PMA06

The Second International Symposium on Plant Growth Modeling, Simulation, Visualization and Applications

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ABSTRACTS

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INTRODUCTION

The PMA symposium series has been initiated by LIAMA, the French-Chinese Laboratory for Computer Sciences, Automation and Applied Mathematics. PMA06 has been organized in partnership with IEEE, and is supported by several Chinese and French Institutes (CAF, CAS, CASIA, CAU, CSIG, NERCITA, CIRAD, INRA, INRIA), as well as by the French Embassy in China and the National Natural Science Foundation of China (NSFC). PMA06 is also supported by scientific journals, i.e. Annals of Botany, Journal of Computer Science and Technology and the International Journal of Virtual Reality, which will publish selected papers in special issues.

This highly multi-disciplinary conference hosts over 100 participants from 15 different countries. The main goal of this event is to bring together researchers working on plant growth modeling and applications, but from different backgrounds, i.e. plant sciences, forestry, agronomy, environmental sciences, mathematics and computer sciences.

The PMA06 conference takes place in Beijing, China, at the Beijing Friendship Hotel. Beijing is the center for culture, science, communication, and many other aspects of Chinese life.

The capital of China is now a modern metropolitan city with a rich cultural heritage, from royal palaces and traditional monuments, of which the most famous are the Forbidden City and the Great Wall, to the popular Hutongs and Beijing Opera. Beijing is also a model of Chinese people's life and is the gateway to other parts of China.

Agriculture-, Forestry- and Environmental- Sciences are very important issues in China. More than 30 universities in the Mainland of China are dedicated to Agriculture or Forestry, some of which are situated in the Beijing area. In this setting, development and application of Plant Growth Models and Visualization tools have become increasingly important. PMA06 also provides opportunities for the increasing number of Chinese researchers active in these fields, to enter the international community.

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SPECIAL KEYNOTE SESSION

Plant growth modelling, simulation, visualisation and applications

Hans Lambers, School of Plant Biology, The University of Western Australia, Perth, Australia

Translocation of N from roots to the grain in wheat (Triticum aestivum) occurs to a major extent via the roots, indicating "cycling" of N between senescing leaves and roots during the grain-filling stage (Simpson et al. 1983). "Cycling" of N is not restricted to wheat in its reproductive stage, but also occurs in its vegetative stage (Simpson et al. 1982a) as well as in other species. It is controlled, at least in part, by cytokinins (Simpson et al. 1982b), whose rate of export from roots depends on the N supply to roots (Kuiper et al. 1989, De Groot et al. 2002). This model accounting for cytokinin effects on N cycling and the partitioning of C and N (Lambers et al. 1998) is largely based on work done one to two decades ago. Is this model still valid, does it need to be expanded, or should it now be discarded? These questions will be the thrust of the first part of this overview. It is concluded that the model as such remains valid, but that partitioning of N by N supply is controlled both directly by nitrate (Stitt 1999) and indirectly by both cytokinins and ABA (Gawronska et al. 2003). Moreover, cytokinins also affect processes in the roots, including nitrate uptake (Collier et al. 2003).

Carbon costs of nitrate uptake in roots vary amongst species and environmental conditions (Lambers et al. 1998). These costs are considerably higher in slow-growing species (Poorter et al. 1900), which is not due to higher costs for growth (Poorter et al.1991) or maintenance (Scheurwater et al. 1998). This suggested that the higher costs are associated with ion uptake. Since nitrate was one of the major ions taken up by the investigated plants, we focused on the costs of nitrate uptake. Costs of nitrate uptake are substantially greater in slow-growing species, and this is accounted for by greater efflux of nitrate, relative to nitrate influx (Scheurwater et al. 1999). Are these greater costs of nitrate uptake the cause of slow growth, or are they the consequence thereof? Using mutant of tomato (Solanum lycopersicum) with reduced levels of gibberellic, it was shown that slow growth accounts for increased respiratory costs associated with nitrate uptake (Nagel & Lambers 2002).

It is concluded that C and N metabolism are linked in different ways. Firstly, as discussed rates of C an N metabolisms are controlled in such a way that their rates are matched. Secondly, there are carbon costs associated with nitrogen assimilation. Similarly, there are nitrogen costs associated with carbon assimilation, but this topic is beyond the scope of this presentation.

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Knowledge-Based Geometry Modeling of Laser-Scanned Trees

Baoquan Chen, Dept. of Comp. Sci. & Eng., University of Minnesota, USA

We present a method for producing full polygonal models of range scanned trees. First, a skeleton of the trunk and main branches of the tree is produced based on the scanned point cloud. Due to the unavoidable incompleteness of the point clouds produced by range scans of trees, steps are taken to synthesize additional branches to produce plausible support for the tree crown. Appropriate dimensions for each branch section are estimated using Allometric theory. Using this information, a mesh is produced around the full skeleton. Finally, leaves are positioned, oriented and connected to nearby branches. We use live examples to demonstrate the effectiveness of our method.

– SESSION 1 –

Plant Growth and Plant Development Models

(K) - **Concepts to model growth and development of plants**

Jan Vos and Ep Heuvelink

Plant Sciences Group, Wageningen University and Research Centre, Netherland

Plant modelling serves several purposes, integration of knowledge being an important one. In plant production sectors the (economic) interest primarily regards mass of plants or harvested organs or their constituents. Therefore it is understandable that first attempts to construct computer based models of plants addressed fluxes of mass and energy, e.g. light absorption, photosynthesis, respiration, dry matter partitioning and leaf area growth. As a class these models are often referred to as ‘process-based models’. Most of these crop growth models commonly do not consider individual plants, and if they do all individuals that make up a crop are similar. Structural plant models do address single plants and the emphasis has not been on processes (fluxes of material) but on the quantification of shapes and orientation in space of organs as well as the 3D development of the structure as a whole. Recently, several research groups started working on models combining ‘function’ (i.e. processes) with ‘structure’, called ‘functional-structural plant models’. Individual plants are simulated, but in a simulated canopy not all plants are the same.

This paper makes some comments on the modelling of processes or functions in plants. Broadly speaking, models have to address two different basic aspects of plant functioning, i.e. growth and development. Growth is increment in mass and volume and is the resultant of processes including photosynthesis, respiration, distribution of assimilates and water relations. The concepts commonly used in modelling these processes will be discussed. Development is the progression through consecutive stages of the life cycle, i.e. from seed or propagule to senesced plant. Developmental processes include the initiation, dormancy or outgrowth of different types of organs, the transition to the generative phase being an important developmental event. Developmental processes are characterized by their rate and their duration. Process-based models commonly do not address such rates and durations, but developmental changes are effectuated by changes in partitioning coefficients of plant material. Modelling development of individual plants requires explicit quantification of rates and duration of initiation or appearance and growth of organs; also their life spans need to be considered. Organs of the same class (e.g. leaf blades) show different attribute values (e.g. leaf length). Often a ‘basic architectural plan’ of the plant can be discerned and quantified, i.e. properties of organ number 'X' can be computed in a systematic fashion from those of preceding organs.

Examples of the areas of application where functional structural modelling may help to advance understanding of plant functioning will be given, e.g. plant responses to environmental cues or signals (light quality, drought).

(O) - **Fruit set in sweet pepper: a modeling exercise**

Ep Heuvelink, Menno J. Bakker, Maaike Wubs, Lia Hemerik, Leo F.M. Marcelis

Fruit set is of utmost importance for yield in many crops. It is not well-understood and it is one of the weakest features in crop simulation models. We studied fruit set in greenhouse sweet pepper, both in experiments and simulation studies. The growth pattern of sweet pepper is dichotomous and indeterminate: fruits of different ages are present on one plant and the plant continues to produce new leaves and flowers.

Sweet pepper shows strong fluctuations in yield (flushing) which is caused by strong fluctuations in fruit set. Weeks with good fruit set are followed by weeks with poor fruit set, again followed by good fruit set and so on (cyclic behaviour). Source strength is the amount of assimilates (g CH^2O day^{-1}) available in the plant. The main sinks of a sweet pepper crop are the fruits. The sink strength of an organ is defined as the potential growth rate, i.e. the growth rate (g CH^2O day^{-1}) under non-limiting assimilate supply. Total plant sink strength is the combined sink strength of all fruits and the vegetative plant parts. Higher source strength (higher light level, wider plant spacing) improved fruit set. Higher sink strength of competing fruits reduced fruit set. A physiological model, also called a functional model, could reasonably predict fruit set patterns based on calculated source and sink strength.

With this model it could also be shown that the pattern of individual fruit sink strength as a function of fruit age determines the pattern in fruit set. A bell-shaped fruit sink strength function resulted in cyclic fruit set, whereas a sink strength function with a peak very early in fruit development resulted in a more regular fruit set pattern. Also the magnitude of the individual fruit sink strength influenced the fruit set pattern. This could be one of the explanations for differences in fruit set behaviour between genotypes.

Under the same circumstances, there are differences between plants with respect to position and number of flowers which set, whereas the current crop growth models simulate an average plant. Survival analysis is a statistical method for analyzing the timing of events, and how these are influenced by some explanatory variables (co-variates). We are the first to use survival analysis for studying and simulating flower and fruit abortion. Sink and source strength are taken as the main time-dependent covariates. This yields a stochastic function which gives the probability of abortion at a certain time given the value of the covariates. This function is used for implementing fruit abortion in an existing crop growth model for sweet pepper. In this way, the model is extended with a stochastic element, thus providing variance in model output. First results will be shown in the meeting.

(O) - **MiniRoot: a simple architectural model of the root system connected to the shoot system**

Loïc Pagès, Xavier Draye, Claude Doussan

Models of the root system architecture are useful tools for studying the plant soil system, and many of these models have been developed and published during the last decade. They capture several specific and interesting characteristics: (i) they simulate both the structure and spatial distribution of the root system; (ii) they allow a straightforward integration of developmental processes at the root level (e.g. elongation, branching) and their interaction with soil properties; (iii) they allow the simulation of root shoot communication via resources and signals. Though, few of them have been integrated into larger crop models, probably because they are not simple enough, too specialised for given species, or they do not have an explicit connection to the shoot system and the soil.

This modelling approach is an attempt to face these drawbacks. The model is built for being as generic and simple as possible, with a low number of plant parameters. It allows the root system of various plants to be simulated in relation to the soil medium and to the availability of photo assimilates provided by the shoot system. It is therefore a means for studying multiple genetic and environmental interactions in a very complex system. The presentation will illustrate these different aspects.

(O) - **Simulation of ecophysiological processes on 3D virtual stands with the ARCHIMED simulation platform**

J. Dauzat, N. Franck, B. Rapidel, D. Luquet, P. Vaast

Most classical ecophysiological models rely on crude representations of canopies as stacks of vegetation layers. Their use in complex canopies therefore implies complicated adaptations as well as simplifying assumptions which are difficult to validate. Alternatively, 3D virtual stands may be used as a support for numerical simulations of biophysical processes such as the irradiation of leaves, their transpiration and temperature and, finally, their carbon assimilation. By doing so, detailed information can be integrated from individual leaf scale up to individual plant scale, even within complex stands such as agroforestry systems. This paper illustrates the ARCHIMED numerical approach for such simulations with a special emphasis on the way to process multiple feedbacks between light, energy, water and CO2 transfers at different scales.

The stomatal conductance (*gs*) is a key variable that regulates leaf carbon assimilation (*An*) and transpiration (*Tr*). On the other hand, recent models state that *gs* is dependent upon *An* or, alternatively, dependent upon *Tr*. In addition, *gs* also controls leaf temperature which, in return, modulates *An*. Therefore, there are multiple links between *gs*, *An* and *Tr* at leaf scale. Other interactions may also link these variables at plant scale, *e.g*. when *Tr* induces large water potential (Ψ) gradients within the plant hydraulic architecture: for isohydric species such as coffee, low water potentials can lead to a sharp decrease of *gs* and, subsequently, of *An* and *Tr*. Finally, at the canopy scale, the heat and water vapour exchanges of vegetation with the surrounding atmosphere modify the micrometeorological conditions for *An* and *gs*.

In order to deal with these multiple interactions between biophysical processes at different scales, a method of numerical simulation is proposed. The starting basis is a numerical irradiative model that outputs leaf irradiance in the PAR (Photosyntactically Active Radiation) range (Q_P) and the total irradiance in all wavebands (Q_T). Then, for each time step (e.g. 15mn), the following iterative calculations are performed: (i) *An* is simulated *vs*. Q_P for individual leaves at a preset temperature; (ii) the temperature of leaves is refined *vs*. Q_T by solving their energy balance; (iii) the sap flow throughout the plant architecture is deduced from *Tr* to account for the Ψ feedback on *gs*; and (iv) latent and sensible heat fluxes are integrated at the plot scale for resetting micrometeorological conditions. All theses steps are reiterated until the variables of interest (*e.g*. *An* and *Tr*) are stabilized for all leaves.

This method was tested for various conditions in coffee orchards and cotton fields. The behaviour analysis of these systems showed that the iterative calculations generally converge rapidly, provided that proper relaxation procedures are implemented. Conclusively, the overall ARCHIMED method of numerical simulations appears to be capable of simulating complex processes within complex cropping systems. As such, it represents a powerful tool for testing hypotheses and evaluating the consistency of models.

(O) - **On functional leaves behaviour in Gossypium growth with respect to defoliation experimentations**

Zhigang Zhan, Hervé Rey, Dong Li, Yan Guo, Philippe De Reffye

Considering plant growth, we take into account two organ types: source organs which are the seed and the blades of leaves, and sink organs, which consist of leaves again, internodes, fruits, and secondary growth. Source organs provide resources for biomass production, and sink organs absorb those resources resulting in growth and development of the architecture of the plant. From that architectural point of view, organs are considered as competitors drawing on a common carbohydrate pool. Architectural data, used as targets for the GreenLab model, enable us to calculate the functioning of source and sink organs during growth and development of the plant by means of inversion of the model. In order to study more precisely the functional role of source organs, controlled defoliation experimentations were conducted on single-stemmed cotton plants (Gossypium hirsutum sp.). Treatments consisted of leaving only 6, 9, 12 and 15 functional leaves left at the top of the stem during whole plant development and control plants (all leaves left intact on single-stemmed cotton plant). Moreover, in some experiments every other leaf was cut , or half of each leaf was removed by a longitudinal cut. Results showed that plant development was not affected. Concerning growth, the area profile of remaining blades at the top of the stem was not much affected in relation with the number of functional leaves and primary growth remains steady apart from the most limiting treatment (6 leaves). On the other hand, secondary growth depended on the number of functional leaves on the stem. Plants with 12 leaves accumulated significantly more dry matter than control plants with all leaves left on the plant. This result clearly shows that leaves at ranks higher than 12 become more sinks than sources.

In this study, we show that manipulations on plant architecture by means of defoliation experiments enabled us to determine with more precision source and sink relationships between various organs of a plant as analysed with the GreenLab model. It also enables us to suggest an agronomic scenario for biomass production optimisation.

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(O) - **Analysis of Arabidopsis growth and development based on the dynamic model GreenLab**

Angelique Christophe, Veronique Letort, Philippe de Reffye, Paul-Henry Cournede

Few models of Arabidopsis thaliana have previously been proposed (De Visser et al. 2003; Chenu et al. 2004; Mündermann et al. 2005). These developmental models simulate the development of aerial parts of the plant in terms of plant geometrical aspects and topological structure, without incorporating physiological processes. We present here a more complete model of Arabidopsis combining both architecture and physiology (through biomass production and partitioning), and considering all the different parts of the plant (leaves, flowers and roots).

In the GreenLab model (Yan et al 2004), the number of the organs and their sizes during their expansions depend on both the environment and intrinsic parameters of source-sink functions. For Arabidopsis, the aerial plant architecture was decomposed into three physiological age levels corresponding to mutation of the meristems. A single set of source-sink parameters was used to describe the different stages of growth and development from seedling to maturity.

The calibration method of the GreenLab model on real plants indicated that the model is able to capture the progression of plant architecture and production over time through a small number of parameters. Considering their stability and their small number, these parameters could be useful for analysing genetic variability between Arabidopsis thaliana genotypes.

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(P) - **Application of Virtual Reality and Plant Modeling for Participation in Urban Planning and Design**

Eunmi Lim, Daisuke Kawashima, Kiyoshi Umeki and Tsuyoshi Honjo

Landscape visualization by virtual reality (VR) is recognized as one of the effective tools to support decision-making in landscape management and policies. Application of VR for participation in landscape policies has been rarely carried out because of the difficulty of making and operating the VR image. In this study, we developed a landscape visualization system with graphic user interface, which we named VR-Terrain(GUI version) as VRT-GUI, to generate the VR image easily by using VRML (Virtual Reality Modeling Language) and plant modeling techniques. In order to test the feasibility of the landscape visualization system, we applied the system to the real process of the plan (Ichinoe Urban Design Plan), which had been started to prevent Ichinoe from indiscriminate development, and to preserve the characteristics and essence of Ichinoe at Edogawa Ward in Tokyo. There is a Sakaikawa River Park surrounded by abundant nature. In the case study, we simulated the landscape of Sakaikawa River Park with about 200 plants and 300 buildings. We used the images simulated by VRT-GUI to explain the concept (such as building height limit) to the residents in the public meetings. It took about 30 hours to make the 3D model of the town. We also conducted a questionnaire about the simulation images. After ten minutes of training, anybody can walk through in the simulated town freely. The VR image by the system helped the public understanding of the concept of the urban plan. This case study showed that the system has practically good performance on the visualization of the landscape and the explanation of landscape planning.

(P) - **Modelling the vegetative growth of olive tree (*Olea europaea L.*)**

AÏACHI MEZGHANI M., SAHLI A. and JEBARI A.

The understanding of the growth rhythm is an essential criterion in the establishment of the architecture of the olive tree and therefore the future tree form. The architectural form of olive seedlings varies around three main forms: bushy form, mixed form and arborescent form.

Growth dynamics were observed throughout the growing season from the end of March to December. Both primary growth (internode elongation and production of new metameres) and secondary growth (increase in basal diameter) were measured on different types of branches produced on the main identified tree forms. These measurements were analysed in terms of relative growth rate along the vegetative growth season. Mathematical models were developed on both primary and secondary growth. The models' validity were specified by root mean square residuals (RMSR) and the Akaike's information criterion (AIC) calculated from measured and predicted growth measurements along the season. The lowest RMSR and AIC were found for the models that used the most detailed data.

Relative primary growth rate shows a sigmoid shape with two phases in the bushy form and three phases in the mixed and arborescent form. Thus the simulation of primary growth in the bushy form shows that internode elongation and production of new metameres can be represented by two logistical functions. Six parameters are identified from the established theoretical curve. This indicates the presence of two main growth waves (a spring and an autumnal growth flush).

The equation for relative primary growth rate in the mixed and arborescent form consists of three logistics functions (spring preformation, summer neoformation and autumnal growth). These equations are identified by nine parameters.

Secondary growth is always represented by an equation composed of three logistics functions and nine parameters indicating three phases in the progress of girth expansion on the three observed form.

(P) - **Sunflower (Helianthus annuus sp.) growth analysis by source – sink relationships study with GreenLab model**

Rey Hervé, Cournède Paul-Henry, de Reffye Philippe, Lecoeur Jérémie

In a previous article, Guo Yan et al. analyzed sunflower architecture with the GreenLab model. Although the plant architecture was correctly reproduced by the model, one single mature development stage was considered and there was no guarantee that estimated parameters were stable enough in order to fit all intermediate growth stages. To solve this problem, a new method of analysis was developed by Guo Yan et al., in order to calibrate simultaneously several stages of development with a unique source – the sink parameter set.

In this paper, plant development is taken into account more precisely, which improves the description of organs and plant growth. We present a study realized on sunflower plants (Helianthus annuus sp.) in controlled environmental conditions on soil columns in a greenhouse. Plants were observed at fruit maturity. Source and sink function parameters were precisely calculated for each organ type: internode, petiole, blade and capitulum. All intermediate growth stages are well described by the model. These results enable us to consider:

(i) simplified methods for intermediate growth observations using compartment measurements corresponding to the various organ types,

(ii) implementation of optimisation and control methods for irrigation and / or fertilizing plans, for example (Wu Lin).

(P) - **Modelling grapevine (Vitis vinifera L.) canopy structure with the reconstruction model TOPVINE: Comparison of various training systems through accurate computation of exposed leaf area and light microclimate in the fruiting zone**

G. Louarn, E. Lebon, J. Lecoeur

Crop canopy structure determines light interception efficiency at the plot scale and light partitioning among the plant organs. In grapevine, both variables are known to influence yield and grape quality. Furthermore, in this species, canopy structure strongly depends on the natural bearing of the cultivars, on soil water content and on various options of canopy management during the growing season. As a consequence, a proper analysis of the quantitative impact of the different management options on yield and quality can only be achieved using a modelling approach. The TOPVINE model was recently assessed in order to fulfil this objective (Louarn et al., 2005).

Model parameterisation was undertaken for two architecturally contrasting cultivars (Grenache N. and Syrah) and for four training systems (two trellised (VSP_2W, VSP_3W) and two non-trellised (Gobelet, 1W) systems) during the growing seasons of 2003 and 2004. Virtual scenes composed of 12 vines of these eight Genotype x Training system (GxT) pairs were then generated using three types of input files: i) field measured leaf area index, ii) leaf removal on the four first nodes, and iii) equal leaf area index in each situation. Radiative balance at the organ scale was finally performed with the ARCHIMED software for each virtual plot (Dauzat et Eroy, 1997).

Our results showed little influence of the GxT pair on the light interception efficiency at the plot scale, even if light distributions at the ground level were highly different. Exposed leaf areas were also similar, the GxT pairs being mainly discriminated from one another by the leaf area into the most shadowed class. On the contrary, light microclimate in the fruiting zone exhibited significant differences between the trellised and non-trellised training systems. Ranking of the GxT pairs in the non-trellised training systems was closely related to the mean shoot leaf area. In all cases leaf removal enhanced lighting in the fruiting zone, reducing significantly the difference between trellised and non-trellised GxT pairs.

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DAUZAT J., EROY M.N., 1997. Simulating light regime and intercrop yields in coconut based farming systems. Eur. J. Agron., 7 : 63-74.

(P) - **Modeling Leaf Morphological Growth in Winter Wheat**

Zhu Yan, Cao Wei-xing, Tan Zi-hui, Tian Yong-chao, Yao Xia & Liu Xiao-jun

Modeling leaf growth dynamics in wheat is of significant importance for realizing virtual and digital wheat plant growth. Based on time-course observations of leaf morphological properties (leaf length and leaf shape) on main stems and tillers under different nitrogen rates and winter wheat cultivars in two growing seasons, the change patterns of leaf morphology with growth progress and environmental factors were characterized and a dynamic model was developed to simulate time-course growth characters of different leaves of the wheat plant. The results showed that the final leaf length at different leaf positions accorded with a bimodal (two peak) curve, which showed marked differences under different nitrogen rates. The growth dynamics of leaf length could be described with a logistic model (sigmoid curve), and the growth dynamics of leaf shape could be described with the power function and quadratic equation. The effect of nitrogen status on leaf growth was quantified by the value of leaf SPAD. The model was validated with the field experiment data of different winter wheat cultivars. The average RMSEs of final leaf length, time-course leaf length and width on the main stem were 1.68, 1.98 and 0.14cm, respectively, and the average RMSEs of final leaf length, time-course leaf length and width on tillers were 2.29, 1.87 and 0.16cm, respectively. The results indicated that the present model had a good performance in predicting leaf morphological growth of the wheat plant, and thus will lay a foundation for further constructing a virtual wheat plant.

(O) - **An Algorithm for Simulation of Leaf Vein, Shoot and Root Growth Based on Their Environmental Factors**

Somporn Chuai-Aree, Suchada Siripant, Willi Jäger, Hans Georg Bock

Branching systems in plants are one of the challenging problems for realistic models. Auxin and water in plants play a major role in plant growth. Auxin is required for differentiation of the vascular cambium to develop the function of transportation. Auxin is important for the induction of leaf vein. The conduits of the xylem and phloem are the pathways of water and auxin transportation through all parts of plant connected from root. We propose a simulation algorithm for the branching of leaves venation caused by the movement of auxin in the leaf blade where there is light support. The branching of shoots is dependent on the production of auxin and water transportation in plants together with light and their space volume. We consider the amount of water and nutrients in the soil for the major roles of root growth. There are five processes in the algorithm: (1) the input boundary for leaf blade based on polar coordinate, shoot and root volume; (2) the distribution of auxin in leaf blade, light concentration for the shoot, and amount of water and nutrients for the root; (3) the construction of leaf vein, shoot and root structure; (4) the growth processes of leaf, shoot and root; (5) repetition of all processes until reaching the growth factors of each component based on sigmoid growth. The application of this algorithm can be used to simulate other biological branching structures based on their environmental factors.

(a) simulated leaf (b) simulated shoots/roots (c) combination

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(O) - **Multicellular computation of plant morphogenesis**

Lionel Dupuy, Jonathan P. Mackenzie and Jim P. Haseloff

Simulation tools and methods are essential to explore and improve our understanding of the mechanisms of development in plants. In this study, we describe a new method to analyse microscopy data and simulate the mechanisms of cell proliferation during morphogenesis. Different steps need to be completed prior to modelling of morphogenesis in order to consider most important developmental aspects of plants. First, segmentation of live microscopy data was used to estimate the model parameters. Second, morphogenetic, transport, and biomechanical models of cell wall expansion were developed in order to analyse coupled mechanisms in morphogenesis. Most importantly, a software platform was developed to provide a flexible environment for the development and the coupling of gene regulatory, spatio-mechanical, and signal transduction models at different levels of plant structure (e.g plant, cell, wall).

(P) - **Plant Distribution from the Greenlab Stochastic Organogenesis Model**

MengZhen Kang, Jean-Pierre Quadrat, Philippe de Reffye

The organogenesis of plants in the GreenLab model can be defined by formal language. We present here the stochastic version of this language, which allows us to define the distribution of possible plants. In this language, a word corresponds to a plant where terminal letters correspond to internodes of a given \PA and non-terminal letters correspond to buds that are distinguished by their \PAs. Then, the weight of a word gives the probability that the plant described by this word appears.

During a growth cycle, a bud can develop organs (leaves, flowers, fruits) attached to internodes and new buds as well. Then, the organogenesis of a plant can be completely described in terms of multitype non-commutatitive branching processesses describing the evolution of internodes and buds. By replacing, in the plant dynamics, the letter that represents an internode by the generating function of organ numbers that this internode bears, we got the recurrent equations defining the generating function of organ numbers. The moment recurrent equations of organ numbers are then obtained by the classic techniques of derivation of the generating functions. A program, written in Scilab, computes explicitly these distributions.

(P) - **Study on Modeling of Soybean Structure**

Zheng Ping, Su Zhongbin, Sun Hongmin, Zhang Jicheng

Given the lack of model research on soybean plants , this paper performs the simulated analysis for soybean topology structure of leaves and bean-pods. We put L system and particle system principles into practice with the technology of agricultural math and machine vision. After describing the growth process with a known quantity, we solve the problem of modeling of certain complex kinds of plants like the soybean. This lays a foundation for correct digital expression of the soybean plant and expands the research field of virtual plants in our nation.

(P) - **A 3D model to visualize maize canopies from simple measurements**

J.F. Ledent

A 3D model presenting wireforms of maize plants based on triangles (triangle mesh surface) has been developed. Lamina surfaces are presented in details taking into account curvature, twisting, undulations of leaf margins and leaf shape (variation of width along length).

Special attention is given to the visible (emerged) part of the laminae in the whorl taking into account progressive unfolding of the leaf along its length and to the part of the whorl forming a closed structure (the margins of successive leaves being in contact with each other, overlapping)

Tassels and ears are represented by taking into account the differences between the central axis and the branches (tassel) and between the base (peduncle + husks) and the ear proper + husks

Two versions exist; one where the information on one or several entire plants is entered to an Excel sheet and the other where the plant is built piece by piece (organ by organ) in interaction with the user who has to respond through message boxes to the information requested by the software.

The code is written in Visual Basic for Application. The output is given in Excel worksheets where each triangle is represented by a row where the 3 coordinates of each 3 vertices are given.

The plants can be visualised with a 3D viewer (either built in Java and available with the program or available in other softwares like VegeStar (from INRA) etc...

The 3D viewer available with the program uses a small in house Java application based on the Java3D API to display simulated plants in a virtual 3D universe which can be viewed through the application window on the physical screen of a computer. The application also listens to mouse and keyboard events to displace the observer in the virtual universe (resulting in translation, rotation and zoom of the plant).

Rows of plants and whole canopies are built from a sample of typical plants introducing random variation to generate the position of stem bases along the row. The azimuths of the successive leaves as well as their height of insertion are subjected to random variation around a mean position.

The model as it stands is static (giving flash views of plant structure at given growth stages). It allows the user to obtain models (geometrical representations) of canopies with different plant architecture due to sowing pattern, leaf geometry, distribution in height etc. It can be used with software like VegeStar to calculate light interception and photosynthesis. It is also a tool to visualise canopies reconstructed from data collected on plant architecture collected during extensive monitoring of plant structure evolution through growth (leaf emergence and unfolding, evolution of the whorl structure etc..). Crop monitoring data required by the model can be obtained without sophisticated instruments (visual ratings of leaf emergence, measurements of height, length and width of laminae, inclination angles at the base of the midrib etc.).

(P) - **Implementation of 3D Visualization System for Maize Growth**

Yan Dingchun, Zhu Yeping, Li Shijuan

Displaying the growth, development and yield formation of maize (Zeamays L.) is beneficial to culture management. The primary objective of this study was to develop a growth simulation model-based visualization system to reflect the time-course dynamics of growth, development and yield formation. The fundamental algorithms of maize growth, development and yield formation, which vary with the variety, environmental factors and production levels, were formulated from the existing literature and research data. Based on the daily output of the growth model, and combined with morphological formation and growth rules of corn seed, root, stem, leaf, corncob, and so on, the mathematic model for changes of morphology in corn was set up. Using computer graphics, VC++ and OpenGL, a 3-dimensional visualization of growth, development, and yield formation was realized based on crop growth simulation model data and a 3D animation technique. The 3D system can basically reflect the rules of real corn growth, development and yield formation, and which has some characteristics such as simple structure, mutual interface, and realistic images.

Guo Y., Ma Y., Zhan Z., Baoguo L., Dingkuhn M., Luquet D., de Reffye P., 2006. Parameter optimization and field validation of the functionnal-structural model GREENLAB for Maize. Ann. Bot, 97 : 217-230.

(P) - **Continuous LOD model of coniferous foliage**

Qingqiong Deng, Xiaopeng Zhang, Sebastien Gay, Xiangdong Lei

Interactive and realistic foliage rendering is a challenge in forest and landscape visualization due to a huge amount of tiny geometric detail. Traditional B-rep model simplification methods are not applicable to plant shapes with special topological structure and geometric shapes. Recently developed foliage LOD models [1, 2] are efficient in geometric simplification and multi-resolution rendering of broad and thin leaves. But they are still not efficient for coniferous foliage. There are two reasons. One is that polygon model presentation is too complex for distant visualization, and too simple for a close view. The other is that the number of leaves included in a coniferous tree is much more than that of other trees of similar height or crown volume. The geometric model for needle leaves in [3] is good for rendering, but it has a single resolution.

We present a new approach to level of detail representation of coniferous foliage geometry for efficient plant rendering. This is a mixed level of detail model defined with multi-resolution cylinders and semi-transparent lines. Cylinders are used to represent coniferous foliage geometry when the needles are bigger than one pixel in the image space. Lines are used to represent and render far or thin coniferous leaves when they are equal to or smaller than one pixel in the image space, and the transparency of the line model is used to anti-alias the needles. We control the number of polygons through error estimation, so that polygon number decreases. The union between different needles inside a phyllotaxy is constructed to decrease the number of lines. Therefore, the data compression is rather high for a far coniferous tree simplification. Contributions are: (1) Coniferous leaf models in this paper are multi-resolution. (2) Reality is increased through the mixture of cylindrical model and semi-transparent line models for needle leaves. (3) A high geometric compression while keeping the original visual effect. (4) Error control and view-dependence. This LOD model has high data compression, and high rendering realism. This approach is view dependent, and can be used for interactive and realistic visualization of coniferous forest.

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Fig. 1 Realistic rendering of coniferous trees

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– SESSION 2 –

Theoretical Advances in Plant Growth Modeling

(K) - **A functional and architectural model of competition for plant growth.**

P-H Cournède, P. de Reffye

Functional-structural models of plant growth were initially developed for individual plants. The main attempts to take into account the effects of competition between plants concerned mostly their spatial developments [Blaise, 94], [Mech and Prusinkiewicz, 96], that is to say the way plants adapt their architecture, especially their branching, according to the competition for space with their neighbours. However, the geometric approach proves too restrictive in order to describe properly how competition affects plant functioning.

Our study focuses mainly on the ecophysiological effects of competition for light, that is to say how it affects biomass production and allocation in plants. This issue has been addressed in several dendrometric models developed for forestry applications [Ford, 84], [Sorensen et al, 93]. Some of these models are based on a two-dimensional projection of space potentially occupied by a plant onto the x-y plane [Ek and Monserud, 74], [Bonan, 88]. Typically, each individual is assigned a disk-shaped zone representing its assumed crown projection with the disk-radius proportional to height or stem diameter. Neighbours are defined as trees having overlapping disks, with the overlapped portion divided according to their relative sizes.

We adapt this idea to the functional-structural model of plant growth GreenLab, [Reffye et Hu, 03], [Yan et al, 04] and derive the new biomass production equation. By coupling our competition model with models of interactions between organogenesis and photosynthesis [Mathieu, 2006], we can study plant plasticity and their adaptation to their environmental conditions, as illustrated by figure 1.

This competition model should reveal of great interest for various applications: optimization of crop density, optimization of clearing strategies in forestry, growth models of mixed crops.

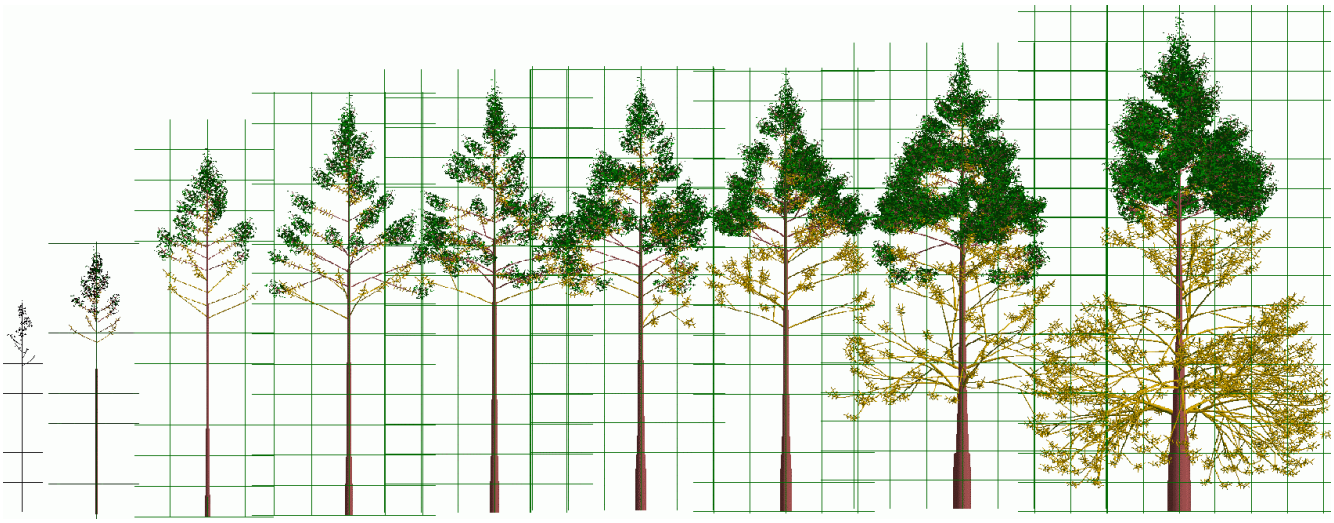

Figure 1: growth simulation of the same tree in different competition conditions; trees are visualized at the same age from the most dense condition (on the left) to the least dense (on the right)

(O) - **Towards "Virtual Barley": Relational Growth Grammars as a universal framework for rule-based hierarchical modelling of morphogenesis, plant function, regulatory networks, and genetic processes**

Buck-Sorlin, G.H., Kniemeyer, O., Hemmerling, R., Kurth, W.

The past decade has seen the rise of a new type of plant model which combines structural with functional aspects, thereby exhibiting varying degrees of complexity and covering different combinations of disciplines (e.g., morphology, physiology, agronomy, genetics) depending upon the original question asked by the modeller or the model purpose. At the same time, the traps and pitfalls associated with the parameterisation and validation of such complex, combined multi-scaled models were recognized and therefore recently a lot of thought has been invested into the optimisation of the organisation and management of existing and future Functional-Structural Plant Models (FSPM).

One perspective, typified by the French ALEA initiative (Pradal et al. 2004) embeds different models or modelling platforms into a common framework, thereby allowing the linkage of modelling tools. In a further approach, which is motivated by concern about the often overwhelming complexity of FSPM, there is an attempt to unify and simplify different concepts at a more general level. This has spawned the creation or extension of new modelling formalisms, languages and software platforms that are designed to be used by researchers in plant biology in parallel or alternating with real experiments. Examples for such projects are the L+C language (Karwowski & Prusinkiewicz 2003), Relational Growth Grammars (RGG)/eXtended L-Systems (XL) (Kniemeyer et al. 2004), which are both extensions of L-systems, or multiset rewriting systems such as MGS (Giavitto & Michel, 2001).

We developed Relational Growth Grammars (RGG) (Kniemeyer et al. 2004) on the basis of L-Systems as we were dissatisfied with several aspects of the data structure, dynamism, and transparency of the latter, especially as far as the representation of genetic processes is concerned. In order to implement and test this new formalism, we created a new modelling language, eXtended L-systems (XL). Models using the XL language are interpreted by the interactive, Java-based modelling platform GroIMP, but XL is quite independent from GroIMP.

Our model organism is barley (*Hordeum vulgare* L.), a cereal crop with a long tradition of breeding research. Barley model modules implemented in RGG/XL so far include an ecophysiological model that combines morphogenetic rules with a hormone biosynthesis network (gibberellic acid, GA) controlling internode elongation and a simplified genotype, as well as the model *BarleyBreeder* which allows the interactive (a)sexual reproduction of individuals from a population, thereby faithfully simulating genetic recombination and mutation.

The ecophysiological barley model presented here reflects our current effort for a mechanistic representation of genotype-environment interactions at the level of the regulatory network. The GA biosynthesis network used provides an excellent example for such an interaction, as the membrane-bound monooxygenases that catalyse an early step in the biosynthesis of GA are assumed to be regulated by light (Hedden & Kamiya 1997). Using a light model written in RGG in combination with multiple instances of the simulated GA-biosynthesis network, we will in the future be able to test current hypotheses on the potential connection between plant morphology and the quality of incident light at the sites of GA-biosynthesis in different scenarios of stand structure (row spacing). Using the current state of the barley model as an example, we discuss the potential and limitations of the RGG formalism to achieve the ultimate goal of the virtual crop plant.

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(O) - **Generation of rhythms in plant development controlled by their functioning: theoretical and numerical study**

Mathieu, A. , Cournède, P.H., Barthélémy, D. and Reffye (de), P.

The GreenLab model describes plant organogenetic development and photosynthetic functioning by a discrete dynamical system, see [3]. The time step is called the growth cycle and corresponds to the duration between the appearances of new organs. The GreenLab mathematical formalism allows studies of the system behavior, see [1].

From the assumption that tree development strongly depends on the amount of available biomass, a new version of the model has been developed to take into account interactions between organogenesis and photosynthesis [2]. The biomass produced is dynamically shared between organs according to a proportional allocation model: each organ has a given sink and the sum of all sinks is the plant “demand”. To implement interactions in the model, the ratio of available biomass divided by plant demand has been chosen as the key variable to control plant development. For example, at a given growth cycle, branches or fruits only appear if the ratio exceeds a particular threshold that is a parameter of the model.

In this paper, we present how the dynamical evolution of this ratio can naturally induce rhythm apparition in the plant development. Two main phenomena are particularly studied: fructification and branching.

After a brief presentation of the model, numerical simulations will illustrate how functioning can generate rhythmic organogenetic phenomena: variations of the ratio of biomass divided by demand around the threshold value create an alternation between cycles with great and low fruit productions (such a process is observed on beech trees). Likewise, periodical branching patterns are generated.

Then, a mathematical study of the system will be presented. Conditions on the appearance of such rhythms are determined as functions of the plant endogenous parameters and of environmental conditions.

This model offers great perspectives in terms of tree behavior representation and study. It should help us understand some hidden mechanisms of tree growth.

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(P) - **Existing state and application on nondestructive measurement of plant growth based on machine vision**

Ming Sun, Shuhuai Zhang, Yaoguang Wei, Dong An

As one of the most important technologies for plant growth modeling, the research of nondestructive measurement based on machine vision is of great significance in hastening development of digital agriculture. In this paper, we provide a review of nondestructive measurement based on machine vision as follows: meaning, method and existing state. In addition, the most urgent problems such as the superposition among leaves have been pointed out. We have also given the solutions applied to nondestructive measurement of tomato seedlings in greenhouse.

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(P) - **Digital image technology in the diagnosis of pests and related algorithms**

Chen Guifen, Jiang Han

This paper elaborates on a computer-aided digital image processing technique in the classification of core plant disease information. With reference to the first order gray histogram of plant disease images and their graphic target zones, related mathematical and statistic weight values such as first order gray statistics and geometrical configuration are acquired. This technique has become a major vehicle to collect such weight values in the taxonomic field of grain plant disease. As experiments demonstrate, this digital image processing technique can reveal a range of reliable weight values and effectively increase the efficiency of identification. Through synthesis using picture processing, and pattern recognition theory, this paper constructs a plant disease picture recognition system. In our system, the plant disease starts with the recognition of the picture, and the differences arise according to the plant disease type, by the computer system automatically adjusting the threshold, to obtain accuracy and intelligence. Experimental tests showed that the results of the plant disease picture recognition system can satisfy practical applications.

(P) - **TraitMill™: A Genomics Platform For Modeling Gene Function In Plant Development**

Pierre Lejeune, Frederic Leyns, Frederic Dhont, Christophe REUZEAU, Anabel Sanz, Yves Hatzfeld, Valerie Frankard, Wim VanCamp, Joris de Wolf, Rindert Peerbolte, Willem Broekaert

One of the biggest challenges of functional genomics is to formulate models that predict variations in plant development based on alterations in expression of one or more genes. Documenting precisely the effect of gene expression on plant growth and morphology is needed to bridge the gap between physical, eco-physiological, and molecular models. Integrating the different models has an enormous potential for the improvement of quality and quantitative traits in industrial crops.

However, assigning functions to genes by conventional methods is very consuming in terms of time and resources, and the task is even more complex when dealing with quantitative traits such as seed yield. To meet this challenge, CropDesign has developed TraitMill™, a platform that allows high-throughput and high-resolution testing of various natural genotypes, and/or the effect of plant-based transgenes on essential plant traits. The focus of the platform is currently on rice, a globally important crop, and a good model for other important cereals such as corn and wheat. TraitMill™ offers a high-throughput prediction of phenotypes from the greenhouse to the field. TraitMill™ involves the following key components:

TraitMill™ is a high throughput assembly line platform, comprising allele-design, vector construction, plant transformation, seed increase, and finally population evaluation. The trait evaluation set-up makes use of robots for automated plant transport, digital imaging tools for plant evaluation and proprietary image analysis software for data production and statistical analysis of the results. This phenotype evaluation includes various parameters such as leaf and root biomass across time, seed yield and seed traits, stress tolerance and yield stability.

A range of interesting phenotypes has been generated over the last years, including transgenic rice lines showing altered seed production, green biomass, shoot/root ratio, or flowering time. Validation of such phenotypes can be done in several rice genotypes and other cereals. Field-trial experiments showed that the plant phenotype observed in TraitMill™ was often conserved in the field. Thus TraitMill™ can be used as a good proxy for the validation of transgenes, in view of their use for crop improvement. Our results demonstrate the potential of gene engineering to modify quantitative traits. Moreover, they provide new tools and new alleles for breeders to be integrated in breeding programs and combined with other traits of interest.

(P) - **Modelling the phenotypic plasticity of the tomato crop (Lycopersicon esculentum Mill.) in response to light and planting density using the structural-functional model GREENLAB**

Q. X. Dong, G. Louarn, Y.M. Wang, J., J.F. Barczi, P. de Reffye

Adaptive responses of plants competing for light are well-known and largely documented. However, mechanistic models able to quantitatively simulate this response in a fluctuating environment are scarce. The functional–structural model GREENLAB was recently presented that simulates resource dependent plasticity of plant architecture (Yan et al., 2004). Its ability to fulfil this role is evaluated here for the tomato, a plant exhibiting a strong morphological adaptation to light regime and presenting an obvious economical interest.

Tomato plants were grown in a greenhouse during the 2004 and 2006 spring seasons (three experiments) at three planting densities (1, 3 and 16 plant/m^2). Detailed morphological and topological observations were made on plant architecture throughout the development of the crops. Data obtained in experiment 1 and 2 were used to establish target files for parameter optimisation. In order to take into account inter-plant competition for light, GREENLAB's production equation was modified as by Howell and Musick (1985), integrating Leaf Area Index (LAI) through a Beer-Lambert law-like equation. The generalized least squares method (multi-fitting, Guo et al., 2006) enabled us to compute hidden parameters characterising relative sink strength of organs and leaf functioning for the different situations. Relationships between parameters and light conditions were established. Finally, fixed values of parameters were replaced by this set of environment-dependent functions and the new model was tested with incoming light measured in experiment 3 as input.

The results show that individual tomato plants are characterized, whatever the light climate experienced, by irregular profile of phytomer weight along the main branch. Assuming adequate weighting of the phytomers within each growth unit, it was possible to reproduce this complex pattern with the GREENLAB model for all the treatments. We demonstrated in addition that the simplification of the architecture through a median phytomer type doesn't modify the estimation of hidden parameters and thus is of greater interest.

Planting density led to strong modifications of plant architecture with significant implications in terms of model parameterisation. While the variation function of the different organs showed remarkably constant behaviour among the treatments (i.e. B_i parameters remained constant), relative sink strength of organs (p_i) were significantly different. Relative strength of the petiole and internode increased when light competition increased and on the contrary relative strength of leaf blade and fruit decreased. As expected, leaf efficiency parameter k displayed a constant value and the ratio parameter r2/Sp, representing the efficiency of light interception per m^2, increased in case of high densities.

At last, the new model integrating these light responses was assessed by comparing simulated outputs to independent measurements. Excellent predictions of plant architecture, vegetative growth and biomass partitioning over the different organs were obtained. This demonstrated the potential use of the GREENLAB model to simulate plant plasticity in fluctuating environments.

Guo Y., Ma Y., Zhan Z., Baoguo L., Dingkuhn M., Luquet D., de Reffye P., 2006. Parameter optimization and field validation of the functionnal-structural model GREENLAB for Maize. Ann. Bot, 97 : 217-230.

Yan H.P., Kang M.Z., de Reffye P., Dingkuhn M., 2004. A dynamic, architectural plant model simulating resource-dependant growth. Ann. Bot, 93 : 1-12.

(P) - **A Quantitative Analysis on Leaf Curvature Characteristics in Rice**

CAO Wei-Xing, ZHU Yan, SHI Chun-Lin, CHANG Li-ying

Leaf shape is a very important characteristic in virtual crop growth modeling, and some empirical curves have been used to describe leaf morphology based on field experiments in previous study. The fitting curves can help to understand organ morphogenesis, but the fitting parameters obtained from the given leaves and time are not suitable to the changing growth process of leaves. So developing a mechanism model to simulate the leaf morphology is critical for virtual crop growth.

Organ morphogenesis of plants is decided by its forces. After using force analysis on a rice leaf, the gravity fraction in the leaf's normal direction keeps equilibrium with elasticity, allowing a dynamic leaf curvature equation to be deduced with some assumptions. The equation included the synthetic effect of leaf blade length, leaf blade width, initial leaf angle, specific leaf weight, and deformation coefficient on leaf space shape. Then the equation was solved with parameterization. The sensitivity analysis showed that the equation could well reflect the integrated effects of leaf length, leaf width, specific leaf weight, and leaf deformation coefficient, consistent with rice plant architecture in practice.

A field experiment was conducted at the Nanjing Agricultural University to test the equation. Two cultivars (SU63 and WYG7) were nursed in dry-beds on May 20, and single seedlings were transplanted on June 20. Water and nutrients were supplied according to high yielding rice management procedures. At the jointing and booting stage of the rice, the 3-dimensional coordinates of several points in the leaf midrib were measured with the 3D digitizer, and at the same time leaf blade length, width, and initial leaf angle were obtained. Then simulation analyses were conducted on the equation with the experimental data. The results indicated that the leaf curvature equation could reasonably and reliably describe the changing pattern of leaf shape characteristics of rice under different conditions.

The leaf curve equation could dynamically simulate the space shape of leaves with different initial leaf angles and special leaf weights by using rice leaf reduced parameters, especially in modeling daily crop growth.

(O) - **Phenotypic plasticity and fractal dimension are strong determinants of grain yield in soybean**

A.A. Jaradat, Derya Surek and David Archer

Reliable models are needed to describe plants with complex geometric structures, quantify the impact of management practices on the plant's geometric distribution in space, and predict yield as a function of fractal dimension. We measured growth and developmental variables on single soybean [Glycine max (L.) Merr.] plants under all combinations of two cropping (conventional and organic), two tillage (conventional and strip), and two fertility (with or without nitrogen fertilizer) systems under the short-growing season of the upper Midwestern USA. The normalized geometric structure and vegetative growth characteristics of two genotypically different soybean varieties were quantified using digital imagery during two cropping seasons. Most vegetative and yield-related variables measured were influenced by different management practices, and these variables were strongly correlated with grain yield per unit area. Midday differential canopy temperature (dT) was the single most important environmental factor in predicting the fractal dimension (FD) of both varieties (R^2 range 0.40 - 0.76) and was a reliable indicator of plant stress under different management systems. A multilayer perception neural network with back propagation identified plant dry weight, plant volume, plant circularity, and leaf area per plant, in decreasing order, as reliable (R^2=0.76) predictors of FD. However, the simplest neural network model accounted for 61.0% of the variation in FD and was limited to plant dry weight and number of pods per plant. The latter is an estimate of the number of fruiting nodes per plant. The fractal dimension was the most important predictor in a generalized regression neural network, followed, in decreasing order, by plant dry weight, plant volume and plant circularity, in predicting grain yield m^{-2} (R^2=0.64). Knowledge of how plants respond to single and multiple management practices will help agronomists develop better predictive models and will help farmers refine management practices to optimize yield. The management implications of manipulating phenotypic plasticity and FD to optimize grain yield are presented.

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(O) - **Quantitative Genetics and Plant Growth Simulation: a Theoretical Study of Linking Quantitative Trait Loci (QTL) to Model Parameters.**

LETORT Veronique, MAHE Paul, COURNEDE Paul-Henry, COURTOIS Brigitte, DE REFFYE Philippe

In this article we use plant growth simulation to study the implications of linking the quantitative trait locus (QTL) to the parameters of a plant growth model.The potential applications of such links are of great interest for geneticists and breeders as simulations based on the growth model can be a helpful tool to improve selection methods and to optimize experiments [1][2].

Here, we choose the deterministic version of the functional-structural model Greenlab [3][4]. This model was calibrated on several agronomic plants (see for example [5]) and, in a wide range of environmental conditions, parameters revealed to be stable during plant growth. For this reason, the genetic determination of GreenLab parameters seems reasonable.Under this hypothesis, we model the whole chain from QTL to plant growth and search for QTL in a population of virtual plants.

To this end, we associate a genotype to each plant: chromosomes are introduced as vectors of numbers, each one representing a QTL. Then we set simple rules to determine gene expression (e.g. additivity or dominance) and a matrix multiplication to calculate the plant parameters values from the chromosome vector. Thus, we can simulate reproduction between two plants in a simple way. This allows us to reproduce virtually the stages of the work done in fields by geneticists.

As an example, we simulate several wheat populations and we use QTL Cartographer software to assess the associations between QTLs and plant traits. With this virtual study, we see in particular that it is more likely to find QTL related to model parameters than to classical features such as plant height or fruit weight. Those quantities result indeed from the whole growth process and highly depend on environmental conditions, whereas plant parameters are much more stable. We show the potential of such an approach by using a genetic algorithm on a virtual population of wheat to find the genotype - and the associated parameters - of the individual bearing the highest ear weight in given environmental conditions.

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(P) - **Characterizing and modelling rice vegetative morphogenesis**

Song Y.H, Luquet D, Mathieu A, De Reffye P, and Dingkuhm M

Today, the genomics revolution allows decoding the genome, and even discovering genes; within this context, understanding plant phenotypic expression has become one great challenge, as relating gene(s) function to their expression and agronomic interest in the field is essential (Dingkuhn et al., 2006; Luquet et al., 2006). Phenotypic plasticity (Wright and McConnaughay, 2002) relies on inherent complex GXE (Genotype X Environment) interactions that are not directly observable on the plant, since they are related to internal morphogenetic processes involved in plant (organ) set up and dimensioning. However, these internal processes or reaction norms are expected to be closer to gene action than integrative variables as LAI, yield etc. During the last decade, many studies were intended to develop and use plant/crop models, to formalize these kinds of reaction norms and relate underlying parameters to genetic determinisms at the organ, crop/plant level.

Greenlab (Yan et al., 2004; Guo et al., 2006) is a generic, mathematical plant growth model, originally developed to simulate 3D plant growth and architectural development. This model is mainly driven by carbon balance throughout the plant, with C source (e.g. plant radiation interception) and C sink as the sum of expanding organ growth (leaves, internodes, fruits, roots). Available carbon is totally partitioned among organs depending on their respective sink strength. This modelling approach thus allows building plant architecture and particularly organ size as an integrated response to environment.

In this study, Greenlab was used to simulate and analyse the vegetative morphogenetic behaviour and carbon sink/source relationships of rice on three case studies: a reference (wild type) genotype Nippon Bare (1) grown under optimal conditions, (2) with a systematic (manual) pruning of tillers and (3) one of its TDNA organogenesis-deficient mutants. The mutant named phyllo is vegetative development deficient, rapidly producing quite small leaves, with nearly absent tillering. Both genotypes were grown during about 40 days after germination under suboptimal conditions in a phytotron (in Montpellier, France, 2005), plants were grown in hydroponics conditions (in a nutritive solution). A set of Nippon Bare seedlings were used as reference, whereas, other sets were systematically pruned to suppress tillering potential sink strength. Plant growth and development was weekly measured in terms of individual leaf size (blade, sheath), fresh weight and root fresh weight, with three replicates for each measurement.

Firstly, the data were used for a general analysis of morphogenetic behaviour of plants according to genetic (TDNA) or artificial (pruning) mutation, to provide insights in modelling analysis. Then the data were used to calibrate Greenlab (hidden parameters mainly concerning sink strengths and expansion laws): Digiplant (one new member of the Greenlab model family) was used to optimize rice growth in terms of tillering (mainly related to organ sink strength, expansion law, hydraulic resistance). Parameter value analysis showed that there are substantial differences among phyllo and Nippon Bare in terms of carbon ‘management’. In particular, for phyllo mutant, the model underlined smaller sink strength and shorter expansion duration of leaf blades, and a general higher resistance of blades all contributing to explain why the mutant has much smaller leaf, whereas this did not happen to artificial pruning treatments. Indeed, the pruning treatment showed roughly the same parameters as the reference. The study demonstrated that Greenlab model has good potential in addressing the challenge of phenotypic analysis.

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(P) - **Integrating Nutrient Cycling into a Growth and Yield Model calibrated for Eucalyptus Plantations in Congo**

Saint-André L., Ranger J., D'Annunzio R., Thongo M'Bou A., Deleporte Ph., Nouvellon Y., Laclau J-P., Jourdan C., Bouillet J-P

There are a wide variety of models available to predict growth of forest plantations. Common classifications distinguish process-based, architectural and growth and yield models, each of them dealing with a particular aspect of forest productivity. In Congo, these three approaches are currently being tested. Among them, the growth and yield (G&Y) model (Eucalypt-Dendro, Saint-André et al. 2002) aims at (i) assessing stand production under different silvicultural options, and (ii) evaluating the risks of nutrient deficiencies for different harvesting strategies.

G&Y models such as "Eucalypt-dendro" are simple and are designed to explicitly take into account silvicultural practices and competition between trees. However, for this class of models, there is no real coupling between the growth module and nutrient cycling models. Firstly, the biogeochemical module is often restricted to the evaluation of nutrient contents within the trees and secondly, "site index", which is generally defined as a dominant height at a given age, is assessed from an inventory and is fixed for the whole simulation. This last assumption is valid for forest ecosystems where there are only small changes in soil fertility within one rotation or between rotations. However, in both temperate and tropical forests, fertility may be changed by silvicultural practices (for example by the slash management). Integrating nutrient cycles into growth and yield models seems to be a useful way to take into account such changes in fertility. Furthermore, this may also allow evaluation of alternative fertilizer practices and to provide a basis for improved nutritional management of plantations.

The incorporation of nutrient cycling into Eucalypt-Dendro started three years ago (Saint-André et al. 2003), focusing on the following topics: (i) assessing amount and composition of litter fall for both above and belowground compartments, (ii) decomposition of harvesting slashes and litter, and (iii) impacts of the nutrient release on tree and stand growth. In this paper, these three steps will be illustrated throughout several studies: (i) litter fall and root turnover at both annual and monthly scales (d'Annunzio 2004, Thongo-M'Bou 2003), (ii) decomposition patterns, including seasonal effects, of litter and slashes (Kazotti 2003), and (iii) consequences of the slash management on the tree and stand growth (Saint-André et al. 2004a and 2004b). Using these elements, it was possible to make a first and innovative attempt of a complete chain of G&Y models where growth and nutrient cycling are closely connected at a yearly scale. Based on the slash management experiment, different hypotheses have been made to simulate the impact of nutrient release on the tree and stand growth (dominant height growth is only affected, dominant height and stand basal area growth are both affected, individual tree growth is also changed by the amount of nutrients released). Consistency of these simulations were checked and discussed (i) against measurements made on several field trials, (ii) and from studying the asymptotic behaviour of the chain of models (large span of stand density and site index). Based on this qualitative evaluation, several perspectives are presented and discussed.

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(P) - **A matrix growth model of natural Spruce-balsam fir forest in New Brunswick, Canada**

Xiangdong Lei, Changhui Peng, Yuanchang Lu, Xiaopeng Zhang

A density-dependent matrix model was developed for Spruce-Balsam Fir natural forest stands in New Brunswick, Canada. It predicted the number and basal area of trees for 5 species groups (spruce, balsam fir, other softwood, soft hardwood and hard hardwood) and 10 diameter classes. Upgrowth, ingrowth and mortality models were established with explicatory variables representing tree size, stand density and stand structure. The model was based on 544 sample plots with inventory periods from 2 to 9 years. The majority of the data (80%) was used for model development, and the rest (20%) was used for model validation. It was concluded that the model is a reliable and fairly accurate tool for prediction of growth of Spruce-Balsam fir forest in Canada. It may become a useful tool for a sustainable management of these forests.

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(P) - **Simulation of Trees by IFS and 3D Reconstruction in Virtual Environment**

Hang Zhang, Mingquan Zhou and Xingce Wang

According to the shape of trees, a method was proposed for simulation. The 2D images of a tree can provide its topological structure after segmentation and feature extraction. The tree skeleton was recursively tracked to pick up the branch points and end points. All the information can be used to reconstruct a 3D tree model in a virtual environment. Iterated function system (IFS) is effective in dealing with some overlapped and unclear branches in the image. 3D reconstruction follows the tree topological structure. It is more available than IFS only, because 3D reconstruction avoids following specific rules to get the information of plant structure and reducing the amount of spatial points. IFS is helpful in simulating some complex parts. Experimental results show that combining of 3D reconstruction and IFS not only can be applied in plant simulation but also can be used in some tree-like objects such as vessels.

(P) - **Applications of Virtual Reality Technology in Forestry**

Zhang huaiqing, Chen yongfu

This paper has introduced the effects of virtual reality technology in the fields of forestry, including forest element simulation, such as shape, structure and function of plants, VR environment and VR forest management activities. Many techniques which can be used to realize VR forestry, such as biological modeling, graphic and remote sensing, are also discussed in this paper.

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– SESSION 3 –

Modeling Plant Interaction with its Environment

(O) - **Soil-plant-atmosphere modeling in a multi-scale and multi-model simulation platform**

Xavier DRAYE, Loïc PAGES

During the last years, modeling has become more and more popular in soil-plant-atmosphere research. From a computational point of view, the growing number of model implementations introduces new issues and challenges. Among these issues, two are of general relevance. The first concerns the linking of various models in order to run more complex simulations addressing a larger set of situations. The second is the organisation of a core of functionalities that are common to many model implementations and that many today's designers repeatedly re-write. A Java-based implementation of a simulation platform is presented that was designed to specifically target these two issues. The effort relies on the definition of minimum interfaces allowing one model to query information about the current status of another model. The platform was designed to be multi-scale. For example, a plant model may simultaneously use cellular models of meristematic activity and whole-plant hydraulic models of C transport. The current implementation offers a set of functionalities that are of general use: interactive 4D visualisation, Graphic User Interface, input and output file management, parameter entry, etc. It is highly flexible, open-source and runs on any operating systems that runs Java. As a proof-of-concept, we propose a simulation of a tomato field that links the Wave 1D soil model (in Fortran), the MacTom tomato shoot model (in C) and the RootTyp root system model (in Java). A very small piece of code was required to link the various models that had all been designed without any intention to be part of a more complex simulation.

(O) - **Modeling Light Distribution within Plant Canopy Based on BSDFs of Single Leaves**

Cailian Lao, Yuan Zhang, Yan Guo, Xiping Wang, Baoguo Li

This paper presents a new model for simulating the distribution of light within plant canopies based on the Bidirectional surface Scattering Distribution Function (BSDF) of single leaves. The Bidirectional Reflectance Distribution Function (BRDF) is formulated with a modified Cook-Torrance model, while the Bidirectional Transmittance Distribution Function (BTDF) with the Lambert model. The canopy leaves are represented by a set of triangles in 3D space. The simulation includes two steps. In the first step, direct solar light is sampled as discrete rays with the adaptive method and is cast from a virtual plane above the canopy, and the intersection of each ray with the nearest leaf triangle is calculated with the hierarchical bounding box approach. In the second step, rays scattered from the intersection point are sampled with the Rejected Method based on BSDFs of the corresponding leaves, then ray intersections are calculated in the same way as in first step. As an example, BSDFs of maize leaves were measured and modeled at wavelength of 650 nm and 830 nm respectively. The distribution of light within maize canopy at these two wavelengths was simulated separately with 5 different solar angles. Factors affecting the distributions of light scattered by leaves within the plant canopy were discussed.

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(O) - **Modelling plant-plant and plant-pathogen interactions with the plant growth model PLATHO**

Sebastian Gayler and Eckart Priesack

Competition between plant individuals for the local resources light, water, and nutrients is a critical process for plant growth in natural and managed ecosystems. Moreover, allocation of plant internal resources to growth-related metabolism and to defence-related metabolism is determined by plant internal competition for common substrates and energy, because resources required to support maintenance, growth and defence are limited, and the total demand for these processes cannot be met in most cases. Resource allocation on the whole plant level can therefore be interpreted as a trade-off between the ability to compete with other plants and the ability to defend against pathogens. From this follows the hypothesis that an increase in growth and competitiveness leads to constraints on parasite defence.

Based on this hypothesis, the plant growth simulation model PLATHO was developed within the framework of a research project, where effects of biotic and abiotic factors on resource allocation to growth and parasite defence were investigated on different scales and for different plants from agronomy and forestry.

PLATHO is a comprehensive process-based model that simulates plant growth depending on climatic conditions and availability of external resources such as light, water and nitrogen. The model comprises a new approach to simulating allocation of carbon and nitrogen to different plant internal pools, including defence-related carbon-based secondary metabolites. It estimates competition effects within pure and mixed canopies based on competition coefficients resulting from the overlap of occupied crown and soil volumes of neighbouring plants.

The parameterisation of the model was done with data from phytotron experiments with juvenile beech, spruce and apple trees. PLATHO was used to analyze the effects of different N fertilizer applications, atmospheric CO2 concentrations and canopy densities on growth of plants and allocation to carbon-based secondary metabolites. Scenario calculations were performed to quantify consequences of the “compound interest effect” of the defence trade-off on competitiveness in longer time periods.

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(O) - **Impact of P deficiency on biomass partitioning and root system architecture**

Zhang Qian, Zhang Bao Gui

In order to elucidate the influence of P deficiency (P-) on biomass partitioning and root system architecture, the biomass of aerial and root system, leaf surface area, and root system architecture were measured on winter wheat (Triticum aestivum L.) seedling grown on sand culture in a greenhouse. The duration of P- was 4 weeks starting just at emergence.

The results showed that P- retarded the plant development, with a phyllochron of about 129 Growing Degree Days (GDD) per leaf for P- plants and 83 GDD/leaf for the control. The water content of plant and the leaf final length were also reduced by P-. Compared at the same thermal time, the leaf surface area and biomass (both fresh and dry matter) of P- plants were significantly reduced; but if compared at the same leaf number, the dry matter of shoot and blade of P- plants were greater than those of the control plants. Similarly, when the total root length and root apex number were compared at a given thermal time, there was a significant reduction in P- plants, but the proportion of length or apex number of the main roots, lateral roots of first and second order in the root system remained relatively stable. Only the density of first order lateral roots was reduced by P- treatment. The total root length and number per unit leaf area were greater in case of P deficiency. We concluded that the development, fresh weight, and leaf area were most sensitive to P deficiency, while the root system architecture was rather conservative.

(O) - **Some hypothesis on the biomechanical adaptation of root structure based on numerical analyses of root-soil mechanical interaction**

Ji Jinnan, Fourcaud Thierry, Zhang Zhiqiang

Modeling of root growth is a very complex task as the root system morphology is highly influenced by the soil medium (Pages, 2002). It is in particular well known that mechanical constraints applied to trees can significantly modify the growth of their structural roots from both the topological and geometrical point of view (Stokes and Guitard, 1997). Such a biomechanical adaptation of root growth results in a better ability of the tree to resist uprooting (Danjon et al., 2005).

This numerical study aims to investigate the influence of soil mechanical characteristics on stress distribution in roots and on the resistance of the root system to uprooting. Preliminary computations have been performed on schematic 2D root patterns using the Finite Element model developed by Dupuy et al. (2004). Pivoting of the root system was simulated by applying a lateral force on the tree trunk. The effect of removing particular structural elements, i.e. lateral roots or part of the taproot, on the root-soil mechanical state has been analysed in both cohesive and sandy soils. Results and hypothesis on the biomechanical adaptation of root structure have been given with regards to the following output: 1- root system strength; 2- position of the root-soil plate rotation axis; 3- distribution of von Mises stresses at the surface of root elements.

In the future, stepwise mechanical analyses could be implemented in process based growth models in order to simulate the biomechanical adaptation of roots following the previous work carried out by Fourcaud et al. (2003).

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(P) - **3D Forestation Simulation Based on Direct 3D-Interaction**

Wang Zhangang, Zhuang Dafang, Qiu Dongsheng

3D forestation simulation based on direct 3D-interaction representing realistic forest scenes provides a useful tool for planning and design in forest management, allowing us to dynamically change silvicultural scenarios into realities. The paper introduces several key techniques for forestation simulation through direct 3D-interaction.

3D modeling of the terrain and trees is the basis of the forestation simulation. For the sake of better viewing and higher system efficiency, this paper uses the TIN model to build the terrain and image model to display trees. Tree modeling is based on billboard technology, which can dynamically adjust its direction and angle according to user's view.

The man-machine interaction is an indispensable part of visualization system. Direct 3D-interaction is adopted in the paper for dynamically selecting the forestation area and style. The key problem of 3D interaction is to find the relation between the 2D coordinates on the computer screen and the spatial 3D coordinates. An algorithm is given which realizes 3D dynamic border demarcation of the forestation area by mouse. According to the selected area, trees are planted in the appropriate style through real-time rendering.

The specific rules are presented which determines the 3D visualization result of forestation. The main rules include tree space, tree layout, planting border disposal and the rules adjusting tree position.

According to the key techniques and important rules mentioned above, a prototype system has been developed to evaluate our methods by choosing Visual C++ 6.0 as software development tool, Multigen Creator 2.5.1 as 3D model building software, and Vega 3.7.1 as visualization engine. The demonstration area is the Lasa District in Xizang province.

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(P) - **Research of Dynamic Monitoring of Land Use Based on Remote Sensing and GIS**

Lu Ke, He Ning, Zhang Peng

In this paper, we will produce a land utilization map (including agrarian, forest, and pasture) by interpreting historical Landsat images of a semi-drought area in the middle of NingXia in China. The land utilization changes and statistical data of this three-layered map can be obtained with time-space analysis. The goal of this research is to effectively manage land utilization data, to provide scientific and detailed data in time, and to provide a technical basis for land utilization blueprint decisions and fundamental agrarian protection. Following then, implementing agrarian dynamic balance should be possible. The accomplishment of this research will provide a decision basis for water and soil use in the upper-middle regions of the Yellow river, environmental protection and surveillance of returning farmland to forest in the 8 counties in the middle of Ningxia. It will surely provide a basis to return farmland to the forest in the west of China.

(P) - **Study on Methods of Digital Design of Crop Structure**

Su Zhongbin, Zheng Ping, Meng Fanjiang, Jia Yinjiang

The structure of crop plants is one of main effects influencing plant resource acquisition and yield. This paper gives the methods and principles of plant breeding digital design, given that it is hard to meet the needs of precision agriculture for the plant breeding design in a traditional field. The methods are performed with a three dimensional digital system, focusing on virtual plant functions and a structure feedback mechanism. The digital expressions of the crop plant reveal the corresponding relationships of function, structure and yield. In the point of view of precision agriculture development, it is significant for research of this kind to provide new research methods and thinking patterns for plant breeding of high yield.

(P) - **Development of Growth Model-based Decision Support System for Crop Management**

ZHU Yan, CAO Wei-xing, Ye Hong-bao, TIAN Yong-chao, YAO Xia, LIU Xiao-jun

Crop growth models and decision support systems can be used as a tool to help optimize crop management strategies and as research tools to evaluate the potential productivity and assess the impact of climate change on crop production. By adopting the characteristics of object-oriented and component-based software and with the effective integration and coupling of the growth prediction and decision-making functions, the growth model-based decision support system for crop management (GMDSSCM) has been developed on the platform of Visual C#.net. The system integrates process models of four different crops including wheat, rice, rapeseed and cotton and includes a decision support function, thus facilitating the simulation and application of the crop models for different purposes. The individual models each include six sub models for simulating phasic development, organ formation, biomass production, yield and quality formation, soil-crop water relations, and nutrient (N, P, K) balance. The implemented system can be used for evaluating individual and comprehensive management strategies based on the results of crop growth simulation under various environments and different genotypes. These GMDSSCM systems have realized dynamic prediction of crop growth and decision making of cultural management, and thus should be helpful for construction and application of an informational and digital farming system.

(S) - **Software development on Inteligent Expert Decision System for Tomato Production Management in Solar Greenhouse**

He Chaoxing, Zhang Peixin, Zhang Zhibin, Wang Huaisong

Tomato plants are one of most important crops cultivated in Chinese solar greenhouse. In order to precisely manage and provide decision-making support for tomato production, a long season tomato simulation system was designed which adopted VC++ 6.0 as a design language and programmed methods based on the Windows programming platform to develop a long season tomato simulation supervisory system. Microsoft access data bases were used to store environment parameters such as air temperature and humidity, by use of PDT(physilogical development date) and an environmental database, the harvest data and yield of tomato fruits can be deduced and forecasted in the advising system, so the system will have good information to improve tomato long season yields in-greenhouse. The system also can be used to prevent disease according to the parameters of the environment in the greenhouse.

Environmental factors in-greenhouse have much more effects on protected vegetables growth; temperature may affect plant development stage, whereas high humidity may have effects on disease. Theory predictions were usually used in simulation models or expert systems. Real environmental factors change dramatically in greenhouse from month to month, so it is difficult to predict plant growth. In this paper, a year-long temperature and humidity database was created by integrating 4 years of data in the same solar greenhouse. When the temperature database was used in the vegetables expert system to predict plant growth, we could get great similarity between theoretical value and real value. So, it is a very useful database for vegetable modelling and creating a management system. The results showed that measurement values were highly comparable with simulated values, so the database can be used in a vegetable management system to prevent growth stages in Chinese solar greenhouses.

The system software can deduce and forecast tomato growth, tomato harvest date, and the relation between plant diseases and insect pests and environmental temperature, humidity, and effective accumulative temperatures; which we integrated with environmental factors in greenhouse and tomato growth and development period based on calculating effective accumulative temperatures of tomato. It will achieve precise and intelligent management for tomato production in greenhouse. With the expert research data and computer application, the system will provide good information to extend tomato yield in greenhouse.

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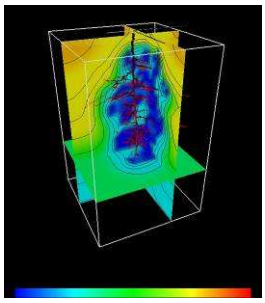
(S) - **PlantVR: Software for Simulation and Visualization of Plant Growth Model**

Somporn Chuai-Aree, Suchada Siripant, Willi Jäger, Hans Georg Bock

PlantVR is a software tool for simulation and visualization of a model for plant growth such as the growth of leaves, shoots and roots. This software can generate the plant leaf vein, shoot, and root structures based on Lindenmayer systems (L-systems) and a particle system dependent from their environmental factors. There are two methods for generating plants in PlantVR. The first method uses L-systems, based on PlantVR's syntax. In order to create the plant structures in an easy way, the particle system is provided in the second method which is designed to generate leaf veins, plant shoots, and roots. Their growth depends on their environmental factors. For example, leaf growth is based on auxin distribution in the leaf blade, while shoot growth is based on the sunlight and available volume space, and root growth is based on the available water, nutrient, and volume space in the soil. The software allows the user to expand from a single plant to an entire crop. The user can export the results to an animation file and display their growth at each time step. Some results of the PlantVR software are shown below.

(a) plant crop



(b) root growth

(c) simulated leaf vein

(d) four steps of plant growth with simulated leaf vein based on particle system

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(S) - **Image based real-time and realistic forest rendering**

Olivier TEBOUL, Xiaopeng ZHANG

Real-time and realistic rendering of a big forest is a challenge in computer graphics and virtual reality. The complexity of each tree model and the number of trees included overwhelmed the capacity of a computer in rendering cost and memory cost. In this paper, we developed a new image-based approach for real-time and realistic forest rendering with the software "ImageForest". This tool takes advantage of the texture mapping power of modern video cards. It can be used for landscape visualization, for the simulation of a walk-through in a forest, and for the simulation of a flight over landscapes.

A popular way for image-based rendering is billboarding with an illusion of using 2D images to represent a 3D object. Its advantage is to tremendously reduce the number of polygons through a conversion to textures. The drawback of a billboard is its week parallax for close viewing, and the drawback of a single billboard is that the illusion vanishes as soon as the billboard is seen from above. One difficulty of billboards is a mixture of alpha blending with depth buffer for a correct hidden removal, and with stencil buffer for shadows.

We use three cross billboards, i.e. three static orthogonal rectangles, to represent the geometry and material of a tree, so that it looks like different 3D aspects of the same object from different viewing directions, i.e. week parallax is avoided. Trees are rendered through alpha blending and depth blending to realize a correct transparency and hidden removal. We use stencil buffer for shadows on the plat ground of each tree with a mixture of shadow on the grass texture. In order to avoid the effect of object torsion due to poor image direction nearly orthogonal to the viewing direction, different textures are chosen on the viewing direction and the lighting direction. Frustum clipping is performed for rendering acceleration. Sorting from far to near is performed to avoid improper transparency on image silhouette pixels due to texture image resizing from automatic mipmaps. Therefore, a real-time speed and realism in shading and shadow are all kept. We acquire billboard images from our work on multi-resolution plant and realistic rendering, so the final rendering result of the forest is rather realistic in Figure 1.

The efficiency of this software is shown with 16888 trees using cross billboards. We have two snapshots to show the realism. This work is supported by National Natural Science Foundation of China under Grant No. 60073007, 60473110, 30371157; by National High-Tech Research and Development Plan of China under Grant No. 20060101Z3027; by the French National Research Agency within project NATSIM ANR-05-MMSA-45.

Fly over a forest at sunset

Fly over a forest at noon

Figure 1: Walk in and Fly over a forest

– SESSION 4 –

Application of Plant Growth Models in Agronomy

(K) - **Application of plant models to Agronomy**

Yan Guo

While the world population is dramatically increasing, arable land is decreasing significantly in developing countries such as China. As a result, food security is and will be a primary concern, especially for developing countries with huge population and limited arable land resources. To sustain food supplies, it is urgent to conduct research towards a second green revolution, which will build high crop yields by means of developing super-high yield varieties and optimizing management practices. Plant models, such as the functional-structural model GREENLAB, have the potential to provide robust tools for designing crop ideotype and best management regimes.

A functional-structural plant model is built up by integrating eco-physiological knowledge and plant structural growth dynamics. It can be used to simulate the resource acquisition, biomass production and partitioning in plants at organ, plant, and plant stand levels. Thus it can be used to design and optimize the morphological traits for new crop varieties so that they can capture sunlight more efficiently. Developing countries, such as China, are facing the problems of irrigation water shortage, low soil fertility, and abuse of inorganic fertilizers, pesticides, and herbicides. Optimized field management regimes are required to solve these troubles. And these management regimes can be achieved with simulation by plant models, which incorporate the function and structure of a plant's aerial part and root system, coupling with soil-water and solute transportation models.

(O) - **Hybrid-Maize: A simulation model that meets the demands of diverse users and their applications**

Yang, HS, Cassman, KG, Dobermann, A and Walters, DT

Crop simulation models are becoming increasingly important as a tool to support scientific research, classroom teaching, extension education and commercial agriculture. Different model applications and users have different demands with regard to model user interface, input requirements, output format, documentation, and technical support. We developed the Hybrid-Maize simulation model (Yang et al, 2004a, 2006) for use by scientists, higher education teachers, extension educators, industry professionals, and farmers. Hybrid-Maize was developed by "hybridizing" the two major approaches in maize modeling: plant physiology-based generic description of plant growth processes (Spitter et al, 1989), and maize-specific empirical description of maize development (Jones and Kiniry, 1986). The model has been validated in high yielding environments in the US Corn Belt (Yang et al, 2004b) and various other countries. It runs on daily time steps and requires daily weather data, including solar radiation, high and low temperature, rainfall, air humidity and maximum evapotranspiration. The model software features intuitive and flexible input options, comprehensive tabular and graphic simulation outputs, and result analysis. The software comes with complete documentation of model formulation and validation. All key model parameters are transparent and modifiable with the option of restoring them to default values. Utility programs are provided in the software to streamline capture of weather data from online sources, their subsequent conversion and reformatting, as well as checkup for suspicious data entries and missing values. The program also has a context-sensitive help system and a comprehensive user's manual with examples of applications. We have developed a dedicated website (www.hybridmaize.unl.edu) for the program and have regularly provided hands-on training workshops to new users as well as advanced users. The model is being used by progressive farmers and crop consultants to improve crop management decisions, and by researchers to estimate yield potential at field research sites as a yardstick for assessing performance of experimental treatments.

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(O) - **Evaluation of functional-structural model GREENLAB-Maize with sparse experimental data**

Yuntao Ma, Meiping Wen, Yan Guo, Baoguo Li, Paul-Henry Cournede, Philippe de Reffye

Simplification of field measurement is an important step to facilitate the application of GREENLAB. But the effect of such simplifications on the accuracy of parameter values must be quantified in order to define to what extent and in which sense simplifications are valid. This study introduces a new methodology for model parameter optimization using multi-fitting technique with a sparse data set, evaluates the effect of simplifications on the parameters, and validates the calibrated model for maize with four independent field data.

The results show that multi-fitting with sparse data sets (including 3 growth stages of which the first two are at compartment level and the last one is at the metamer level) can provide the same accuracy of parameter values as fitting with the complete data set, and respect as well the shape of sink variation functions. Parameter values optimized with the sparse data set of the year 2000 were used to simulate plant growth under 4 different climate regimes. Excellent predictions of plant architecture and biomass were obtained. The bias between the observed and simulated values may be due to imperfections in the modeling of cob sink development and leaf senescence. Model outputs are automatically converted to 3D representation for each simulation time step which can be used to calculate precise light interception and energy balances.

This kind of simplification significantly reduced the time required for measurements on the plants and could open the way for the application of GREENLAB (e.g. in the analysis of a large number of genotypes together).

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(P) - **A Web-based Simulation System for Greenhouse Crops**

Chu Jin-xiang, Sun Zhong-fu, Du Ke-ming, Wang Ying-chun, Liu shuang

On the basis of TOMSIM, web techniques, and Object Oriented Programming (OOP), by using of the ASP.NET framework and Visual C# language, a web-based simulation system for greenhouse crops were designed, which can be used to simulate the growth of greenhouse crops such as tomato, cucumber, etc. The optimal environmental parameters in the greenhouse control system can be obtained by calculation from the simulating system. By this way, countermeasures can be used more precisely according to these environmentally calculated parameters. Graphs of the crop's growth for its entire lifetime can also be drawn out with the simulation system. It makes observing the whole crop growing process more convenient. Meanwhile, a sub-model of water and nutrition was added to the simulation system to help understand its influence on crop growth.

Key Words: Web techniques, ASP.NET, Crop model, Crop simulation system, Greenhouse control

(P) - **Simulation of the effect of the amount and distribution of soil mineral nitrogen on wheat yield and grain N concentration**

Jan Haberle

Economical and ecological concerns stimulate farmers to seek new approaches to fine tuning of nitrogen fertilization. Grain quality parameters of cereals, greatly affected by N nutrition, play a key role in reaching a high net profit. Crop models may provide information helpful in manipulating and improving nitrogen uptake and utilization efficiency by better synlocalization and synchronization of mineral nitrogen supply and demand by crops. It is even more urgent in low-input and other alternative systems.

The objective of the study was to evaluate the effect of available mineral N (Nmin) distribution in a soil profile on yield, grain N concentration and amount of residual N after harvest with the help of a model. The effect of alteration of root growth rate and maximum rooting depth on simulated Nmin uptake distribution was examined as well.

The CERES-Wheat model (v 4.1, Hoogenboom et al. 2003) was calibrated and validated with data from field experiments with winter wheat in the years 1995-2005. In the experiments one or two cultivars of wheat were grown at two or three levels of nitrogen fertilization, in the years 2001-2005 an increased Nmin supply in subsoil was induced. The field is Chernozem clay-loam soil on loess in Prague-Ruzyne, the Czech Republic (50° 05´ N, 14° 19´ E), altitude 340 m a.s.l., average precipitation and temperature (1961-90): 477 mm per year and 7,9 ^{o}C, respectively. Phenology, growth, yield formation, N uptake and allocation, root distribution and water and nitrogen uptake from top- and subsoil layers were observed (Haberle et al., 2006, Svoboda et al. 2006). The model reasonably simulated growth, yield, and N uptake in most years.

The calibrated model was used to simulate the effect of different amounts and distributions of Nmin in a soil profile at the start of a main growth period at early spring on N uptake and grain yield in 40 years. Different N fertilization schemes, representing low N input, high “assurance” doses, and N rates considering Nmin distribution were analysed. Also, the effect of variation of root growth rate and rooting depth was evaluated in respect to depletion of N from soil zones.

The results showed how different distributions of available N affect growth, yield formation, and grain nitrogen concentration. As expected, the effect of Nmin distribution and also the change of roots traits were more pronounced especially under low Nmin supply. The effects reflect trade-offs among yield components during growth. A high content of Nmin in arable and shallow subsoil layers favoured yields but without satisfactory grain quality due to unsatisfied demand for N, while increased content of Nmin in subsoil layers enhanced grain N concentration at the expense of lower yields. When total Nmin content in the rooted soil profile is high, considering a Nmin distribution in fertilization scheme may reduce the amount of residual N after harvest without risk of impairing grain quality. The results suggest it is possibile to manipulate grain quality to some extent under specific Nmin distributions.

This study was supported by projects MZE QF4176 and MZe 0002700601.

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(P) - **Determination of Crop Water Use and Crop Coefficient of Corn Silage Based on Crop Growth Stages**

M. E. Asadi and M. Gheysari

Crop water use and crop coefficients are required for implementing irrigation scheduling and practicing proper irrigation management. Crop coefficients of some crops have been reported by FAO only for four growth stages; namely initial, development, middle, and late stages. Crop coefficients are affected by many factors including soil, irrigation management, climatological conditions, and growing season. The objective of this study was to determine crop coefficients based on growth stages and to measure crop water use of sprinkler irrigated corn silage in one semi-arid region of Iran. The corn crop water use was determined by monitoring soil moisture in 24 filed plots up to the depth of 180 cm. Daily reference evapotranspiration was estimated by the FAO-penman-monteith equation. Various mathematical relationships were developed to estimate the corn crop coefficient and "the ratio of corn water use to pan evaporation" as functions of "days after sowing", "growing degree-day", and "leaf area index" with coefficients of determination ranging from 0.8 to 0.93. The corn crop coefficients for initial, development, middle, and late stages were found to be 0.59, 1.06, 1.15, and 0.8, respectively. The extreme values of the ratio of "corn water use to cumulative pan evaporation" were 0.39 for initial stage and 0.88 for middle stage. The cumulative corn crop water use during the 90 day growing season according to the soil moisture volume balance was 635 mm. However for the same period, the corn crop water use was estimated by the FAO-PM equation to be 668 mm.

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(P) - **The Development of a Dynamic Information Management System for Maize Based on GPS, GIS**

Guifen-chen, Yueling-zhao, Shengshen-wang, Guowei-wang

Global satellite position system (GPS), the geography information system (GIS) and the expert system (ES) techniques are important techniques supporting digital agriculture. The application of DGPS, GIS, ES, and the database technique are studied in this paper, which realizes intelligent precision management systems for the maize digital information in Jilin province. The paper elaborates on how the dynamic information system is developed with the control component of Map Objects (MO), besides the functions and the methods of the system. We use technology to manage the agriculture information and deal with the spatial relationships. In short, we formed a dynamic link between the attribute and spatial database in the system.

(P) - **Assimilation of crop architecture models and canopy spectrum data in winter wheat**

Wenjiang Huang, Chunjiang Zhao, Jihua Wang, Liangyun Liu

Simulation models are established for the leaf shape factors, the vertex of a single leaf in space, the cumulative projected leaf area at intervals of the height, the interspace direction and leaf angle distribution. The consequent system of the models can be used to precisely calculate the cumulative projected leaf area for the interval of the height, and used as the integrated evaluation indicator of the structure characteristics.

An assimilation system was established based on a crop architecture model and canopy spectrum data. Canopy structure parameters are quantitatively described for winter wheat in this paper, this system could make visualization computation on wheat populations according to the assimilation models of growth models, morphological architecture models, geometric mathematic models and remote sensing derived data. It also could describe geometry form and configuration changes for the output of morphological and topological structure in wheat and to form the crop management decision models based on the wheat architecture models and canopy spectrum data.

(O) - **Fitting weight of individual organs in spring wheat using the GreenLab model**

MengZhen Kang, Jochem B. Evers, Jan Vos, Philippe de Reffye

Traditionally, in crop models, assimilate production and partitioning are described with empirical equations. In the GreenLab functional-structural model, however, allocation of carbon to different kinds of organs is computed from the summed sink strength of all growing organs in the crop structure. In this model, the temporal unit is the phyllochron, corresponding to the spatial unit, the phytomer. Development of organs is simulated with an automaton, parameters of which are deduced from the tillering pattern (timing of appearance, number of leaves and elongated internodes in tillers of different orders). In each cycle, all growing organs share the growth substrates according to their relative sink strength. From the dry weight, the sizes of organs can be computed, the most important being leaf area. Biomass production in each cycle is based on the Beer-Lambert Law. Although the aim of current study is to simulate dynamic tillering and plant production under different climate conditions, in this paper, we first present the calibration results using the GreenLab model and experimental data of spring wheat cultivar Minaret, collected in a climate chamber. Four harvests were done on six plants to collect the size and weight of individual organs, including the root system, leaf blades, sheaths, internodes, and ears of the main stem and different tillers. Leaf status (appearance, full-grown and death) of these 24 plants was recorded every two to three days. A nonlinear least square root fitting procedure minimized the difference in weight of the organs between measured data and model output, giving the hidden parameters (sink strength of organs of each type and each tiller order, and two empirical parameters linked to transpiration per unit area and effect of mutual shading of leaves) of the model. The weight of all measured organs in two plants at each harvest were fitted at the same time. The simulated LAI and dry matter partitioning from the calibrated model were close to the experimental results. However, for adequate modeling, the mechanism of tiller death and degeneration still needs to be fully understood. Future work will focus on the relationship between plant population density and both tiller bud outgrowth and tiller death.

(O) - **Phenological approaches to support adaptation and modeling for prediction of essential oil production and quality as total Geraniol content of Cymbopogon commutatus (Steud.) Stapf**

A.K. Shahi, M.K.Kaul and S.Chandra

The essential oil yielding genus Cymbopogon belongs to the family Poaceae and tribe Andropogonae. The genus comprises about 140 species that are distributed in semi-temperate parts of tropical areas of Asia, Africa and America. Forty-five species are found in India either indigenously or introduced from other places (Khanuja et al, 2005). Understanding the growth and development as influenced by environments is vital to understanding the relation between environmental indices, energy indices representing degree days, Phenothermal index, pan evaporation, photo-thermal unit, heliothermal units, potential transpiration, photosynthetically active radiation (PAR), etc. Models have been developed to interpret crop-weather interactions and its impact on essential oil quality and quantity of a citral-yielding elite strain of Cymbopogon citratus (DC) Stapf. (Shahi, et al, 2005).

The occurrence of geraniol and geranyl acetate as major chemical components have been found in the essential oil of Cymbopogon commutatus (Steud.). Stapf was separated through GC and GC-MS, following a mass selection technique, and a solution of □80% geraniol has been selected and coded as RL (J) CC1. Phenological analysis has been studied by way of quantifying the growth response coefficient (b) values of morpho-economic characters, which was 1.0, signifying its good adaptability under a subtropical environment. Leaf (foliar growth) adaptation has been quantified as phyllochron which exhibited 519.60 and 775.61 degree days for the production of a single natural leaf during the 1st and 2nd harvests, respectively. This is termed the phyllothermal response coefficient (b), exhibiting more sensitivity during 2nd harvests shown by the comparatively higher value. Floral adaptation was quantified as the photoperiod response coefficient b = 412 (□C day/hour) between degree days and day length. Based on two years pooled observation (2001-2002), regional crop models have been developed for prediction of essential oil production and its percent geraniol content by using the most-efficient energy indices viz., phenothermal index and thermo/photo ratio either singly as linear regression equation or jointly in multiple regression equations along with essential oil production and validation by the correlation coefficient (r) and index of agreement (d) between predicted and observed values. These are as below:

$$YTG(I) = -24.950 - 6.227 \times \text{oil (g/plant)} + 68.915 \times \text{Thermo/photo ratio} + 3.838 \times \text{phenothermal index}$$

$$YTG(II) = -85.38 - 9.874 \times \text{oil (g/plant)} + 100.415 \times \text{Thermo/photo ratio} + 4.571 \times \text{phenothermal index}$$

where,

YTG(I) = Total geraniol content (%) of 1st harvest
YTG(II) = Total geraniol content (%) of 2nd harvest

The phenological model quantified the optimal values of essential oil production along with the phenothermal index and thermo/photoratio of each harvest to produce better quality and quantity of essential oil, which has been based on growth stages. This work also helps to support harvest management decisions.

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(O) - **Study on Application of Cotton2k Model in Cotton Growing in Xinjiang, China**

Zhou Ke-fa Sun Li Chen Xi Zhang Qing LUO Yi Ouyang Zhu

The Cotton2k model is improved in the aspects of saline or alkaline content, plastic film for covering young plants, time input, output forms and allowance to high-level users to update the parameters based on GOSSYM model, the explanation about the mechanism of drip irrigation process is lengthened, the cotton growth under drip irrigation can be accurately simulated, and the model can be more effectively used in cotton production management under irrigation conditions in arid areas. Cotton2k model is used to make decisions about cotton growing and management at normal growth stages of cotton, so cotton growth at all the growth stages can be predicted. The model can be commonly used to simulate the growth of all the organs of cotton plants, predict the phytophysiological stress of cotton, and provide the scientific data for management systems.

Cotton2k is a dynamic simulation model, and can be used to simulate the growth and yield formation of cotton at a phytophysiological process level. In this study, the simulated results of the morphologic growth and the weights of the dried organs of cotton plants during cotton growth in north Xinjiang before and after improving the model are compared and analyzed. The results are as follows: (1) Before improving the model, the simulated results of cotton plant heights are quite different from the measured data, but they accord with well after improving the model; (2) Before improving the model, the simulated results of weight of all the dried organs of cotton plants accord basically with the measured data except that of dried leaves, but they accord with basically after improving the model.

These reveal that, in modifying the parameters of Cotton2k, the simulation of mineralization and nitration of nitrogen in soil is modified, and the modules of nitrogenous fixation and urea hydrolysis under denitrification and high C/N are increased. Moreover, the effect of nitrogen absorption of cotton plants on their growth is simulated by the Michaelis-Menten equation, the nitrogenous stress factors are calculated, and the effects of nitrogenous stress on cotton growth, aging of cotton leaves and bolls, and shedding of young bolls are simulated. In phytophysiological aspects, the growth of cotton leaves, leaf stalks, seed-wool and young-boll rinds are separately simulated with the improved cotton growth functions, and the subprograms of aging and shedding of cotton leaves, young bolls and bolls are completely modified. Other simulated results are also ideal, especially the simulated results of dry weight can be regarded as the basis for diagnosing irrigation and fertilization conditions in agriculture management.

– SESSION 5 –

Application of Tree Growth Models in Forestry

(K) - **Models for Forest Ecosystem Management, a European Perspective**

Hans Pretzsch

Initially the concept of Forest Ecosystem Management will be sketched. Then five paradigms of forest ecosystem management are revealed: Multiple use forestry, dominant use, environmentally sensitive multiple use, the ecosystem approach, and ecoregional management. These paradigms do not follow upon each other in a chronological order, but reflect states along a continuum. Since the early years, forest research followed and developed these paradigms by delivering models: maps and early experience tables, growth and yield tables, individual tree simulators, biogeochemical models resp. other process based models, and landscape models. They serve as tools to instill scientific knowledge into the decision process of forest ecosystem nanagement. Due to the longevity of trees and forest stands, new management options or questions can hardly be analysed by experiment in a reasonable time. The strength of the models is that they display „in quick motion“ the consequences of management options and answer „what if-questions“ by means of scenario calculations. The concept of Forest Ecosystem Management and the potential of simulation models is obvious. However, models still play a minor role at the round table in practical forest management. There are still some severe bottlenecks to geting the models accepted and to make good use of them; a number of obstacles, challenges and current solutions are discussed.

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(O) - **Determinants of diameter growth of current-year and one-year-old shoots in Betula platyphylla in Hokkaido, northern Japan**

Kiyoshi UMEKI, Akihiro SUMIDA, Tatsuyuki SEINO, Enmi LIM and Tsuyoshi HONJO

To model developmental processes of tree architecture, a considerable number of studies have been made on extension growth of stems and their branching pattern because they determine the overall structure of individual trees. However, diameter growth of stems is also important because it affects water transport and mechanical stability. In many tree models, stem diameter has been incorporated as a function of stem length (e.g. allometry) or the number of leaves (e.g. pipe model) without strong supports of empirical evidence.

To examine what factors determine the diameter of shoots (here, a shoot is defined as a segment of a stem that originates from a bud and grows in one season), we analyzed data taken from 49 saplings of Betula platypylla in Hokkaido, northern Japan. We used the generalized linear model (GLM) to relate the diameter of shoots to structural and environmental factors at the shoot, first-order branch (branch attached directly to the main trunk; hereafter, branch), and individual level. The response variables examined in GLM were the diameter of current-year shoots at the shoot base, and the diameter of one-year-old shoots at the shoot base and tip. The explanatory variables at the shoot level were shoot length, the number of leaves in a shoot, and the length of parent shoot. The explanatory variables at the branch level were light intensity at each branch and the height, length, angle, and age of the branch. The variable at the individual level was the maximum light intensity within an individual.

The GLM showed that the most important factors determining the relationship between the diameter and length of a current-year shoot were light intensity of the branch and the maximum light intensity within the individual. The relationship between the diameter of current-year shoots and light availability seems reasonable because current-year shoots bear leaves which capture light and conduct photosynthesis. The strong effect of the maximum light intensity within individual on shoot diameter suggests that there is an individual-level control on shoot diameter. The most important factors determining the diameter of one-year-old shoots were the branch height and the number of leaves in offspring shoots of the one-year-old shoots. This indicates that water transport to offspring shoots becomes more important than light availability as shoots age.

When functional-structural tree models are built and they are scaled-up to the stand level to estimate stand functions such as production, these patterns should be incorporated in functional-structural tree models.

(O) - **Stable foliage cluster (FC), a basic unit of the crown structure of tree species and its application to modeling of tree and forest structure**

Akihiro Sumida and Kiyoshi Umeki

Forking structure of branches enables trees to quickly occupy space to compete with neighboring trees and exponentially increase the amount of leaves. However, in closed canopies, there is very little space for tree crowns to exponentially expand. In such situations development of new branches is maintained by forming a "stable FC (foliage cluster)".

Stable FC is an objectively and concretely definable module composed of yearly shoots several years old. Once a stable FC is formed, it can keep a stable size (stable amount of leaves and twigs) with a constant turnover time of several years, while a forking branch structure is maintained inside it (Sumida & Takai 2003). Based on an analysis of the real branching structure resulting from birth and death of yearly shoots, we modeled development of stable FC for a deciduous oak (*Quercus serrata*), and found that a stable FC was formed within 5 years after a growth from a single current-year shoot on a branch (Sumida & Takai 2003).

Here we show several properties of FC in the light of its applicability to modeling of the tree/forest structure development. We first demonstrate how the size and structure of a stable FC vary within a species. In the branches sampled from top canopy of three *Q. serrata* trees, the ramification ratio of the twigs within a stable FC was 2.6 per shoot-age on average, and the turnover time of a stable FC was in most cases 5 years. This suggests that the turnover time of the stable FC is almost constant while the size of stable FC may slightly vary according to local conditions of branches. The result also suggests that stable FC corresponds to the structure of clustered leaves that appear on a crown.

We further show how the size and structure of a stable FC may vary between species with different branching morphology (e.g., acrotony/ basitony/ apical control). Application to structural development of an individual tree is also considered by modeling development of the first-order branches (branches from the main stem) using FC.

Stable FC can be treated as a basic component of the crown structure alternative to individual leaf or current-year shoot. Modeling of the structure of tree crowns and its development using FC would significantly decrease the load of computation.

Sumida A & Takai Y (2003) Formation of a structure of exponentially forking branches with a steady-state amount of current-year shoots in a hardwood tree crown. In: (eds. T.Sekimura, S. Noji, N.Ueno & P.K.Maini) Morphogenesis and Pattern Formation in Biological Systems: Experiments and Models. pp 247-256. Springer-Verlag Tokyo.

(P) - **Methodology to evaluate productivity and profitability in plantations of Pinus radiata D.DON in Chile**

Pedro Real H., Cristian Higuera C.

A methodology to evaluate different management regimes according to site productivity and economic return is presented. The growth and yield simulator RADIATA Plus developed for commercial plantations of Pinus radiata D. DON in Chile is intensively used in this case.

The silviculture of commercial plantations has evolved toward regimes of high yield and wood quality, with different treatments of site preparation, fertilization and weed control in the establishment stage. In the management stage, different regimes of pruning and thinning are carried out. They differ in their application by opportunity, intensity and severity. The management regimes are aimed at obtaining different products and yields according to the industrial requirements that a particular stand or demands of forest patrimony.

This work presents the methodology of using the RADIATA Plus simulator to evaluate the management of Pinus radiata D. DON plantations in Chile, using different silvicultural and economic configurations. The effect of management regimes is shown in the yield of the plantations and its economic return, caused by establishment techniques and the interaction of these with the silvicultural treatment of pruning and thinning.

(P) - **National Growth and Yield Simulation Project: example of cooperation among private sector and research institutes**

Pedro Real, Roland Peters y Cristian Higuera C.

In November 1987, a first discussion about the state of art of Simulation growth models was prepared. Later a study was conducted to compare the alternatives of a national development versus an alternative model developed abroad. The recommendations of the study ended in 1989 with the creation of a cooperation agreement that merged efforts of professionals of private forest enterprises and those from research institutions. The objective of this agreement was the creation of a National Growth and Yield Simulator for Pinus radiata (D.Don) (pino radiata).

16 years later this cooperative effort is still going on. A national network with more than 100 experimental trials has been established. A strong relationship among the co-operators companies and the research sector was also created. This effort has materialized in a powerful and effective computer planning tool, whose contribution to management and utilization of plantations is invaluable.

The main advantages of this national development are:

1. Formulation of a coordinated research policy regarding the Growth and Yield of pino radiata.
2. Better utilization of technical and financial resources.
3. Creation of a permanent and specialized team that has periodically counted on support from highly qualified foreign specialists.
4. Permanent technical assistance of the project team to the companies, producing the necessary feedback for project development.
5. Entire coverage of the growth zones of pino radiata plantations in the country.
6. Development of a National Model, representative of the Chilean growth conditions, flexible, user friendly and technologically advanced to provide reliable predictions.
7. Design of an optimal network of experimental trials for long and short run management study.
8. Improvement and standardization of the installation methods and measurement of trials.
9. Creation of a National Data and Information Data Bank.

Currently, the research scope has been expanded to the area of establishment and utilization, as well as creating a cooperation group for the development of simulators for the species Eucaliptus globulus and Eucaliptus nitens. For pino radiata, advances have been made from a stand level model to an individual tree and mixed model to improve resolution.

(P) - **Study on RS- and GIS-based Ecological Capital Assessment in Arid Areas**

Zhang Qing, Cheng Xiuwan，Zhou Ke-fa， Chen Xi， Sun Li

Ecological capital assessment is currently one of the important research subjects in the interdisciplinary field of ecology, resource economics, environmental economics and ecological economics. Scientifically assessing ecological capital allows decision-makers to consider the ecological cost of economic development, and is also necessary for sustainable development in arid areas.

From the macroscopic-ecology point of view, based on the use of remote sensing to measure a region's ecological capital, considering the possibility and reliability of acquiring the data, we developed a regional ecological capital assessment index for remote sensing. This paper calculates the total ecological capital from nine kinds of ecological value, such as watershed conservation, water and soil conservation, maintaining the balance of the atmosphere, nutrient circulation, production of organic matter, absorbtion and decomposition of pollutants, maintaining biodiversity, recreation, and other social benefit.

In this thesis, based on the research achievements of the methodology of calculating per unit area ecological service value and with the support of RS, GPS and GIS, the RS-based quantitative measurement of assessing the ecological capital developed by using the Landsat TM data, CBERS satellite data, meteorological data, MODIS satellite data and ecological data, we divided the study site into four ecological districts and assessed their ecological capital index. A case study on the Spatial Analysis of the assessment of ecological capital in Changji Hui autonomous region in 1990, 1995 and 2003 was carried out. Maps of the spatial distribution of ecological capital in the study area were charted, and the characteristics of the spatial distribution of ecological capital were analyzed.

The results show that the total ecological capital indices in the study area for 1990, 1995 and 2003 were $1.47368*10^{11}$ Yuan RMB, $1.6616*10^{11}$ Yuan RMB and $1.77895*10^{11}$ Yuan RMB, respectively. The distributions of the ecological capital reduced from the alpine zones to the plains and from the oases to the deserts, which accords with the distribution of the vegetation zones. The results can objectively reveal the spatial distribution of the ecological capital in arid areas, and can also provide a reference for further studies. The integrated approach of ecology and remote sensing provided a new method to measure ecological service value based on the complete coverage data, and the results can indicate the quality states and the productivity of nature objectively and spatially in an explicit manner.

(P) - **Development of a spatial decision support tool for the management of eucalypt plantations in Congo**

Cucchi V., de Coligny F., Cornu G., Gazull L., Deleporte P., Moukini R., Saint-André L.

Intensively cultivated clonal (纯种的) eucalypt plantations are established around Pointe-Noire (Congo), covering a large area of 42000 ha. Due to topographic constraints, they are spatially fragmented, and divided into several thousand stands planted with more than 150 clones. In this context of a complex structure, forest managers need a decision support tool to assist them in planning the silvicultural operations and exploitation for wood sale. Our aim is to develop a tool to assess wood production by simulating stand growth evolution according to various silvicultural scenarios. Accordingly, a growth and yield model was connected to a Geographical Information System (GIS) which is used as the Graphical User Interface.

The system is based on a dynamic linkage between the EUCALYPT-Dendro chain of models (Saint-André et al. 2002), hosted by the CAPSIS (Computer-Aided Projection of Strategies in Silviculture, de Coligny et al. 2003) software platform intended for forestry modellers and developed in Java, and ArcGIS GIS. The main database shared by all components contains data on eucalypt (尤加力树) stands as inventories, geographical localisation, characteristics and applied silvicultural（森林学。造林学） practices. Starting with a stand inventory, EUCALYPT-Dendro can predict individual or stand basal area and height increments, as well as biomass in each compartment and distribution of nutrient concentration among rings.

On the plantation map displayed on the GIS, the user can select stands and choose parameters defining a given silvicultural scenario to perform a simulation. At the end of the simulation, results predicted by the model are automatically shown by ArcGIS as thematic maps. Using formatted requests, the user can also manage the geo-database, and visualise current information on stands. Then silvicultural operations can be more easily planned. Development of the tool has been done in close cooperation with foresters.

For research, the connection between the growth and yield model and the GIS is also used to calibrate and to validate the model for various clones. In a following step, biogeochemical cycle models will be integrated into EUCALYPT-Dendro to simulate inter-stand interactions, in order to manage nutrient flows at the forest management unit level. In the future this tool will be devoted to questions about the spatialization of ecological phenomena, and the problem of up-scaling from stand scale to range and regional scales, and to suggest strategies to improve sustainability of forest management.

The subject of this publication is to introduce the tool and the technical ways applied to achieve our goal. The communication will be closed by a software demonstration.

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(P) - **Integrated Stand Growth Model (ISGM) and Its Application**

Tang Shouzhen, Hong Lingxia, Li Yongci, François de Coligny, Li Haikui

The Integrated Stand Growth Model (ISGM) is a group of nonlinear correlated models for pure even-aged stands which include the following: 1) basal area growth model; 2) self-thinning model; 3) dominant tree height growth model or site index curves; 4) relationship between average tree height and dominant tree height; 5) form height model and density index definition; basal area formula; stand volume formula. The method of nonlinear error-in-variable simultaneous equations is used to estimate the parameters of ISGM, so the parameter estimation of the group of correlated equations in ISGM is unbiased and the equations are compatible. The ISGM model can be used to simulate pure even-aged stand growth with different values of site index, stand density, or different thinning methods, and to draw stand density control charts with ForStat (Chinese software) and on the Capsis platform (English). This work is supported by National Natural Science Foundation of China (Grant No. 30371157, 60073007, 60473110).

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(O) - **INSIGNE the new growth and yield simulator for Pinus radiata D.DON in Chile**

Pedro Real H., Jaime Sánchez P., Cristian Higuera C., Alfred Krogger

The advances in the development of the growth and yield simulator for Pinus radiata D.DON in Chile are described. The INSIGNE individual tree simulator projects the growth at 0 and 30 years at levels of stand variables, individual tree and mixed. This strategy of simulation allows us to take advantage of the major resolution of the model of the individual tree and the stability and hardiness of the projections of the stand simulations.

The new simulator allows us to realize prunings, thinnigs and bucking in each of the simulated trees, increasing considerably the resolution in the results, especially in forests handled in intensive form. Additionally, it allows the follow-up of the quality characteristics and managing realized in each of the individuals of the list of trees or cohorts.

In the generation of the current simulator there have are proven technologies of incorporation of variance for projections of list of trees; in addition they could have reconciled the projections of both simulators, to generate mixed simulations of long term, which allows us to represent the information of plantations managed intensively with prunings and thinnings.

The simulator in addition will allow us to incorporate the updates of the qualities of each one of the trees, for which strategies of quality simulation were designed for a level of classes of diameter for the stand simulator and of each of the trees of the list for the case of the individual tree simulator. This method of projection will allow us to simulate the qualities of the wood in the forest that will have the industrial uses.

(O) - **Development of a National Data Bank System as a tool to administrate the Data for growth and Yield models of Pinus radiata (D.Don) and Eucaliptus spp. in Chile**

Cristian Higuera , Christian Loayza

Efforts to create a National growth and yield Simulator for fast growing species in Chile began in the 1970's with a series of research programs in institutions related to management and utilization of Pinus radiata (D.Don) (pino radiata o insigne) plantations.

The need to store, recover, analyze and distribute the trials data generated the development of many administration information systems obeying to particular needs of each one of the user or projects. In 1989 a National growth and yield Simulation Project for pino radiata concentrated all the resources and individual efforts in a cooperative action that articulate the development of this research.

The project standardized the sources and formats of the data, as well as the information required for growth modeling of pino radiata and thereinafter of Eucalyptus. Among the steps followed include standardizing measurements and recording processes of the data with a series of technical manuals for forest trials installation and measurement. This by itself produced a better quality of data and by extension a reduction in the administration costs of the data handled by the cooperative member.

Methodology used in the generation of the Data Administration System of the Growth and Yield Simulation Projects of Pinus radiata(D.Don) and Eucaliptus spp. in Chile is described. The system development has also suggested the creation of other tools to support project, companies, and university researchers that use the data originating on the trials. Finally the software solution for the administration of the network trials established is presented.

(O) - **Efficient building of forestry modeling software with the Capsis methodology**

François de Coligny

To predict growth and yield of forests and plantations, forestry scientists often build models. In order to run simulations, these models are then implemented in computer programs. The resulting simulators can be used to run various scenarios, for instance to evaluate the effect of different initial situations (density, age, spatial structure, etc.), to assess various management strategies (number, date and type of interventions) or to study the effect of natural disturbances (gaps, wind, fertility changes, etc.).

Building the software can be difficult. As a matter of fact, forestry scientists are not computer developers and their efforts may result in a software prototype with either poor performance, lack of flexibility or robustness, missing capabilities for connection with other sofware, minimum user interface, etc. It is possible to do better by investing in a platform with the help of computer developers. Various solutions exist, for example with software dedicated to a given model and adaptable to various species, situations or studies (Pretzsch et al., 2002).

The Capsis Platform (de Coligny, 2005 ; de Coligny et al., 2004) aims at being even more generic and accepts a great number of model types : from mono specific stand level or distance-independent tree models to heterogeneous individual based models, spatially explicit or not. Such forestry growth and yield or dynamics models are integrated into Capsis by their authors in co-develoment with a computer developer after a short training and starting session together, according to the Capsis charter (http://capsis.free.fr). This process quickly (in days or weeks) results in a running simulator with a bilingual user interface, customizable outputs (graphs, tables, files, etc.), running on several operating systems (Windows, Linux, Mac OS X...), easily distributable to partners thanks to the Capsis free licence, running in script mode if needed for long or repetitive simulations and connectable to other upstream or downstream simulators. The author then has all the simple tools he needs to continue the development on his own, with technical support when needed.

At present time, Capsis hosts about 30 models, under development or finalized, and 4 applicative libraries related to economics, tree biomechanics, genetics and spatial structures.

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– SESSION 6 –

Analyzing and Modeling Plant Structure

(O) - **Tree Skeleton Extraction from a Single Range Image**

Zhanglin Cheng, Xiaopeng Zhang, Thierry Fourcaud

Tree skeleton extraction and diameter measurement with the help of electrical instruments is of significance in the research fields of geometric modeling and pattern recognition and in the application of forestry and ecosystems. Range scanners can be used as a new tool for assessing the tree geometry. Due to occlusions, data incompletion, and ramification structure, tree modeling from scanned data remains a challenge [4]. Current research focuses mainly on the reconstruction of single trees from multiple scanned data, which might introduce artifacts after registration of these data [2].

We intend to reconstruct the trunk and branches from a single scan of a bald tree (which can be done in winter). The reconstructed model provides information about the skeleton with accurate locations of branches, diameters and length of the tree. Given a single range image of a scanned tree, our method for automatically extracting skeleton and assessing the diameter at every point has the following steps:

Range image segmentation: The 2D range image is segmented based on the detection of edges corresponding to depth discontinuity [3]. The segmentation result is several connected regions, which is equivalent to a three-dimensional decomposition of the point cloud model into a series of consecutive point sets sampled from tree branch geometry.

3D cylinder fitting: In this step, pixels in the range image are regarded as a point cloud in three-dimensional space. We propose a new cylinder fitting method to estimate the local implied shape at each point. This estimation has a linear complexity. The axes and diameters of these cylinders provide accurate information about the skeleton of the tree. The result of this step is a series of 3D skeleton segments, and each segment corresponds to one point cloud patch.

Occluded branches prediction: The skeleton of hidden parts of each branch is predicted through shape analysis. All skeleton segments are connected according to their neighboring relationship, so that the result is a 3D hierarchical skeleton.

3D skeletonization refinement: The hierarchical skeleton obtained above may be not smooth due to discrete skeletonization. We refine the skeleton through least square local curve fitting.

The contributions of this work lie in 2 aspects. 1) Our approach is the first time to use cylinder fitting to estimate skeletons of branching geometry. 2) Our cylinder fitting algorithm is much more efficient than [1] due to an analytic expression of the local shape rather than a recursive approximation. The range images for experiments are generated from the depth buffer images when rendering the branch geometry of a virtual plant from AMAP-Genesis™, on AMAP plant growth modeling research.

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(O) - **Interactive Modeling Trees with Ball B-Splines**

Zhongke Wu, Mingquan Zhou and Xingce Wang

This paper proposes a novel approach to modeling realistic trees with ball B-Splines easily through interactive methods. As ball B-Splines are flexible for modifying, deforming and editing, these methods provide more freedom for users to model trees. These methods can also be used in conjunction with other methods like generating tree models through L-systems or iterated function systems (IFS) such that the models are more realistic and natural through modifying and editing. The method can be applied to the design of bonsai tree models. As the compressed data set of the model represented by ball B-Splines, the model is suitable for transmitting via the internet. Therefore, it can be used for the distributed design of tree models.

(O) - **Analysis of assimilate source and sink forces in Pinus tabulaeformis Carr. using the functional-structural model Greenlab**

Hong Guo, Letort Veronique, Mengzhen Kang,Hong Lingxia, Fourcaud Thierry, Lu Yuanchang

The goal of this paper is to analyze the growth of pine trees (Pinus tabulaeformis) from the structural and functional point of view. For this purpose, the Greenlab model has been used (Yan et al. 2004). This model can deal with both architectural development and physiological processes. It is based on the concept of supply and demand of assimilates by the whole plant organs. This concept is formulated using source and sink force parameters. The analysis of these source and sink forces was carried out by fitting the Greenlab equation on real trees that were measured at different stages of their growth. This analysis allowed simulation of tree growth to be performed using the Digiplante software.

Pine trees (Pinus tabulaeformis) were selected in the open area of Shisanling forest farm in the suburb of Beijing. We supposed that these trees had not been submitted to any stress or competition during their growth and were thus representative of average trees of this species in this area. A complete topological description of the trees was done, including both geometrical and topological parameters. The fitting of the GreenLab model was made using biomass and geometrical data obtained in the spring of 2006. First fitting was performed aggregating the data of branches of order greater than 2 on the order 2 ramification level. Parameter accuracy was evaluated by using the coefficient of variance. The resulting Greenlab parameters were then used in order to simulate and visualize 3D pine trees using the Digiplant software (Cournede and de Reffye, 2005). Results were compared to the original trees.

The work is supported by National Natural Science Foundation of China Grant No. 60073007.

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(P) - **An auto-regressive integrated moving average model for characterising winter wheat root branching**

Chen Y.H. Zhang B.G.

Root branching has been described either as a purely temporal process or a combined tempo-spatially determined process. In order to investigate the influence of interlateral (or inter-branch) distance on the formation of lateral roots, a time series analysis was carried out on the interlateral distances on seminal roots of winter wheat grown in-greenhouse in a sand culture. The interlateral distances could be taken as a time series from root base to apex based on the fact that the formation of seminal lateral roots in winter wheat root follows an acropetal pattern and their number is linearly proportional to thermal time. In this paper we developed an auto-regressive integrated moving average (ARIMA（p,d,q）) model to characterize the root branching.

The first 5 seminal roots of winter wheat were named as following：a_0 for the first root (radicle), and those that appeared successively in pairs were named as a_1,a_2 and a_3,a_4. The original data of interlateral distance is not stationary, so one difference was used to smooth it; after standardization, we got a series of stationary and standardized variables with mean value 0 and variance 1. The moving average (MA) model was identified as the autocorrelation curve was tail-truncated while the partial autocorrelation had a long tail. The optimal order was 1 using the AIC (Akaika Information Criterion) value. Model parameters were estimated accurately with the least squares method. After diagnostic checking, it was found that an ARIMA(0,1,1) model could describe stochastic branching of winter wheat roots. The equation for a_0,a_1,a_2 and a_3, a_4 were respectively: $X_t - X_{t-1} = a_t - 1.0000a_{t-1}$ and $X_t - X_{t-1} = a_t - 0.6948a_{t-1}$.

Since this was the first time that time series analysis was used in the quantitative study of the processes of root branching, the model was rather satisfatory as almost all the forecasted interlateral distance values in the model were within the 95% confidence bands based on the observed values. We concluded that the root branching is determined both temporally and spatially.

(P) - **Analysis of 3D structural root architecture data of trees grown on slopes**

Frédéric DANJON, David H. BARKER, Michael DREXHAGE, Alexia STOKES

Soil reinforcement by plant roots is of primary importance in landslide occurrence in natural slopes or in man-made slopes. Influence of slope on coarse root architecture and potential influence of tree root architecture on shallow-seated slope reinforcement have rarely been studied because of the lack of suitable measurement methods. Three-dimensional digitising in situ and software devoted to plant architecture analysis now provide an efficient method for these purposes.

A methodology analysing 3D coarse root system architecture of trees grown on slope is applied to two Quercus alba trees located in sloping ground, exposed in situ by using high-velocity air jetting.

We propose the following additions to the published 3D root architecture data analysis (e. g. Danjon et al. Plant Soil 211 - 1999, Danjon et al. New Phytol 168 - 2005):

Root dry weight was calculated in addition to root volume. The dry weight of each root segment was computed from root density data gained from five root samples representing five diameter classes.

All the measured root segments were divided into 1 cm long virtual sub-segments to compute root dry weight per circular sector or by depth.

The root system data coordinates were rotated around the Y axis to derive root characteristics as a function of distance to the soil surface and to compute characteristics of root crossing planes parallel to the slope.

Potential contribution to soil reinforcement:

The influence of slope was assessed by examining slope oriented heterogeneities (variabilities) in root length and volume as well as SRL, branching angle and inter-lateral length.

1D cumulative root length and volume distributions were determined as a function of distance to the soil surface, radial distance and azimuth, each for upslope and downslope to analyse the spatial configuration of coarse roots relative to the slope.

Potential contribution to soil reinforcement:

Three types of figures visualize the spatial distribution of root parameters intersecting planes parallel to the slope - i. e. representing potential sliding planes:

1) One dimensional distributions of both upslope and downslope characteristics as a function of distance to the soil surface including characteristics related to soil reinforcement (e. g. root number, cumulative cross sectional area, mean diameter, mean angle toward soil surface, mean length to the previous branch).

2) Multiple 2D root impact maps on 4 planes parallel to the slope.

3) Root area ratio horizontal distribution, mapped in eight 45° sectors in 5 rings radiating out from the stem center on 4 planes parallel to the slope at 30 cm depth intervals.

Graphs and data provided an overview of the 3D structure of root reinforcement. The results will be discussed due to critical failure plane depth and inclination. The data show an asymmetrical distribution of coarse roots in soil exploitation. The unequal development of the two root systems are discussed as a reaction to growth conditions and soil slope.

(P) - **A Study on Branching Structures of One Year Old Branch of apple tree by Pruning Using Hidden Semi-Markov Chain**

Xia Ning, Barczi Jean-Francois, Hu Baogang

A computer simulation model of branching structures of apple trees (Malus domestica cv. Fuji) in an intensive orchard for different levels of pruning intensities is presented. The model simulates the numbers and distributions of the axillary production along one year old parent branch using the Hidden Semi-Markov Chain (HSMC). For simplifying pruning operations, one year old parent branches are divided into three zones, namely, a basal non-branching zone with only latent buds, a median branching zone with spurs and/or medium shoot, and an apical branching zone with a long shoot around the heading cut. Each branching zone is represented by a state in the stochastic model. The model parameters are estimated by using an EM algorithm from the observation data. A numerical study was made for simulating the pruning effects on the structures of apple trees. With different levels of pruning schemes, the proportion of axillary budbreak in heavy heading back and severe heading back (83%-100%) was significantly different from that in "light heading back" (50%-58%) and "moderate heading back"(68%-83%). The proportion of the long shoot in heavy and severe heading back was more than the medium shoot, while the medium shoot was more for the moderate heading and light heading back. The numbers of latent buds along the parent branch for light heading backing were higher than heavy and moderate heading back. The modeling method of this paper aims at providing a quantitative tool for orchard managements, particularly to pruning practices.

(P) - **Towards an architectural approach to drive maize breeding for cold tolerance**

Chenu Karine, Andrieu Bruno, Fournier Christian, Giauffret Catherine

In maize, grain yield is highly associated with light interception and photosynthetic activity during grain filling. In Europe, this period typically occurs when solar radiation is already decreasing and water availability may be limited. The improvement of cold tolerance is a major challenge for maize production because earlier sowing would allow a better fit between crop cycle and availability of natural resources.

Low temperatures have a major impact on radiation interception through the modification of foliage development and on radiation use efficiency through the reduction of leaf photosynthetic activity. Little is known about the specific contribution of each of these traits to the lower biomass production under cold conditions, and their genetic variability. We propose to use recent advances in biophysical models to design a method to quantify the contributions of plant development and leaf photosynthetic activity for different genotypes grown under low temperatures.

A field experiment with two planting dates was carried out on four maize inbred lines from temperate or highland tropical origin, also used for QTL mapping studies. These lines were chosen as a source of genotypic and phenotypic variability for cold tolerance. Biomass production was measured over time and analysed with respect to the amount of radiative energy received by the plant to quantify the radiation use efficiency of the different genotypes.

The results presented here are a first step to provide a phenotyping tool of plant response to low temperatures, considering both plant structure and functioning. Such a study should help to identify key characters and related chromosomal segments that could be used for genetic improvement of cold tolerance.

(P) - **Effect of inter- and intraspecific competition on the crown structure of Silver birch**

Anna Vehanen, Pekka Kaitaniemi

We examined how the crown structure of Silver birch (Betula pendula) is influenced by it's neighboring tree species. The neighboring species considered were Scots pine (Pinus sylvestris), Black alder (Alnus glutinosa), Siberian larch (Larix sibirica), and Silver birch, which was included to also study intraspecific competition. The number of sample trees growing in 12 different mixed forest study sites was 74, and their age ranged from 4 to 39 years. To distinguish the competition effect of different species, we selected sample trees so that individuals of mainly one tree species surrounded them. Neighbor trees within a circle with a radius of five meters from the sample trees were characterized with their distance from the sample tree, with the diameter at the base or at the breast height of the tree, and with the height of the tree. 3D digitizing was used to record the detailed structure of the tree top and a number of sample branches along the stem of the sample trees. 3D positions of the base and the tip of each primary branch (branching from the trunk) were also recorded. Digitized coordinates enabled us to rebuild the 3D structure of trees with a computer, and further to calculate various crown variables to analyze the effect of competition on growth, crown shape, numbers of different shoot types, as well as on branch length and angle. Growth responses of individual shoots and branches were considered by examining the effects of variables such as relative position inside the crown, tree age and size, shoot distance from the tree base, and the branching order of shoot position.

(O) - **Architectural and geometrical representations of cotton plants for simulating their light interception at low density**

Martin P., Dauzat J., Luquet D., and P. Clouvel

Crop models are based on simplified representations of biological systems. A customary simplification is the assumption of an exponential light extinction (Beer's Law) vs. the leaf area index which implicitly supposes a homogeneous 3D distribution of leaves within the canopy. Actually, this assumption is acceptable for most crops whenever their canopy is closed but does not apply in early growth stages or when the plant density is too scarce. This latter situation is met in many cotton cropping systems designed for specific purposes such as water saving or pest control. In such cases, the canopy may no longer be considered as homogeneous and the light interception deviates from Beer's law. The aim of the present study is (i) to analyse the light interception within young and/or sparse cotton canopies and (ii) to propose simple geometrical representations for simulating the light interception by such canopies.

Experiments were carried out in Montpellier (France) on DES 119 cultivar. Experimental plots were designed with varying densities (3, 6, and 12 plants m-2 in1995 and 1, 2, and 4 plants m-2 in 2003). Exhaustive architectural descriptions of ten plants (5 adjacent plants x 2 rows) were realized within each treatment form. The architectural traits of the observed plants were then analysed in order to parameterise the COTONS model in terms of organogenesis, biomass allocation between organs and plant geometry. The COTONS model was then used for simulating the cotton plants architecture at different growth stages and densities.

The ARCHIMED software includes tools for simulating the light interception within stands constituted of "architectural" or geometrical representations of plants. In a first step, the software was used for simulating the light interception by "architectural" cotton plants at different ages and densities. In a second step, simpler representations of individual cotton plants were tested, using the architectural representations as references. Results showed that simple geometrical shapes can be used for simulating the light interception by individual plants within a canopy, provided the optical properties of the shapes are properly calibrated. Finally, alternative choices in plant growth modelling are discussed in terms of accuracy, information handling and computing time.

(O) - **Exploring cost and benefit of tree crown plasticity using a 3D dynamic stand growth simulator**

By G. Vincent and D. Harja

Morphological plasticity may be as important as physiological plasticity in determining plant adaptability to changing environmental conditions (e.g. (Vincent 2001; Vincent 2006)). Because plants are sessile organisms facing spatial and temporal heterogeneity in resource distribution, their capacity to respond to such heterogeneity is likely to be of particular adaptive value (Brisson and Reynolds 1997; Hodge 2006). A number of experimental studies have shown that tree crowns respond to anisotropic light and space availability in a species specific way (Brisson 2001; Muth and Bazzaz 2002; Muth and Bazzaz 2003).In this modelling study we explore how tree crown deformation in response to anisotropic light and space distribution may affect individual, sub-population and total stand growth performance. We use a dynamic stand growth simulator (SExI) calibrated for multi-species rubber agroforest stands. The model computes light availability and subsequent growth response (diameter increment, height increment, live crown surface increment) of individual trees in a stand. The tree crown is modelled as a deformable solid which responds to local light and space availability and which is constrained by overall allometric relationships.

We evaluate the competitive advantage conferred to a tree by crown plasticity in various dynamic competitive “landscapes”(Levin 2000). We make use of the models simulation capacity to test separately the impact of two main types of plasticity which may or may not be linked in trees in natura: a) the ability to alter height-dbh relationship (a global response to vertical light gradient) and b) the ability to develop an asymmetric crown following radial anisotropy of light or space availability. Preliminary results (to be confirmed as the simulation experiment is still underway) tend to indicate that

- Degree of morphological plasticity can affect significantly not only individual performance but also stand level productivity
- Morphological plasticity confers an absolute competitive advantage as long as it incurs no additional construction cost
- Competitive advantage of highly plastic species is generally higher if the strategy is rare in the pool of competing individuals.

We briefly discuss some ecological implications of those findings and also how tree architectural growth models may affect the shape of the cost function associated with crown plasticity.

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(O) - **AMAPsim: an interactive plant architecture simulator based on botanical concepts**

Barczi J.F., Rey H., Caraglio Y., de Reffye P., Barthelemy D., Fourcaud T.

AMAPsim (http://amap.cirad.fr/amapsim/referman/amapsim.html) is an interactive tool dedicated to the simulation of plant morphogenesis and allows the user to produce accurate botanical shapes (Barczi et al., 1997). This software is the result of more than a decade of development and research devoted to plant architecture and growth (Barthelemy, 2003). The AMAPsim kernel is composed mainly of modules devoted to: 1- management of the topological structure via specific data structure; 2- the management of bud growth processes via a time scheduler.

The simulation of plant topology is based on the growth of a set of buds, whose activity, i.e. apical growth and branching, is modeled using stochastic processes (Guedon et al., 2001). The geometry of resulting axes, e.g. branching angle, phyllotaxy, bending, organ shape and size, is modeled through simple descriptive functions. Throughout their life, the potential growth of each bud is represented through a numerical value called physiological age, which controls each other parameter value. This advanced botanical concept allows classification of components within the plant, i.e. the main stem, short axes, long axes, leaves and flowers, as well as allowing the time differentiation within each class to be taken into consideration . The set of values of physiological ages is called the reference axis (de Reffye et al., 1991). The evolutionary rules of the physiological age along this reference axis are represented through an oriented automaton.

A specific software interface has been implemented in AMAPsim which allows interactions with dynamically loaded additional functions. This interface gives access to both topological and geometrical parameters before use by the AMAPsim kernel. Additional functions can also be run at any time during simulations, according to user-inserted events that are handled by the scheduler. These communication procedures can be used to test alternative growth models or functions, e.g. branching models, photosynthesis and/or allocation rules, thus bypassing or modifying the default AMAPsim routines' behaviour. This opening to external functions also offers a larger field of applications, such as allowing feedback between plant growth and the physical environment to be performed. This interaction will be shown through several simulation examples (Rey et al., 2004).

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– SESSION 7 –

Plant and Landscape Geometrical Models and Visualization Techniques

(K) - Realistic Rendering of Landscapes directed to Real Time Requirement in Virtual Reality

Wu Enhua, Faculty of Science and Technology, University of Macau, Macao, China

Though modeling and realistic rendering of landscapes have been investigated in many years, real time rendering in high quality to the large scale model of landscapes had been just a dream some years ago. Nowadays, landscapes come to play an important part in virtual environments and become increasingly important in virtual reality applications, including those in computer simulation and gaming industry. The increasing demand in this aspect in recent years comes up to drive the real time rendering to landscapes, and therefore puts forward a serious challenge to the computer graphics professionals, both in research and in applications.

This talk will start from an introduction to the fundamental rendering techniques for landscapes, including trees, forest & grassland, and then moves to the introduction to the state-of–the-art technology, directed to real time rendering to various landscapes in virtual reality. The techniques by image based and/or geometry based approaches will be introduced. In particular, the recent progress in rendering large scale landscapes in real time will be addressed, and the typical solutions to solving the challenging problems will be presented. The techniques in taking advantage of contemporary programmable graphics processing unit (GPU) will be also involved in the talk.

(O) - **Simulation and Visualization of Functional Landscapes : Effects of the Competition between Plants**

Le Chevalier, V., Lesluye, A., Jaeger, M., Mei, X. and Cournède, P.H.

Vegetation ecosystem simulation and visualisation are a challenging topic involving multidisciplinary aspects [3]. We present here a generic frame focused on the functional growth of large vegetal ecosystems, showing coherence from single plant to crop scales.

The proposed approach is based on plant growth models under environmental resource conditions: the growth model is coupled to the climatic conditions (temperature, light, rainfalls) and the competition between plants is taken into account through plant shadowing and soil hydrological budget.

A voxel space is used to store the water resources and to build the interfaces between the environmental data and landscape components [4]: temperature, rain, altitude, plants position, lakes, etc.

At the plant level, the simulation is performed individually by a structural-functional growth model [7], simplified, interacting with its environment.

The competition for light [2] is reduced to a purely geometric problem. In our approach, degraded geometric model of plants are defined and used. They allow fast light interception computations, via classical algorithms such as ray tracing or depth buffer projections.

The competition for water is based on a soil hydrological model [6] taking into account rain fall, water runoff, absorption, diffusion, percolation in soil, evaporation, and plant transpiration. Water runoff [1] processes are integrated on the full landscape over a daily time step.

In our implementation, we propose a simulation scheme to synchronise the water cycles updating (daily based) and the plant growth steps (temperature based).

New visualisation tools are presented, based on the voxel space and its interfaces. Volume rendering [5] of the resulting scene or classical surface extractions allows both morphological and functional landscape visualisations. The visualisation techniques dedicated to these functional landscapes provide interesting tools for ecosystem management.

The implementation of the proposed frame leads to encouraging results presented in this paper, illustrating academic cases. The approach proposes a novel frame for simulation of natural phenomena, through simple, manageable models.

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(O) - **Fast Ambient Occlusion Algorithm for Real-Time Plant Rendering**

Jun Teng, Baogang Hu

Global illumination effects are crucial for virtual plant rendering. Where real-time global illumination rendering of a plant is impractical, ambient occlusion is an efficient alternative approximation [1]. A tree model with millions of triangles is common, and the triangles can be considered as randomly distributed. The existing ambient occlusion methods fail to apply on such an object. In this paper, we present a new ambient occlusion algorithm dedicated to real-time plant rendering.

This algorithm follows a three-step procedure.

1. In the first step, the organs of a plant are hierarchically organized using a tree-like structure. A leaf node of the tree structure is a cluster. It contains organs that are close and topologically related.
2. In the second step, we calculate each organ's static distance within its own cluster.
3. In the last step, the accessibility value of a given organ is obtained from both the within-cluster statistical distance and the between-cluster statistical geometrical structures.

While rendering, the diffuse lighting calculation is scaled by the accessibility value. The contributions of this paper concerns two parts:

Plant organs (leaves, internodes, fruits, etc.) usually appear in a non-balanced spatial distribution. The current existing hierarchical scene splitting schemes [9] are not suitable for plant organ organization. Although they provide a "fair" space partition, this partition is not related to plant topology and geometry. For instance, organs within one branch may be split into several clusters, which exhibit an "odd" scene division. In order to solve this problem, a modified KD-tree structure called "Offset KD-tree", is proposed. Unlike traditional KD-tree, the splitting planes and splitting axes can be specified arbitrarily, under statistical criteria or under user control. This data structure groups organs according to the topology and geometry structure of a given plant.

Secondly, we propose also a new accessibility value definition as the product of the within-cluster accessibility value and the between-cluster accessibility value. That is, an organ is not only occluded by organs in its own cluster, but also occluded by organs from other clusters.

Within-cluster accessibility value calculation is performed only inside each cluster. For each organ, statistical distance calculated in step 2 is used as a parameter for accessibility value calculation. In contrast to the ray tracing like methods, this scheme gives large performance gains. Concerning the between-cluster accessibility value calculation, a single organ is abstracted as a splatter, while clusters are abstracted as ellipsoids. This second accessibility value is defined from the solid angle between the splatter and the ellipsoids. On a single tree, a cluster number lower than twenty is usually enough; thus between-cluster calculation does not add much extra cost.

We show that the complexity for this algorithm is $O(n)$, compared to the conventional methods with complexities of $O(n^2)$ [5], [7], [8]. The approach makes ambient occlusion calculation affordable for real-time plant rendering. Implementation and practical experiments confirm this theoretical result.

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(O) - **Fast and Progressive Simplification of Complex Foliage**

Qingqiong DENG, Xiaopeng ZHANG, Marc JAEGER

This paper presents a new generic algorithm for the simplification of foliage with complex mesh shapes. Its scheme of simplification is to perform progressive mesh simplification for each single leaf at first, until only one quadrilateral representative is generated. Following this, a quadrilateral leaf union is preformed in phyllotaxy in the second step. To get fast simplification pre-processing, quadrilateral leaf union is preformed inside of the crown with the help of an uneven subdivision of the space occupied by the crown of the tree considered in the last step, so that the scope for searching the best leaf pair is reduced. A new concept, leaf density, is defined to describe the spatial distribution of leaves in the crown. Since a bigger simplification error is allowed in a denser part of the crown, which is contrary to the state of the sparser part where a small simplification error is still sensitive, leaf density is used to control the progress of simplification. As a result, the general compression ratio with leaf density is higher than without it, and the visual effect is better with it also.

Contributions of this paper include four aspects:

1) General foliage shapes. The existing foliage simplification methods either have the limitation that the shape of leaves to be simplified must be quadrilaterals, triangles, or have a complex leaf mesh decomposed into a cluster of independent quadrilaterals or triangles. To get a smooth transition from the complex original leaf shape to a simplified quadrilateral one, we use progressive mesh to simplify the mesh of each complex leaf.

2) Density of foliage distribution. Leaf density is defined as the number of leaves inside a space and it is used to represent leaf distribution in the crown. The density of a new leaf constructed in leaf union is chosen as the average density of the two leaves before union. Density is used as one factor of controlling leaf union. The larger the density of leaves is, the smaller the error should be. This means that leaves with different positions in-crown should have different simplification degrees and errors due to the density there, and more significant simplifications are allowed in leafy spaces, so that a high compression ratio is obtained and the visual quality of simplification can be kept as well in the part with dense leaves.

3) Leaf union acceleration. We choose the potential leaf pair for leaf union with a condition that the distance of the leaf pair is smaller than a threshold. So avoiding considering leaf pairs with a large internal distance can accelerate the simplification process. To have an easy search of all the leaf pairs that satisfy the distance condition and to avoid a quadratic number of comparisons between leaves, we cluster the leaves in an octree-like structure. Additionally, the record of leaf pairs is updated each time after each leaf union. With this method we generate multi-resolution models of big trees.

4) Strategy for big models: We keep separate records of simplification data, i.e., the simplification processes are saved separately in three parts, one for the process from original mesh to a single quadrilateral representative, another for the process from all leaves inside a phyllotaxy to a single phyllotaxy quadrilateral representative, the last for the process of all phyllotaxy representatives inside the crown. So computer memory is saved for big trees when their full details are not requested simultaneously.

This is a two-step process, offline for pre-processing with intermediate geometry and errors recorded, and online for rendering on appropriate geometry. Experiments on foliage simplification are performed with seven species of trees, including willow, poplar, maple, Crab apple, basswood, apricot and holly, where the models of leaves of the willow, poplar, maple, basswood and apricot trees are complex leaves.

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(O) - **Realistic Simulation of Seasonal Variant Maples**

Ning Zhou, Weiming Dong, Xing Mei

The appearance of computer generated plants has improved significantly due to recent advances in both modeling and rendering. In this paper, we describe a system that can realistically simulate the seasonal variant appearances of green maples, taking into account the changing and vanishing of the maple's leaves as well as their shape and color changes. A forest with maples and other trees can also be rendered by our system; the leaves' color for each maple is determined by the environmental conditions. First, the original shape of the maple leaves can be modeled with tools like [1]. We use a simple scaling operation to simulate the changing size of the leaves during the seasons of the year, from an initial value near zero to its original size given by the user. The color of the maple leaves ranges from greenish yellow to flaming orange to brilliant red between spring and later autumn. We use texture mapping to display the patterns of the maple leaves. Different patterns can be used in one maple tree. The scanned image of a maple leaf (green) is used to provide the basic information for the pattern. The venation is detected by an edge detector. We set two points to determine the start of the seasonal changes for the leaves color: from greenish yellow to flaming orange and from flaming orange to brilliant red. We use the ratio of the chlorophyll (for green), carotene (for yellow) and anthocyanin (for red) as three parameters to adjust the pixel colors of the leaf texture. Sunshine and temperature are also used to generate the pattern of the leaves. Bright sunshine and low temperature will destroy chlorophyll and promote the formation of anthocyanin. Unlike the earlier systems [2], the parameter of sunshine is very important when we want to set the leaves in one maple or the maples in the forest with different patterns. Here the directions of the leaves will also be used. Photon mapping [3] is used to generate the final images, taking into account global illumination and lighting effects such as color bleeding and soft shadows.

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(O) - **Plant Reconstruction from image streams based on weak structured lights**

Jing Hong, Zhigeng Pan, Xinyu Guo

We implement a system to reconstruct a 3D model of a plant from image streams with a method based on weak structured lights. The equipment required only includes a digital camera, a common lamp, and a stick. The camera is facing the plant, which is illuminated by the lamp. A stick, moving above, casts its shadow on the plant. We digitize the plant from image-streams of several views by the following steps: (1) Camera Calibration, to obtain the internal and external parameters of camera. (2) Light-source Calculation, to acquire the 3D coordinates of the lamp position. (3) 3D reconstruction, to calculate the 3D coordinates corresponding to 2D points of the plant in-image through the temporal and spatial space of the observed shadow with a few interactions. (4) Modeling to create a 3D model of the plant after combining 3D data from different views. Finally, we provide an interactive display and measuring function to display and calculate 3D information from the model, such as height of plant, length, and areas of leaves, in support of agriculture research.

(O) - **Geometric Modeling and Visualization of Corn Based on Morphological Characteristic Parameters**

Guo Xinyu, Zhao Cunjiang, Xu Xuezhang, Deng Xuyang, Wang Jihua

To more quantitatively describe morphological characteristics of different corn cultivars and conduct geometric modeling and visual demonstration of corn organ, individual plant, and population structure, geometric modeling methods were proposed based on cultivar morphological characteristic parameters. Based on observation of morphological development of corn root, leaf, stem, spike, and ear, geometric models of the above organs were constructed. The models realized vector-description of organ morphology and its development using limited morphological parameters with a biological definition. Geometric model parameters and plant topological structures of different corn organs can be produced with the corn growth modeling system. Three dimensional structure of the corn organ, individual plant, and corn population can be reconstructed, and on computer by incorporation of VC++ and OpenGL. Virtual growth and visual calculation of morphological structure were also realized. The simulation results demonstrated that morphological data from the corn organ and individual plant produced by computer are identical to field observations.

LIST OF PARTICIPANTS

Aiachi Mouna
Olive Institute Research
Sousse, Tunisia
Email: ayachimouna@yahoo.fr

Asadi Mohammad
Azad University of Gorgan
Gorgan, Iran
Email: iwc977127@yahoo.com

Barczi Jean-Francois
UMR AMAP, CIRAD
Montpellier, France
Email: barczi@cirad.fr

Barthelemy Daniel
UMR AMAP, INRA
Montpellier, France
Email: barthelemy@cirad.fr

Berard Severine
UMR AMAP, Univ. Montpellier2
Montpellier, France
Email : Severine.Berard@toulouse.inra.fr

Buck-Sorlin Gerhard
Leibniz-Institute of Plant Genetics and Crop Plant Research (IPK)
Gatersleben, Germany
Email: Gerhard.Buck-Sorlin@ipk-gatersleben.de

Chai-Aree Somporn
IWR
Heidelberg, Germany
Email: meng@somporn.net

Chen Guifen
Jinlin Agricultural University
Jinlin, China
Email: guifchen@163.com

Chang Liying
Nanjing Agricultural University
Nanjing, China
Email: changly@klia.cn

Chen Baoquan
University of Minnesota
Maple Grove, USA
Email: baoquan@acm.org

Chen Yanhua
CAU
Beijing, China
Email: yanhua1230@126.com

Cheng Zhanglin
LIAMA, CASIA
Beijing, China
Email: zlcheng@nlpr.ia.ac.cn

Chu Jinxiang
IEDA,CAAS
Beijing, China
Email: chujx1168@126.com

Coligny de Francois
UMR AMAP, INRA
Montpellier, France
Email : coligny@cirad.fr

Cournede Paul-Henry
DigiPlante, ECP
Paris, France
Email : cournede@ecp.fr

Dauzat Jean
UMR AMAP, CIRAD
Montpellier, France
Email: dauzat@cirad.fr

de Reffye Philippe
DigiPlante AMAP, INRIA/CIRAD
Montpellier, France
Email : philippe.de_reffye@cirad.fr

Decaudin Philippe
LIAMA, INRIA
Beijing, China
Email: philippe.decaudin@imag.fr

Deng Qingqiong
LIAMA, CASIA
Beijing, China
Email: qqdeng@nlpr.ia.ac.cn

Dong Qiaoxue
CAU
Beijing, China
Email : dongqiaoxue@163.com

Draye Xavier
Université catholique de Louvain
Louvain-la-Neuve, Belgium
Email : draye@ecav.ucl.ac.be

Dupuy Lionel
University Cambridge
Cambridge, UK
Email: lxd20@cam.ac.uk

Fourcaud Thierry
LIAMA/AMAP, CIRAD
Beijing, China
Email: fourcaud@cirad.fr

Gayler Sebastien
GSF-National Research Center for Environment and Health
Neuherberg, Germany
Email: gayler@gsf.de

Guo Hong
CAF
Beijing, China
Email: hongguocaf@gmail.com

Guo Xinyu
NERCITA
Beijing, China
Email: guoxy@nercita.org.cn

Haberle Jan
Research Institute of Crop Production, Plant Nutrition
Prague, Czech Republic
Email: haberle@vurv.cz

He Chaoxing
Institute of Vegetables and Flowers, CAAS
Beijing, China
Email: ivf_sszp@mail.caas.net.cn

Heuvelink Ep
Wageningen University and Research Centre
Wageningen, Netherlands
Email: ep.heuvelink@wur.nl

Higuera Christian
Universidad de Concepción, Facultad de Ciencias Forestales
Concepción, Chile
Email : chiguera@fundacionchile.cl

Hong Lingxia
CAF
Beijing, China
Email: honglx@forestry.ac.cn

Honjo Tsuyoshi
Department of Environmental Science and Landscape Architecture, Chiba University
Chiba, Japan
Email: honjo@midori.h.chiba-u.ac.jp

Hu Baogang
LIAMA, CASIA
Beijing, China
Email: hubg@nlpr.ia.ac.cn

Huang Wenjiang
NERCITA
Beijing, China
Email: yellowstar0618@163.com

Jackson Michael
AoB, School of Biological Sciences, University of Bristol
Bristol, UK
Email: mike.jackson@bristol.ac.uk

Jaeger Marc
UMR AMAP, CIRAD
Montpellier, France
Email: jaeger@cirad.fr

Jaradat Abdullah
USDA-ARS
Morris, USA
Email: jaradat@morris.ars.usda.gov

Ji Jinnan
Beijing Forestry University
Beijing, China
Email: jjn0402@126.com

Jia Liu
LIAMA, CASIA
Beijing, China
Email: jliu@liama.ia.ac.cn

Kang Mengzhen
LIAMA, CASIA
Beijing, China
Email: mzkang@liama.ia.ac.cn

Lambers Hans
The University of Western Australia
Crawley, Australia
Email: hans.lambers@uwa.edu.au

Lao Cailian
CAU
Beijing, China
Email: laowan@cau.edu.cn

Ledent Jean
Université catholique de Louvain
Louvain-la-Neuve, Belgium
Email : ledent@ecav.ucl.ac.be

Lei Xiangdong
CAF
Beijing, China
Email: xdlei@caf.ac.cn

Lejeune Pierre
Cropdesign NV
Zwijnaarde, Netherlands
Email: pierre.lejeune@cropdesign.com

Letort Veronique
DigiPlante, ECP
Paris, France
Email : letort@mas.ecp.fr

Li Xunxiang
Huangshi Institute of Technology
Huangshi, China
Email: lixunxiang@163.com

Li Baoguo
CAU
Beijing, China
Email: libg@cau.edu.cn

Lim Enmi
Faculty of Hort., Chiba Univ.
Chiba, Japan
Email: limeunmi@faculty.chiba-u.jp

Louarn Gaetan
LIAMA, CAU
Beijing, China
Email : gaetan.louarn@gmail.com

Lu Ke
Graduate University of CAS
Beijing, China
Email: luk@gucas.ac.cn

Lu Yuanchang
CAF
Beijing, China
Email: Ylu@caf.ac.cn

Luquet Delphine
CIRAD
Montpellier, France
Email: luquet@cirad.fr

Ma Yuntao
CAU
Beijing, China
Email : mytao@cau.edu.cn

Martin Pierre
CIRAD
Montpellier, France
Email: pierre.martin@cirad.fr

Mei Xing
LIAMA, CASIA
Beijing, China
Email: xmei@nlpr.ia.ac.cn

Ming Sun
CAU
Beijing, China
Email: drmingsun@163.com

Ning Xia
LIAMA, CASIA
Beijing, China
Email: nxia@nlpr.ia.ac.cn

Pages Loic
INRA
Avignon, France
Email : Loic.Pages@avignon.inra.fr

Pan Zhigeng
Key Lab CAD/CG, Zhejiang University
Hangzhou, China
Email : zgpan@cad.zju.edu.cn

Real Pedro
Universidad de Concepción, Facultad de Ciencias Forestales
Concepción, Chile
Email : preal@udec.cl

Rey Herve
UMR AMAP, CIRAD
Montpellier, France
Email: herve.rey@cirad.fr

Stokes Alexia
LIAMA/AMAP, INRA
Beijing, China
Email: stokes@liama.ia.ac.cn

Su Zhongbin
Beijing Institute of Technology
Beijing, China
Email: szb001@163.com

Sumida Akihiro
Institute of Low Temperature Science, Hokkaido University
Sapporo, Japan
Email: asumida@lowtem.hokudai.ac.jp

Sun Zhongfu
IEDA,CAAS
Beijing, China
Email: sunzf@263.net

Tang Liang
Nanjing Agricultural University
Nanjing, China
Email: tl@klia.cn

Teng Jun
LIAMA, CASIA
Beijing, China
Email: jteng@nlpr.ia.ac.cn

Umeki Kiysohi
Graduate School of Science and Technology, Chiba University
Chiba, Japan
Email: umeki@faculty.chiba-u.jp

Vehanen Anna
University of Helsinki, Department of Forest Ecology
Helsinki, Finland
Email: anna.vehanen@helsinki.fi

Verstegen Hoarold
Keygen M.V., Wageningen
Netherlands
Email: Harold.Verstegen@keygene.com

Vincent Gregoire
UMR AMAP, IRD
Kourou, France
Email: vincent@mpl.ird.fr

Vos Jan
Wageningen University and Research Centre
Wageningen, Netherlands
Email: jan.vos@wur.nl

Wang Ning
LIAMA, CASIA
Beijing, China
Email: nwang@liama.ia.ac.cn

Wang Lei
China National Rice Research Institute
Wangzhou, China
Email: hzwanglei@gmail.com

Wang Zhangang
Institute of Geographic Sciences and Natural Resources Research, CAS
Beijing, China
Email: wangzg@lreis.ac.cn

Wu Enhua
Institute of Software, CAS/Univ. Macao
Macao
Email: EHWU@umac.mo

Wu Zhongke
Beijing Normal University
Beijing, China
Email: EHWU@umec.mo

Xian Jiang
CAF
Beijing, China
Email: trista@caf.ac.cn

Yan Dingchun
Agricultural Information Institute, CAAS
Beijing, China
Email: yandc@caas.net.cn

Yan Guo
CAU
Beijing, China
Email: yan.guo@cau.edu.cn

Yang Haishun
University of Nebraska
Lincoln, USA
Email: hyang2@unl.edu

Zhan Zhigang
CAU
Beijing, China
Email: zhigang.zhan@cau.edu.cn

Zhang Baogui
CAU
Beijing, China
Email: zhangbg@cau.edu.cn

Zhang Huaiqing
CAF
Beijing, China
Email: finfosys@forestry.ac.cn

Zhang Qian
CAU
Beijing, China
Email: qian.zhang.cau@gmail.com

Zhang Xiaopeng
LIAMA, CASIA
Beijing, China
Email: xpzhang@nlpr.ia.ac.cn

Zheng Ping
Northeast Agriculture University
Haerbin, China
Email: cathylele@163.com

Zhou Kefa
Xinjiang Institute of Ecology and Geography
Urumqi, China
Email: zhoukf@ms.xjb.ac.cn

Zhou Mingquan
Beijing Normal University
Beijing, China
Email: mqzhou@bnu.edu.cn

Zhu Chao
LIAMA, CASIA
Beijing, China
Email: czhu@nlpr.ia.ac.cn