Evaluation and Calibration of the Carbohydrate Assimilation, Partitioning, and Transport Processes in the L-PEACH Model

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Introduction

The goal of the L-PEACH functional-structural plant model (Allen *et al*., 2005) is to simulate the development of a plant's architecture, track its functional elements during growth, exchange carbon and other resources between all the plant's elements and make the individual components sensitive to local availability of carbon and external environmental signals. L-systems (Lindenmayer, 1968) with subsequent extensions (Karwowski & Prusinkiewicz, 2003; Mech & Prusinkiewicz, 1996; Prusinkiewicz & Lindemayer, 1990) were used to integrate these elements. The carbon source-sink interactions and carbohydrate transport within the plant were modeled using an analogy of electric circuits (Minchin *et al*., 1993). The underlying method was proposed by Federl and Prusinkiewicz (2004) for linear circuits, and was extended in L-PEACH for non-linear circuits. While the original model provided a prototype for how to integrate plant architectural growth and carbon economy, much calibration and quantitative evaluation work on the functionality of the proposed electrical circuit network analogy for distributing carbohydrate within the modeled tree structure remained. The goal of this presentation is to document this calibration and quantitative evaluation and present recent upgrades to the L-PEACH model.

General improvements to the L-PEACH model

The original model (Allen *et al*., 2005) was not calibrated to specific units of carbon and did not address plant respiration. The model is now calibrated to a basic "currency" of grams of carbohydrate. Organ maintenance respiration has been included as a component in the electrical circuit of each module and is estimated during each daily time step. Growth respiration is accounted for in the carbohydrate cost of adding dry matter to each organ. Real time weather data can be included to account for changes in temperature and light.

The original model contained more than thirty–two functions describing theoretical responses of each module type to various parameters. Many of these functions were similar; so, the model was simplified by replacing the similarly shaped functions with a single function that is scaled for the particular relationships of other various components. Architectural components were also improved; but, these will be reported in a separate paper. An important new practical feature is that the model outputs can be saved at the end of several years of the simulation and then the model can be repeatedly restarted from the same point. This allows *in silico* management experiments (*eg.*,.tree pruning and fruit thinning).

Calibration and evaluation of the electrical circuit analogy for distributing carbohydrate

Due to the extreme complexity of the interactions of the components of the model, the most difficult aspect of calibration and quantitative evaluation has been the development of meaningful tools for systematically displaying quantitative outputs and tracking the behavior of individual modules in connection with other components of the model. Subroutines to automatically transfer model generated data files to MatLab and MatLab programs were developed to graphically display data. With each simulation, hundreds of data files can be generated in MatLab and the quantitative behavior of each electrical component of every module can be displayed and analyzed, if desired. This has allowed systematic analysis and debugging of many aspects of the model and increased confidence that the source-sink/carbon partitioning components of the model are actually functioning in the manner that was originally anticipated. Using these techniques, the sensitivity of the model to resistance functions in several parts of the electronic circuitry has been tested and functional ranges for many resistances have been identified. The model is highly sensitive to some specific resistances in the electrical circuit and the complexity of interactions in the model can lead to unanticipated consequences, similar to real biological experiments. It is intriguing to anticipate specific carbohydrate transport resistance values within various parts of the plants may eventually be developed as emergent properties from this type of modeling effort when they have been virtually impossible to measure *in vivo.*

For demonstration purposes two figures are presented to illustrate the types of outputs that can be generated during simulation runs of L-PEACH. Figure 1 provides output data on the behavior of various organ types and some general data over two years of simulation. Stem weight declined between years because of stem loss during pruning. Stem and root storage declined early in the second year due to mobilization of stored carbon. The net source-sink balance is an error term indicating that virtually all the CHO that was fixed was distributed somewhere in the plant. Figure 2 provides the detailed behavior of the CHO balance in a single leaf over one year. The photosynthetic rate was quite sensitive to cloudy days but oscillations in the leaf CHO export rate were dampened over the same period. The leaf maintenance respiration rate was strongly influenced by fluctuations in temperature.

Conclusion

The basic approach for simultaneously modeling plant architectural growth and carbohydrate source-sink relationships and transport in plants appears to be functioning well in L-PEACH. More work remains in quantitatively calibrating and validating the model but it already has been used for integrating, simulating and understanding interactions between CHO source-sink relationships, architectural growth in trees and crop yield characteristics.

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