is a highly suitable tool for testing and sorting out hypotheses on growth and allocation processes involved in plant development. In the fields of systems biology and ecology, it can contribute to current work aimed at analyzing the interactions between genotypic and environmental characteristics affecting plant behavior.

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