

Functional Plant Biology

Contents

Volume 35 Issue 9/10 2008

Special Issue: Functional–Structural Plant Modelling

Foreword: Studying plants with functional–structural models

Jim Hanan and Przemyslaw Prusinkiewicz

The rule-based language XL and the modelling environment GroIMP illustrated with simulated tree competition
Reinhard Hemmerling, Ole Kniemeyer, Dirk Lanwert, Winfried Kurth and Gerhard Buck-Sorlin 739–750

The programming language XL extends Java by implementing relational growth grammars (a variant of parallel graph grammars and a generalisation of L-systems). Using the example of a beech model, some features of XL are discussed that are particularly useful for combining models of structure and function and for querying plant architectural data.

OpenAlea: a visual programming and component-based software platform for plant modelling
Christophe Pradal, Samuel Dufour-Kowalski, Frédéric Boudon, Christian Fournier and Christophe Godin 751–760

The OpenAlea architecture designed by Pradal *et al.* allows the integration of simulation models and other computational methods for plant modelling and analysis in an interactive, platform-independent environment. An example of the simulation of light interception shows the suitability of this platform to assemble heterogeneous components and to rapidly prototype new plant models.

Integrating simulation of architectural development and source–sink behaviour of peach trees by incorporating Markov chains and physiological organ function submodels into L-PEACH
Gerardo Lopez, Romeo R. Fayreau, Colin Smith, Evelyne Costes, Przemyslaw Prusinkiewicz and Theodore M. DeJong 761–771

L-PEACH is an L-system-based functional–structural model for simulating architectural growth and carbohydrate partitioning in peach trees. Improvements in the architectural model and the carbohydrate-partitioning algorithms significantly improved simulations of seasonal carbon dynamics and organ growth, and responses to management practices such as pruning and fruit thinning.

Modelling phloem and xylem transport within a complex architecture
André Lacointe and Peter E. H. Minchin 772–780

The biophysics of phloem and xylem transport is well established, but only simple architectures have been mechanistically modelled, as available numerical methods become intractable. These authors offer a new approach, which is first validated on a simple architecture by comparison with a previous method, and a more complex system that previous methods have not been able to handle has been examined.

A process-based model to simulate nitrogen distribution in wheat (*Triticum aestivum*) during grain-filling
Jessica Bertheloot, Bruno Andrieu, Christian Fournier and Pierre Martre 781–796

Considering the turnover of photosynthetic nitrogen, a single pool for mobile nitrogen and a potential N demand of grains allowed to simulate accurately the kinetics of N mass in laminae and grains in wheat culm after anthesis. N gradient between laminae occurred as an emerging property of these processes.

Cover illustration: Functional–structural plant-modelling software platforms make it possible to address a wide range of research questions at different spatial and temporal scales, and to build on shared data and model components. The cover shows a data-flow diagram used to organise such a model, and visualisations at the scale of tissue, whole plant and plant ecosystem (see Pradal *et al.* pp. 751–760).

<p>Photosynthesis–stomatal conductance model LEAFC3-N: specification for barley, generalised nitrogen relations, and aspects of model application</p> <p>Johannes Müller, Henning Braune and Wulf Diepenbrock</p>	797–810	<p>Generalised parameter ν. nitrogen relations are introduced for barley, wheat and rapeseed to account for the variation of photosynthesis with respect to leaf age, rank and nitrogen nutrition by the LEAFC3-N model. The accuracy of key model parameters and the time step required for reliable predictions of the integrated diurnal carbon gain by the model is assessed.</p>
<p>Dissecting external effects on logistic-based growth: equations, analytical solutions and applications</p> <p>Alla N. Seleznyova</p>	811–822	<p>Growth patterns of leaves and internodes are determined by genetic factors and affected by environmental conditions and competition for resources. Seleznyova proposes a new approach for representing these effects in the context of functional–structural plant models. The approach could be also useful in ecology and in comparative genetic studies.</p>
<p>Evaluation of a turbid medium model to simulate light interception by walnut trees (hybrid NG38 \times RA and <i>Juglans regia</i>) and sorghum canopies (<i>Sorghum bicolor</i>) at three spatial scales</p> <p>Didier Combes, Michaël Chelle, Hervé Sinoquet and Claude Varlet-Grancher</p>	823–836	<p>In the frame of lighting virtual plants, the hypothesis on leaf random dispersion was tested to estimate the light attenuation at canopy scale, horizontal layers and local scale, by comparing the Beer-Lambert and projection-based 3D models. Comparisons were made for walnut trees and sorghum canopies showing satisfying results at higher scales.</p>
<p>Quasi-Monte Carlo simulation of the light environment of plants</p> <p>Mikolaj Cieslak, Christiane Lemieux, Jim Hanan and Przemyslaw Prusinkiewicz</p>	837–849	<p>Since light environment plays a major role in plant growth and development, the ability to simulate it is an important component for functional-structural plant modelling. Here, the authors outline a path-tracing algorithm for approximating the absorbed radiant energy of leaves, assess its performance, and evaluate its application to the kiwifruit vine.</p>
<p>Estimation of light interception in research environments: a joint approach using directional light sensors and 3D virtual plants applied to sunflower (<i>Helianthus annuus</i>) and <i>Arabidopsis thaliana</i> in natural and artificial conditions</p> <p>Karine Chenu, Hervé Rey, Jean Dauzat, Guillioni Lydie and Jérémie Lecoeur</p>	850–866	<p>Light distribution in artificial environments such as growth chambers and glasshouses is highly heterogeneous. These authors propose a method based on 3D virtual plant modelling and directional light characterisation to estimate light intercepted by plants in such structures. The method also improved estimation in the field for young and low density crops, and offers new opportunities for genotype comparison.</p>
<p>Estimating photosynthetically active radiation distribution in maize canopies by a three-dimensional incident radiation model</p> <p>Xiping Wang, Yan Guo, Xiyong Wang, Yuntao Ma and Baoguo Li</p>	867–875	<p>A three-dimensional radiation model was introduced to simulate the direct, diffuse and total incident photosynthetically active radiation (PAR) distribution in crop canopy. The modelling was assessed with a multi-point PAR measurement in real maize canopies with different densities for the simulation of direct PAR, sunfleck area, diffuse PAR and total PAR.</p>
<p>Modelling leaf phototropism in a cucumber canopy</p> <p>Katrin Kahlen, Dirk Wiechers and Hartmut Stützel</p>	876–884	<p>In greenhouse cucumber, a leaf that becomes shaded by a neighbouring leaf moves towards light by bending its petiole. The authors present a model explaining the canopy responses induced by gradients in the local light environment of the individual leaf and show that simulations can reproduce the reorientation of canopy elements realistically.</p>
<p>Relative contributions of light interception and radiation use efficiency to the reduction of maize productivity under cold temperatures</p> <p>Gaëtan Louarn, Karine Chenu, Christian Fournier, Bruno Andrieu and Catherine Giauffret</p>	885–899	<p>This paper disentangles effects of cold temperatures in maize on leaf expansion and radiation use efficiency. A 3D model was combined with a light transfer model to infer light interception (PAR_c) and radiation use efficiency (RUE). RUE was the main cause of biomass reduction during early cold events whereas PAR_c explained most of the variability observed at flowering.</p>

<p>Comparison of architecture among different cultivars of hybrid rice using a spatial light model based on 3-D digitising Bangyou Zheng, Lijuan Shi, Yuntao Ma, Qiyun Deng, Baoguo Li and Yan Guo</p>	900–910	<p>The architecture of three hybrid rice cultivars was compared by using data collected by a digitiser <i>in situ</i> in a paddy field. Their light capture and potential carbon gain were simulated using a 3D light model. The simulation results indicated steeper leaf angles resulted in relatively uniform light distribution in rice canopy.</p>
<p>A study of ryegrass architecture as a self-regulated system, using functional–structural plant modelling Alban Verdenal, Didier Combes and Abraham J. Escobar-Gutiérrez</p>	911–924	<p>The authors have designed an exploratory functional–structural model of ryegrass morphogenesis in order to test the robustness of the hypothesis suggesting that architectural plasticity is mediated by a self-regulation process. Simulation results show that this hypothesis: (i) is of practical use for modelling, and (ii) is not incompatible with experimental data.</p>
<p>Analysis of maize canopy development under water stress and incorporation into the ADEL-Maize model Youhong Song, Colin Birch and Jim Hanan</p>	925–935	<p>This study develops an approach for functional–structural modelling of the effects of water stress on a maize canopy, based on a simplified, linear representation of organ extension, combined with the linear response of rate of organ extension to fraction of extractable soil water. This captures the experimentally observed responses of maize to mild water stress, which show reduced rates of extension of leaves and internodes, while duration of organ extension in most phytomers is not significantly affected.</p>
<p>MAppleT: simulation of apple tree development using mixed stochastic and biomechanical models Evelyne Costes, Colin Smith, Michael Renton, Yann Guédon, Przemysław Prusinkiewicz and Christophe Godin</p>	936–950	<p>MAppleT simulates a fruit tree that develops over years with a global shape reacting to gravity. With a mixed modelling approach and a first validation of the model outputs, that includes tree topological and geometrical changes over time, MAppleT contributes to the foundation of innovative tools for fruit tree simulation and will allow further <i>in silico</i> investigations.</p>
<p>Parametric identification of a functional–structural tree growth model and application to beech trees (<i>Fagus sylvatica</i>) Véronique Letort, Paul-Henry Cournède, Amélie Mathieu, Philippe de Reffye and Thierry Constant</p>	951–963	<p>An original method of parametric identification for a functional–structural model (GreenLab) was developed and tested on two understorey beech trees (<i>Fagus sylvatica</i> L.). Both topological and functional parameters were estimated based on data of trunk growth units and of compartment mass of branches.</p>
<p>Toward extension of a single tree functional–structural model of Scots pine to stand level: effect of the canopy of randomly distributed, identical trees on development of tree structure Risto Sievänen, Jari Perttunen, Eero Nikinmaa and Pekka Kaitaniemi</p>	964–975	<p>A ‘shoot-based’ individual tree model of Scots pine was applied to a group of identical trees. The predictions of the model were comparable with observations of real Scots pine trees and tree stands. If the amount of sapwood required to support a unit amount of needles was high, allocation of photosynthates to needles as well as growth of the tree declined in the simulations.</p>
<p>Forest patch modeling: using high performance computing to simulate aboveground interactions among individual trees George E. Host, Harlan W. Stech, Kathryn E. Lenz, Kyle Roskoski and Richard Mather</p>	976–987	<p>Parallel processing was used to simulate growth of a patch of individual trees. Simulations ran on an hourly timestep and tracked the light environment and photosynthetic production of individual leaves. Tree metrics for a 64-tree, 8-year simulation were comparable to experimental measurements. Allowing individual functional–structural plant models to interact is a step towards generating functional–structural models of ecosystems.</p>

Spray deposition on plant surfaces: a modelling approach
**Gary Dorr, Jim Hanan, Steve Adkins, Andrew Hewitt,
Chris O'Donnell and Barry Noller** 988–996

In this article, the complexities of interactions between pesticide droplets and plant canopies are investigated using computational models of particle trajectories and plant architectural development. This approach allows evaluation of pesticide application techniques intended to maximise the effectiveness of pesticides while reducing the amount of off-target deposition and damage.

Coupling a 3D virtual wheat plant model with a *Septoria tritici* epidemic model (Septo3D): a new approach to investigate plant–pathogen interactions linked to canopy architecture
**Corinne Robert, Christian Fournier, Bruno Andrieu
and Bertrand Ney** 997–1013

This work presents an application of functional–structural plant models to study plant–pathogen interactions linked to canopy architecture. These authors combine a virtual plant model of wheat with an epidemic model of *Septoria tritici*. They show how the model (Septo3D) could help to analyse the limiting factor of epidemics. Model simulations are also used to compare the effect of different architecture parameters on epidemic development.

A stochastic 1D nearest-neighbour automaton models early development of the brown alga *Ectocarpus siliculosus*
Bernard Billoud, Aude Le Bail and Bénédicte Charriat 1014–1024

The early development of the filamentous brown alga *Ectocarpus siliculosus* has been simulated by an automaton in which cells behave (divide and/or differentiate) according to a stochastic model, controlled by their immediate environment. The global patterning of the organism is shown to emerge from these local interactions.

Virtual phyllotaxis and real plant model cases
Beata Zagórska-Marek and Marcin Szpak 1025–1033

This paper shows that the computer simulations of the shoot apical meristem's organogenesis produce phyllotactic patterns very close to the natural ones, including less common or even irregular patterns. Initial pattern's ontogenetic transformations increase phyllotactic diversity. The effect of transition depends upon how the pattern elements change their size and how the first available space is utilised.

New stereoscopic reconstruction protocol for scanning electron microscope images and its application to *in vivo* replicas of the shoot apical meristem
**Anne-Lise Routier-Kierzkowska and
Dorota Kwiatkowska** 1034–1046

This article presents a new method for stereoscopic reconstruction of the shoot apical meristem surface from scanning electron micrographs. It is applicable to the non-invasive replica protocol, enables to study growth and geometry changes on the meristem surface with a high precision and is free from some important limitations of other protocols.

Preliminary use of ground-penetrating radar and electrical resistivity tomography to study tree roots in pine forests and poplar plantations
**Terenzio Zenone, Gianfranco Morelli, Maurizio Teobaldelli,
Federico Fischanger, Marco Matteucci, Matteo Sordini,
Alessio Armani, Chiara Ferrè, Tommaso Chiti
and Guenther Seufert** 1047–1058

The evaluation of tree root biomass is significant and difficult to survey accurately. Test and develop new indirect tools for roots biomass survey appears of leading importance. This paper assesses the possibility of using two geophysical techniques Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) as indirect non destructive techniques for root detection.

A double-digitising method for building 3D virtual trees with non-planar leaves: application to the morphology and light-capture properties of young beech trees (*Fagus sylvatica*)
**Jean-Christophe Chambelland, Mathieu Dassot,
Boris Adam, Nicolas Donès, Philippe Balandier,
André Marquier, Marc Saudreau, Gabriela Sonohat
and Hervé Sinoquet** 1059–1069

A double-digitizing method combining a hand-held electromagnetic digitiser and a non-contact 3D laser scanner was developed to reconstruct 3D virtual trees with non planar leaves. The method was applied to analyse variability in leaf morphology in response to light availability and light interception of beech tree (*Fagus sylvatica* L.).

An automated procedure for estimating the leaf area index (LAI) of woodland ecosystems using digital imagery, MATLAB programming and its application to an examination of the relationship between remotely sensed and field measurements of LAI

***Sigfredo Fuentes, Anthony R. Palmer,
Daniel Taylor, Melanie Zeppel, Rhys Whitley
and Derek Eamus***

1070–1079

Leaf area index (LAI) is critical to model growth and water use in forests. Digital image acquisition, coupled with MATLAB image data analysis offers a rapid, robust, cheap and simple method for determining LAI of tree canopies. This method was used as a rapid procedure to calibrate MODIS LAI data.

Building a topological and geometrical model of poplar tree using portable on-ground scanning LIDAR

***Maurizio Teobaldelli, Alcoriza David Puig,
Terenzio Zenone, Marco Matteucci, Günther Seufert
and Vitor Sequeira***

1080–1090

In 2005, the main architectural characteristics of poplar trees growing in Italy were investigated using direct (destructive) and indirect (portable on-ground scanning LIDAR IMAGER 5003) methodologies. A complete 3D representation of the stand was created using JRC Reconstructor software and multiscale tree graph modelling of poplar trees was created using AMAPmod software.