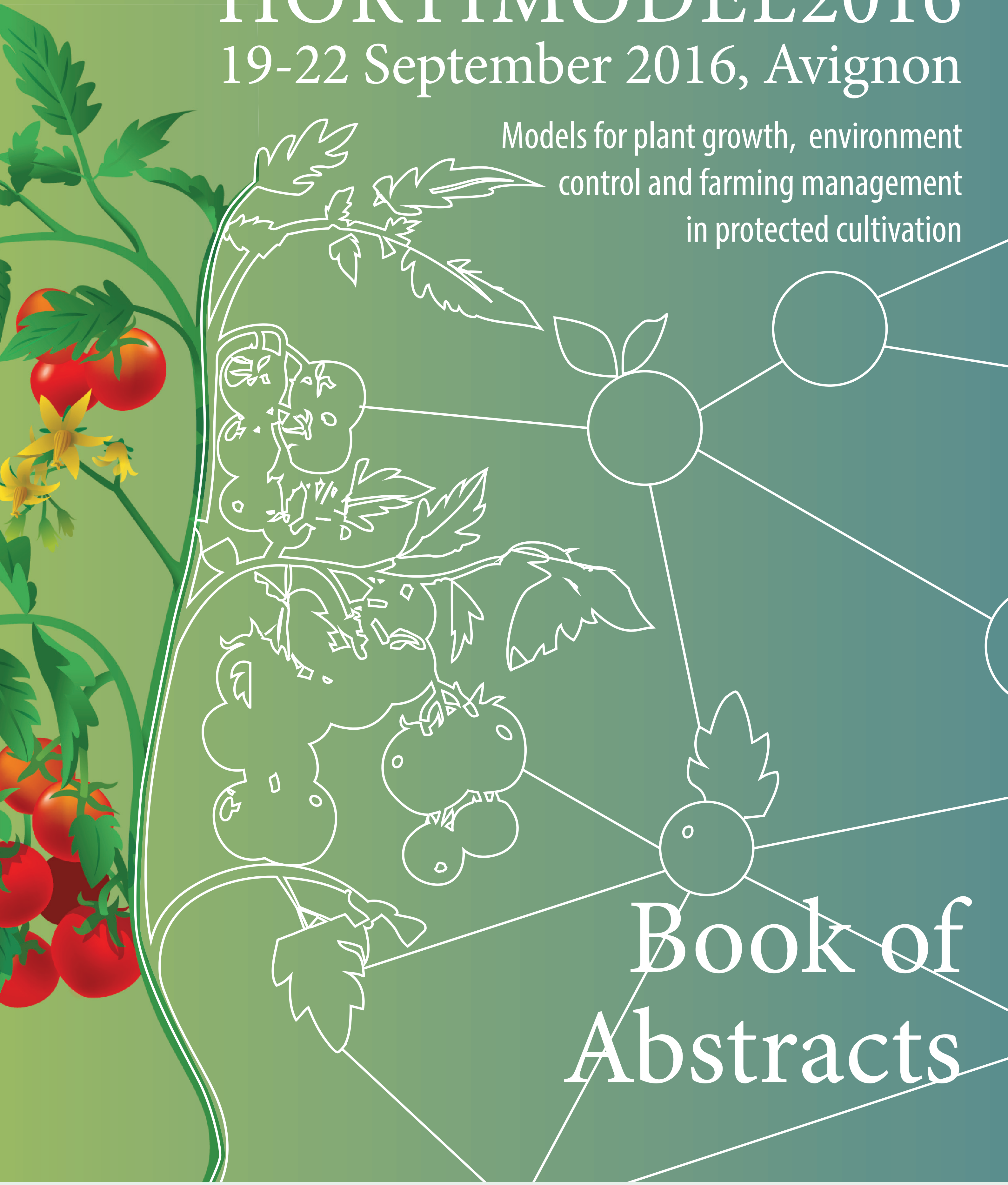
A kinetic model of sugar metabolism in peach fruit allows the exploration of genetic variability

Elsa Desnoues, Bénédicte Quilot-Turion, Michel Génard, Valentina Baldazzi

HORTIMODEL2016

19-22 September 2016, Avignon

Models for plant growth, environment control and farming management in protected cultivation



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HORTIMODEL

Models for plant growth, environment control and farming

Management in protected cultivation

ISHS International Symposium

Avignon, France   September 19-22, 2016

AIM AND SCOPE OF THE SYMPOSIUM

Fruits and vegetables are a main source of health compounds and a hedonic constituent of human diet. In the context of global change, plants will be facing increasing abiotic and biotic constraints. Therefore, innovations are expected in order to improve plant adaptation to these constraints as well as to reduce water, nutrients and chemical inputs. Plant breeding, innovative cultural practices and climate control are all effective levers that can be combined in order to improve crop yield and quality in low input production systems. In this context, a renewed modeling effort is needed in order to provide an integrated understanding of horticultural system functioning. Model goals for the future are to describe the cross-talk between physiological processes at multiple plant scales, simulate complex greenhouses designs, anticipating the consequences of environmental fluctuations or pest attack for system control and management.

Program and abstract book

This booklet contains the general symposium program, followed by the abstract. Each session includes the page numbers where the abstracts for that session can be found. The oral abstracts (presenting author is underlined) are listed first in the order of their planned presentation during a session, grouped by each of the 4 topics addressed. Abstracts presented as posters, are grouped together in separate section, at the end of the book.

Organizers and financial support

HORTIMODEL 2016 has been organized by the INRA unit “Plants and Cropping Systems in Horticulture” (PSH) under the auspices of the International Society of Horticultural Science (ISHS), involving three groups: Commission Horticultural Engineering, Commission Protected Cultivation, Workgroup Modelling Plant Growth, Environmental Control, Greenhouse Environment. The National Research Institute of Agronomy (INRA) division Environment and Agronomy, the National Research Agency (ANR Investissment d’avenir ANR-10-LABX-001-01 Labex Agro coordinated by Agropolis foundation), the Federative Research Structure TERSYS, and two private companies, Cybeletech and CMF, have provided fruitful financial support for the planning and execution of the symposium.

We also thank all the members of the organizing and scientific committees for their key contributions to the organization of this symposium.

HORTIMODEL 2016: Symposium Programme at a Glance

Monday September 19th

10h-12h Registration (room Paneterie)

13h-14h Registration - Coffee (room Paneterie)

14h-14h20 Welcoming and practical information (Cellier Benoit XII)

Topic 1: Decision-support modeling tools

14:20 -15:05	Keynote: Juan Ignatio Montero "Ongoing developments in greenhouse climate control"
15:05-15:25	F.D. Molina Aiz "Using computational fluid dynamics to analyse the CO2 transfers in naturally ventilated greenhouses"
15.25-15:45	H. Fatnassi "CFD coupled modeling of distributed plant activity and climate in greenhouse"
15:45-16:05	M. Cossu "Solar light distribution inside a greenhouse with the roof area entirely covered with photovoltaic panels"

16:05-16:30 Coffee break (room Paneterie)

16:30-16:50	R. Salazar "A dynamic model for temperature and humidity control in a semiclosed greenhouse"
16:50-17:10	A. Rojano "Solar drying device tested with lettuce leaves"
17:10-17 :40	F. Lauriks "Use of leaf thickness sensors in horticultural crops"
17:40-18:00	Short video on the Popes' Palace

18:00-19:00 Poster session

22:00-23:00 ***Social Event at the Popes' Palace: "Les Luminessences d'Avignon "***

Tuesday September 20th

Topic 1: Decision-support modeling tools (part 2)

9:00-9:30	Keynote: Shmulik Friedman "DIDAS - A user-friendly software package for assisting Drip Irrigation Design and Scheduling"
9:30-9:50	C. Lili "Potentials of energy saving for crop production in different types of greenhouses in China"
9:50-10:10	M. Gallardo "Development of the VegSyst-DSS program to calculate irrigation and N requirements and N concentration of the fertigation solution in major greenhouse vegetable crops in SE Spain"
10:10-10:30	P. Cannavo "Improving water use efficiency for ornamental crops grown in greenhouses: a substrate-plant-atmosphere model validation for transpiration prediction"

10:30-11:00 Coffee break (room Paneterie)

11:00-11:20	L. Weihong "Simulation analysis of energy consumption per unit yield of cucumber crop grown in a Venlo-type greenhouse across China"

11:20-11:40 L. Ledda “Modeling tomato growing and production in a photovoltaic greenhouse in southern Italy”

11:40-12:00 I. Seginer “Optimal day-to-night heat storage in greenhouses: a simulation study

12:00-12:30 Conference photo

12:30-14:00 Lunch-poster session

Topic 2: Modeling plant and organ response to biotic and abiotic constraints

14:00-14:45 Keynote: Leo Marcelis “Modeling crop, plant and organ responses to biotic and abiotic constraints”

14:45-15:05 E. Poisson “Modelling sulphur allocation and partitionning in high S-demanding species of the *Brassicaceae* family”

15:05-15:25 H. Van de Put “Simulation of a reference line for plant growth in Rosa chinensis cv. and Ficus benjamina”

15:25-15:45 H. Camargo Alvarez “Predicting the dormancy and bud break dates for grapevines”

15:45-16:05 K. Boote “Simulating growth, fresh weight and size of individual fruits under water and nitrogen limitations with the CROPGRO-tomato model”

16:05-16:35 Coffee break (room Paneterie)

16:35-16:55 A. Elings “The effects of different LED colours on tomato crop growth and production”

16:55-17:15 D. Bevacqua “A compartmental epidemiological model for brown rot spreading in stone fruits orchard”

17:15-17:35 S. Nilusmas “A multi-seasonal model of plant-nematode interactions and its use for durable plant resistance deployment”

17:40-19:00 Poster session & Wine tasting (room Paneterie)

Wednesnay September 21st

Topic 3: Methodological issues

8:45-9:30 Keynote: Paul-Henry Cournède “Reduction of parameter uncertainty and genotypic differentiation in plant growth models”

9:30-9:50 E. Hadavi “Application of structural equations modeling (SEM) in horticultural studies”

9:50-10:10 I. Lopez-Cruz “Uncertainty analysis of modified VegSyst model applied to a soilless culture tomato crop”

10:10-10:30 L. Miranda “Graphical representation of model fit as an aid for input selection”

10:30-11:00 Coffee break (room Paneterie)

11:00-11:20 P. Verboven “Determination of cell wall elastic modulus using a micro-mechanical compression model of apple tissue”

11:20-11:40 I. Lopez-Cruz “A comparison of Bayesian and classical parameter estimation methods in greenhouse crop models”

11:40-12:00	B. Quilot-Turion “A model-based approach for peach fruit transpiration process and its genetic variability”
12:00-12:20	E. Fitz-Rodriguez “Neuro-Fuzzy modeling of weekly harvest rates of greenhouse tomatoes »

12:30-14:30 Lunch-poster session

14:30 – 18:00 Organized Tour of Avignon (English speaking guide)

20:00 Conference Dinner (room Jeanne Laurent)

Thursday September 22nd

Topic 4: Multi-scale, integrated approaches

9:00-9:45	Keynote: Karine Chenu "Bottom-up and top-down approaches ' The value of modelling in trait dissection and phenotypic prediction"
9:45-10:05	M. Génard "A kinetic model of sugar metabolism in peach fruit allows the exploration of genetic variability"
10:05-10:25	D. Constantinescu "Model-based analysis of the genetic variability in tomato fruit growth under contrasted water conditions"
	10:25-11:00 Coffee break (room Paneterie)
11:00-11:20	P. Verboven "Modelling the vasculature of apple fruit"
11:20-11:40	V. Baldazzi "Cell division, endoreduplication and expansion processes: setting the cell and organ control into an integrated model of tomato fruit development"
11:40-12:00	I. Cheddadi "Multicellular modelling of plant tissues as hydraulic systems"
12:00-12:20	K. Kahlen "Challenges in modelling climate change effects on the productivity of vegetable crops"
12:20-12:40	J. Coussement "Introducing turgor-driven growth dynamics into functional-structural plant models"
	12:40-14:30 Lunch - poster session (room Paneterie) 13:30-14:15 Meeting for next Hortimodel
14:30-14:50	Z. Dai "Modeling the growth and quality of grape berry in changing environments"
14:50-15:10	B. van de Wal "An integrated plant and fruit model for grapevine (*Vitis vinifera* L.)"
15:10-15:30	S. Maqrot "Designing mixed fruit-vegetable cropping systems by integer quadratic programming"
15:30-15:50	C. Demestihas "A crop simulation model supporting multiple ecosystem services analysis in apple orchards"
	15:50-16:15 ISHS Student Award
16:15-17:00	***Closing notes (ISHS)***

Outlook

TOPIC 1

Decision-support modeling tools

Models are efficient tools in facilitating the implementation of interactive decision support systems, for crop and (micro-)climate management. This topic will encompass all modelling developments regarding the understanding, monitoring and management of plant (micro-) climate, energy saving, and water and nutrient supply in protected cultivation.

Oral presentations (19th September pm)

ONGOING DEVELOPMENTS IN GREENHOUSE CLIMATE CONTROL

Juan Ignacio Montero Camacho[1], Esteban Baeza [2], Pere Muñoz [1], Cecilia Stanghellini[2]

[1] IRTA, Cabrils, Spain ;,[2] Wageningen UR Greenhouse Horticulture, Wageningen ;

Passive (unheated) greenhouses are typical of mild winter climate areas. Passive greenhouses seek environmental sustainability by reducing inputs of energy and materials. Besides, they have to be economically viable. This paper reviews recent studies on passive techniques and their effect on the night time greenhouse climate: the role of thermal inertia, humidity issues in semi-closed greenhouses and the effect of covering materials properties on temperature and humidity are examined. Research studies show that most passive techniques give moderate temperature rise (in the range of 2 to 4°C). Even though such effect may seem meagre, relevant benefits are derived by extending the growing period, increasing yield and ensuring frost protection. In active high technology greenhouses of cold areas, one of the main focuses is on energy saving, and for that, a new generation of semi-closed greenhouses is on development. Main efforts for energy saving are the reduction of heat losses by making greenhouses tighter (with multiple covers), intensive use of screens to minimize radiative losses at the expense of maintaining higher ambient humidity values. Canopy condensation is prevented by means of different dehumidification systems, such as fans that drive cold/dry air from above the screens to the canopy area or systems based on the use of heat exchanges to drive external preheated dehumidified air to the canopy area with the help of perforated sleeves, among other systems which are preferred over rising the heating set point.

Keywords: energy saving, passive greenhouses, thermal screens, thermal inertia

USING COMPUTATIONAL FLUID DYNAMICS TO ANALYSE THE CO2 TRANSFERS IN NATURALLY VENTILATED GREENHOUSES

Francisco Domingo Molina-Aiz[1], Tomas Norton [2], Alejandro López [1], Audberto Reyes-Rosas [1], María Angeles Moreno [1], Patricia Marín [1], Karlos Espinoza [1]

[1] Universidad de Almería, CIAIMBITAL, Almería, Spain ; [2] Engineering Department, Harper Adams University, Shropshire Newport, United Kingdom

The purpose of the present study is to analyse the variability of the concentration of CO_2 inside greenhouses naturally ventilated using Computational Fluid Dynamic simulations and experimental measurements. The photosynthesis of two tomato crops growing in coconut fibre substrate (leaf area index of 0.29 and 0.97 m^2 m^{-2}) was calculated using the model of Acock. This model was included in the CFD simulations using a user-defined function (UDF). In each cells of the domain corresponding to the crop, the photosynthesis was computed as a function of the CO_2 concentration estimated by the CFD software. Photosynthesis was included as a negative source term in the conservation equation for chemical species. Insect proof screens placed in the greenhouse openings and the crops were simulated as porous media. Experimental measurements were carried out in multispan and *Almería* type greenhouses. Inside air CO_2 concentration was measured using 6 non-dispersive infrared (NDIR) sensors. Temperature and humidity measurements were taken at 12 locations, while crop temperature, photosynthesis, evapotranspiration and stomata resistance were recorded with a portable photosynthesis system. Sonic anemometers were used to measure the airflow through the greenhouse openings. The results of CFD simulations were compared with the experimental data and good agreements were observed. Inside concentration of CO_2 ranged from 410 ppm in the middle of the greenhouse to 220 ppm inside the tomato canopy. The measured photosynthesis rates of the tomato crops were 7.6-15.8 A µmol CO_2 m^{-2} s^{-1} (equivalent to 11.4-20.0 kg CO_2 ha^{-1} h^{-1}).

Keywords: greenhouse, photosynthesis, CFD, natural ventilation, CO2 concentration

CFD COUPLED MODELING OF DISTRIBUTED PLANT ACTIVITY AND CLIMATE IN GREENHOUSE

Hicham Fatnassi [1], Thierry Boulard [1], Ricardo Suay [1], Jean Claude Roy [2], Christine Poncet [1]

[1] INRA, Univ. Nice Sophia Antipolis, CNRS, UMR 1355-7254, Institut Sophia Agrobiotech, 06903 Sophia Antipolis, France ; [2] Institut FEMTO-ST, Energy department, Parc Technologique, 2 avenue Jean Moulin, 90000 Belfort, France

For the 1990’s computational Fluid Dynamics (CFD) has allowed significant progresses for modeling the greenhouse distributed climate, including at crop level. It chiefly relies on the dynamic action of the crop on air flow and the subsequent heat and mass exchanges.

Thus, the CFD approach combined different scales of modeling: the greenhouse and its environment together with crop canopy with a precision of a couple of cm^3, corresponding to the current dimension of the average finite volume meshes inside the greenhouse. This modeling approach accounts for the coupling of air transfers within the crop that is assimilated to the solid matrix of a porous medium exchanging heat and mass with air. Thus, the source terms for sensible and latent heats and other mass exchanges are assigned to each cell of the porous medium (i.e. canopy). These source terms are encapsulated in so call “User Defined Function’s” (UDFs) dynamically linked with the CFD solver. Temperature, air humidity and CO_2 distributions within the crop canopy can then be deduced from the local air velocity and the distributed climate parameters together with canopy temperature and activity.

Keywords: Greenhouse, Model, Plant, CFD, porous medium, UDF

SOLAR LIGHT DISTRIBUTION INSIDE A GREENHOUSE WITH THE ROOF AREA ENTIRELY COVERED WITH PHOTOVOLTAIC PANELS

Marco Cossu [1], Luigi Ledda [2], Paola A. Deligios [2], Antonella Sirigu [3], Lelia Murgia [2], Antonio Pazzona [2], Akira Yano [1]

[1] Faculty of Life and Environmental Science, Shimane University, Japan ; [2] University of Sassari, Department of Agriculture, Division of Agronomy and Plant genetics, Sassari, Italy ; [3] Agris Sardegna, Department of Plant Science, Cagliari, Italy;

Most photovoltaic (PV) greenhouses in Europe have maximised the energy production without considering the requirements of the crops, by applying PV panels on most part of the roof area. The aim of this work is to calculate the solar light distribution in a photovoltaic (PV) greenhouse where the entire roof area is covered with PV panels (100% cover ratio). The calculation of the incident global and PAR radiation was estimated with clear sky conditions on several observation points located inside the greenhouse and at two canopy heights (0.5 and 1.5 m from the ground). The validation of the simulated data was conducted through measurements inside a PV greenhouse complex located in Florinas, Italy (40°38’38”N, 8°39’31”E), composed by 24 single-span greenhouse modules of 837 m^2 each and total area of 2.2 Ha. The roof area of each module was completely covered with a monocrystalline PV array with slope of 20° and a rated power of 22 kWp. The results were shown through a map of light distribution on the greenhouse area, which highlighted the most penalised zones and the percentage of available global radiation, compared to the same greenhouse without PV array. Good agreement was shown by the simulated data, compared to measurements (mean R^2=0.87). The global radiation on the greenhouse area was 28% on yearly basis, compared to the potential value with no PV panels on the roof. The zones close to the gable walls and the side walls suffered less shading compared to the central portion of the greenhouse area. The map of cumulated light distribution can support the growers to increase the agronomic

sustainability of the PV greenhouse, since it will allow in perspective the identification of species and crop management practices for a profitable cultivation.

Keywords: Solar radiation, Energy, Crop, Model, Agricultural sustainability

A DYNAMIC MODEL FOR TEMPERATURE AND HUMIDITY CONTROL IN A SEMICLOSED GREENHOUSE

Raquel Salazar [1], Irineo López Cruz [1], Uwe Schmidt [2], Efren Fitz Rodríguez [1], Abraham Rojano Aguilar[1]

[1] Univesidad Autónoma Chapingo, Texcoco, México, Mexico ; [2] Humboldt University of Berlin, Berlin, Germany ; [3]

Some of the advantages of using closed and semiclosed greenhouses are the energy and water savings as well as the increase in efficiency of CO_2 enrichment. However, the building costs is still high for most of the growers. A simulation model of the greenhouse environment is an unexpensive and accurate process for studying the inside conditions response without the cost of building a greenhouse. Therefore, the purpose of this study was to develop a dynamic model for temperature and humidity control in a Semiclosed Greenhouse.
The information was provided by the Institute of Horticulture at Humboldt University of Berlin. The 307.2 m^2 semiclosed greenhouse with tomato crop is equipped with hydroponic and fogging systems, double glazing, double heat shield, and heating system in the floor, below banks and between plants. There are aluminum fin tubes on the roof, for condensation of water vapor inside the greenhouse. Also, it is equipped with cooling tower, heat pump, hydraulic switches, plus a 300 m^3 water tank for storing energy. In addition, the facility have a weather station for measuring the external weather conditions and a phytomonitoring system, wherein the main physiological variables are recorded. Data every 5 minutes from January to September 2012 was used.
A dynamic energy and water balance model includes: the effects of solar radiation, heating, partial ventilation, transpiration and condensation; also, the sensitivity analysis and calibration of the parameters was performed. After calibration, the model describes the dynamics of the internal temperature and absolute humidity in the semiclosed greenhouse and can be used for management strategies to improve the environmental conditions inside the greenhouse.

Keywords: Transpiration, condensation, ventilation, tomato crop

SOLAR DRYING DEVICE TESTED WITH A LETTUCE LEAVES

Abraham Rojano [1], Jorge Flores-Velazquez [2], Alberto Santos [3], Raquel Salazar [1], Agustin Ruiz [1]

[1] Km 38.5 Carr Mex-Tex, Texcoco, Mexico, 36250, Mexico; [2] Paseo Cuauhnahuac, 8532, Col. Progreso. Jiutepec, Morelos, Mexico, 62550, Mexico ; [3] Chapingo, Mex, Texcoco, Mexico, Mexico

The search for new drying systems taking advantage of alternative energy such as solar and wind energy involves constructing and testing new devices in order to understand, to control and to obtain the maximum benefits. This work is based on increasing the local demand of dryers for vegetables on either mild or tropical conditions where sometimes the meteorological conditions defies the drying goals. As a result, a prototype was made, a lettuce sample was tested and experimental models were fitted.

Keywords: solar energy, diffusion, convection, fitting models

USE OF LEAF THICKNESS SENSORS IN HORTICULTURAL CROPS

Fran S. Lauriks, Hans A.L. Van de Put, Kathy Steppe, Dirk J.W. De Pauw

Ghent University, Gent, Belgium

Changes in leaf thickness can be a rapid indicator of a plant’s water status and can therefore serve as an alarm signal for potential water deficits. Installation of leaf thickness sensors on stems or roots with small dimensions enable the measurements of diel stem and root diameter variations as well as long-term growth. To ensure accurate measurements, determined by plant variations only, the temperature response of the leaf-thickness-sensors has been investigated in the interval from 10 to 35 °C on aluminium plates, of which the thermal expansion can be theoretically calculated. In addition, the sensors were calibrated with stainless steel calibration plates. The accuracy of the leaf-thickness-sensors for measurements on small-dimension stems, branches or roots has been experimentally tested on a cylindrical rod. Finally, the effect of different installation positions has been investigated and a protocol for installation has been established. The practical use of leaf thickness sensors has been demonstrated by installing the sensors on three ficus trees (*Ficus benjamina*) and three pot roses (*Rosa chinensis* cv.) from cutting stage to the time they are ready for sale. Moreover, a model is used to simulate the observed patterns in leaf thickness variation. This model has been incorporated in an existing stem diameter variation model and can possibly be used for stress detection by comparing leaf thickness measurements and simulations.

Keywords: leaf thickness, leaf-thickness-sensor, sensor validation, ornamental horticulture, plant monitoring, mechanistic modelling

DIDAS - A USER-FRIENDLY SOFTWARE PACKAGE FOR ASSISTING DRIP IRRIGATION DESIGN AND SCHEDULING

Shmulik Friedman, Gregory Communar, Alon Gamliel

Institute of Soil, Water and Envir. Sci. , The Volcani Center, Bet Dagan 50250, Israel

The DIDAS software package, based on analytical solutions of linearized water flow and uptake problems, assists in drip-irrigation system design and irrigation scheduling. Water flow is described by superposition of solutions for positive sources (on-surface or subsurface emitters) and negative sinks (root systems). Steady water flow is assumed in the design module and unsteady flow in the irrigation scheduling module. The design tool, based on relative water uptake rate (RWUR) criterion, assesses the effects on water use efficiency of geometrical attributes: distances between emitters along drip lines; separation between drip lines; depth of subsurface emitters; and size and depth of root systems. Evaluation of the maximum possible RWUR assumes no plant-atmosphere resistance to water uptake, i.e., the roots are assumed to apply maximum suction and the water uptake rate depends only on the soil capability to conduct water from sources to sinks. The RWUR computations require only three parameters describing the soil texture, the root zone size, and the potential evaporation, in accounting also for evaporation from the soil surface. The optimizing tool for irrigation scheduling is based on a relative water uptake volume (RWUV) criterion. The computations of diurnal variations of water uptake rates and RWUV for a given irrigation scenario require additional information on the diurnal pattern of plant resistance to water uptake and on the soil hydraulic conductivity. DIDAS also contains a diurnal pattern module for evaluating diurnal water-uptake patterns; it assumes quasi-steady flow and accounts for the diurnal variations of plant-atmosphere resistance and evaporation in fine-tuning the design and in preliminary evaluation of scheduling scenarios. DIDAS was programmed in Delphi, runs on a PC under the Windows operating system, and requires no further software. The drip irrigation scenario is constructed via a few GUI windows, which contain also a library of the required soil input parameters, and a best-fitting procedure for determining them. The computed RWURs and RWUVs are displayed graphically and the tabulated output results can be exported to, e.g., Microsoft Excel for further processing. An updated DIDAS version can be downloaded freely from http://app.agri.gov.il/didas. The present, second public release of DIDAS meets the major demands dictated by its development objectives. Short-term development goals include minor graphical improvements, addition of new drip irrigation configurations, and addition of a module for evaluating water uptake from drip irrigation in the presence of shallow groundwater. We also intend to extend DIDAS to sprinkler irrigation. Depending on feedback from DIDAS users we may consider also other development options; 710 people from 83 countries downloaded either the first or the second DIDAS versions 1.0.1 (and 1.1.1) from March 2014 through March 2016. In the lecture we will briefly introduce drip irrigation and its application to protected crops, outline the major DIDAS concepts and describe the purpose and operation of the main software modules.

Keywords: Drip irrigation, Water use efficiency, Decision support system.

POTENTIALS OF ENERGY SAVING FOR CROP PRODUCTION IN DIFFERENT TYPES OF GREENHOUSES IN CHINA

Lili Chen, Weihong Luo, Wenli Wu, Gang Li

College of Agriculture, Nanjing Agricultural University, Nanjing, Jiangsu, China

Energy is consumed in forms of greenhouse construction and structure, as well as crop management to perform various operations for greenhouse crop production. Energy saving in greenhouse crop production depends on greenhouse structure and ways of crop management.To what extent that energy consumption can be reduced is important information for assessing risk of greenhouse investment and applying cost effective technologies for greenhouse constructions and crop management. To identify this extent, life cycle assessment (LCA), models of crop growth and energy consumption for climate control were used to estimate specific energy for cucumber production in three types of greenhouses (lean-to greenhouse, plastic tunnel, and multi-span plastic greenhouse). Simulation analysis on changes of specific energy was implemented for the following scenarios: (1) for the lean-to greenhouse, using the traditional structure composed of bamboo-tube roof frame and clay walls as reference, (1.1) replacing bamboo-tube roof frame with steel-tube roof frame; (1.2) replacing both bamboo-tube roof frame and clay walls, respectively, with steel-tube roof frameand brick walls; (1.3) combining (1.1) with improving resource use efficiency from current level (fertilization: 35%, water: 17%, pesticide: 15%) to advanced level (fertilization: 63%, water: 49%, pesticide: 25%) for crop management; (1.4) combining (1.2) with improving resource use efficiency from current level to advanced level; (2) only improving resource use efficiency from current level to advanced level for crop management in all three types of greenhouses. Climate data from 225 stations (18°N -53°N, 75°E-131°E) in China were used to run the crop growth and energy consumption for climate control models. The simulation analysis showed that scenario (1.1) and (1.3) decrease the specific energy, respectively, by 6.5%-8.0% and 13.8%-18.9%. Scenario (1.2) and (1.4), however, increases the specific energy by 10.5%-12.8% and 0%-7%. Under scenario (2), specific energy decreases by 12.6%-18.3% in plastic tunnel, by 7.1%-13% in lean-to greenhouse, and by 0.2%-3.5% in multi-span plastic greenhouse. Compared to multi-span plastic greenhouse crop production, the lean-to greenhouse composed of the steel-tubes, improving resources use efficiency in lean-to greenhouse and plastic tunnel have the greater potentials in energy saving for crop production in China.

Keywords: Greenhouse structure; resource use efficiency; life cycle assessment; model; specific energy

DEVELOPMENT OF THE VEGSYST-DSS PROGRAM TO CALCULATE IRRIGATION AND N REQUIREMENTS AND N CONCENTRATION OF THE FERTIGATION SOLUTION IN MAJOR GREENHOUSE VEGETABLE CROPS IN SE SPAIN

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The context of this work is the greenhouse-based vegetable production system located in coastal regions of south-eastern (SE) Spain, which is associated with appreciable NO_3^- contamination of underlying aquifers. The areas where greenhouses are concentrated have been declared nitrate vulnerable zones, in accordance with the EU Nitrate Directive. Consequently, growers are required to improve nitrogen (N) and irrigation management in order to reduce NO_3^- leaching losses. The VegSyst-DSS software has been developed to determine daily volumes of irrigation, amounts of N fertilizer, and the N concentration in nutrient solutions applied by fertigation for the main vegetable crops grown in this system. The VegSyst-DSS calculates irrigation from estimates of crop evapotranspiration (ET_c) made with the VegSyst model, the uniformity of the irrigation system and water salinity. Nitrogen requirement is calculated with a daily N balance that consider crop N uptake simulated with the VegSyst model and various soil sources of N. The use of the VegSyst-DSS can reduce the concentration of N in the fertigation solution leading to reduced N fertilizer application and reduced N losses to the environment

Keywords: model, fertigation, decision support system

IMPROVING WATER USE EFFICIENCY FOR ORNAMENTAL CROPS GROWN IN GREENHOUSES: A SUBSTRATE-PLANT-ATMOSPHERE MODEL VALIDATION FOR TRANSPIRATION PREDICTION

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Agrocampus Ouest, Angers, France

In greenhouses, reducing water consumption by increasing water efficiency is of high interest. To reach this goal, predictive models of soil-plant-atmosphere water transfers could be helpful. However, such models have been mainly developed for open field conditions, and very few models exist for greenhouse plants grown in pots. Moreover, most of these models were implemented under water comfort conditions, and very few are available under water restriction. In this study, an integrated soil-plant-atmosphere water balance model was developed for potted plants grown in greenhouses, to predict plant transpiration under different restrictive irrigation regime. Such a model is able to estimate accurately the stomatal resistance Rs under water restriction conditions. Several irrigation scenarios were tested for a set water supply reductions or frequency (or both) irrigation. To validate the plant transpiration for such scenarios, an experiment has been conducted for sixteen weeks inside a greenhouse with ornamental plants (New Guinea Impatiens) grown in containers on shelves. Three scenarios were tested: (1) reduced water supply, with unchanged irrigation frequency, (2) reduced frequency, (3) a mix of both. The input parameters corresponded to the measured peat matric potential, radiation, temperature, humidity and transpiration, that were continuously recorded, while Rs was measured punctually. The model demonstrated its ability to predict satisfactorily both Rs and plant transpiration under different water restriction regimes. Such a model could therefore be useful to establish irrigation strategies combining both water use reduction and acceptable plant transpiration

Keywords: Transpiration, stomatal resistance, water restriction, matric potential

SIMULATION ANALYSIS OF ENERGY CONSUMPTION PER UNIT YIELD OF CUCUMBER CROP GROWN IN A VENLO-TYPE GREENHOUSE ACROSS CHINA

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Energy consumption per unit yield of greenhouse crop is essential information for optimizing greenhouse climate control as well as for assessing the risk of greenhouse investment in different climate zones. To identify the variation of energy consumption per unit yield of greenhouse crop across China, we used a greenhouse energy consumption model and a crop growth simulation model to estimate the energy consumption per unit yield of cucumber crop grown in a Venlo-type greenhouse. Firstly, hourly meteorological data (air temperature, global radiation, water vapor pressure and wind speed) were derived based on the 30 year (1980-2010) average meteorological data (daily maximum and minimum air temperature, water vapor pressure, sunshine hours and wind speed) of 224 weather stations in China. The hourly meteorological data were then used as input of the two models to estimate the greenhouse energy consumption, cucumber potential yield under two different strategies for greenhouse temperature and CO_2 control used for commercial greenhouse cucumber production: (1) daytime ($T_{set,d}$) and nighttime ($T_{set,n}$) set-point for temperature control $T_{set,d}$=24℃, $T_{set,n}$=19℃, CO_2 enrichment= 1000 L/L and natural ventilation CO_2=350 L/L; (2) $T_{set,d}$=20℃, $T_{set,n}$=15℃, CO_2 enrichment= 1000 L/L and natural ventilation CO_2=350 L/L. The energy consumption per unit yield of cucumber was then derived based on the simulation results. The results showed that under the two strategies for greenhouse temperature control, CO_2 enrichment reduced greenhouse energy consumption in a greater degree in the south than in the north and higher altitude regions. Energy consumption per unit yield of cucumber between the two temperature control strategies was less than 8%, but with temperature control strategy II and CO_2 enrichment, it could be reduced up to 29%-67% (from the north and higher altitude regions to the south). Under the given two temperature control strategies, CO_2 enrichment can greatly increase crop potential yield, and can be an effective approach to increase the use efficiency of greenhouse energy consumption. The results obtained in this study can be used for assessing the risk of Venlo-type greenhouse investment and optimizing greenhouse climate control in different regions of China.

Keywords: model, potential production, temperature, CO2 enrichment, set-point

MODELING TOMATO GROWING AND PRODUCTION IN A PHOTOVOLTAIC GREENHOUSE IN SOUTHERN ITALY

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The aim of this work was to calibrate and validate CROPGRO-Tomato model, included in the Decision Support System for Agrotechnology Transfer (DSSAT) software, for a cherry tomato genotype grown in a photovoltaic greenhouse in Southern Europe (39°19´59´´N, 8°59´19´´E). The experiment was carried out in Decimomannu, Sardinia, in an east-west oriented pitched-roof greenhouse with two spans (50 m × 9.6 m each) covering an area of 960 m^2. Silicon photovoltaic (PV) panels (REC 235PE, REC Solar, USA) were used to completely replace the south-oriented roof of each span, resulting in a 50% roof cover ratio. Tomato was grown hydroponically with a plant density of 2.3 plants m^{-2}. Two tomato crop cycles were carried out, the first from August-2011 to January-2012, the second from January-to July-2012. Microclimatic conditions were monitored for the whole lifespan of the experiment (e.g. internal global and PAR radiation and greenhouse internal temperature). Phenology, leaf area, aboveground biomass, and fresh fruit production were determined at weekly interval for both cycles. CROPGRO-Tomato model was calibrated over the first crop cycle data. The genotype files (cultivar and ecotype), including the main parameters of crop phenology and plant growth, were adapted to the cherry tomato cultivar ‘Shiren’. The first flowering date showed a good agreement between simulated and observed data throughout the cycles and treatments. The model fitted well the observed leaf area index data with a coefficient of determination (R2) of 0.78 and an average root mean square error (RMSE) of 0.39. Good agreement was observed between the measured and simulated plant development parameters as biomass and fresh weight yield. Overall, the CROPGRO-Tomato model proved to be suitable for predicting tomato growth and yields inside PV greenhouses and under different light intensity conditions. However, validation is necessary, also, to show how the model works under a supplementary lighting system.

Keywords: Lycopersicum esculentum Mill., DSSAT model, genetic coefficients, phenology, leaf area, fresh weight yield

OPTIMAL DAY-TO-NIGHT HEAT STORAGE IN GREENHOUSES: A SIMULATION STUDY

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In cold-climate locations, where natural gas is burned during the day to enrich greenhouses with carbon dioxide, water tanks (buffers) are sometimes used to store the surplus daytime heat for nighttime heating. A practical control strategy for charging and discharging of the buffer, based on a virtual value of the increment of stored heat, is suggested and illustrated by simulation. Greenhouse-environment control decisions (heating, ventilation, etc.) are obtained by maximizing the virtual increase in value of the greenhouse system (increased value of crop and virtual value of heat storage, minus cost of environmental control). As long as the heat buffer is neither empty nor full, the virtual value of an increment of stored heat remains constant. When the buffer becomes full (towards the end of a day), this value is gradually *decreased*, until the storage starts to discharge. When the buffer becomes empty (towards the end of a night), the virtual value is gradually *increased*, until recharging of the storage starts again. This strategy is meant to minimize the time that the buffer is empty or full, because in these states the buffer is inactive. Simulations with an annual weather sequence representative of the Netherlands show the following: (1) The winter-time virtual value of stored heat is equal to the actual cost of heat, while in summer it is zero. (2) The utilization of the buffer is most intensive in spring and autumn, when the daytime supply of CO_2 matches best the nighttime heat requirement. (3) The performance of the system improves asymptotically with an increase of the installed capacity of the buffer.

Keywords: Greenhouses; CO2 enrichment; Day-to-night heat storage; Control policy

TOPIC 2

Modeling plant and organ responses to biotic and abiotic constraints

Crop yield and quality result from many developmental and growth processes. During the production cycles, plant plasticity allows to mitigate the effects of environmental fluctuations and eventual stresses, in particular in low-input production systems. In this topic, models predicting the effects of biotic and abiotic constraints on crop growth and physiology will be presented. All scales from gene to plant will be considered. Because the physiology of greenhouse-cultivated plants is not an inherent property, models developed on model plants or on plants cultivated in the open field can be included in this topic.

Oral Presentations (20th of September, pm)

MODELING CROP, PLANT AND ORGAN RESPONSES TO BIOTIC AND ABIOTIC CONSTRAINTS

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Greenhouse production systems enable a high level of control of abiotic and biotic conditions. For sustainable production of high quality products, it is important to optimize all the different growth conditions in an integrated way. Crop simulation models are powerful tools to analyse these optimal conditions in relation to characteristics of the plant. Nowadays a wide range of simulation models exist for greenhouse grown crops ranging from simple descriptive models to complex mechanistic models that consider a large number of plant processes. The last decade in a number of process-based models the simulation of 3-D structure of a crop has been incorporated, resulting in functional structural plant models (FSPM). Scaling from organ to plant and from plant to crop level and vice versa are important aspects in understanding behaviour of a crop. Simulation models for plant growth and quality typically use the (greenhouse) climate as measured at a central position as input. However, the response of the plants as well as biotic factors such as fungal diseases (e.g. mildew, botrytis) are more related to the microclimate, which might deviate from the average climate. For instance shoot apex temperature may be 4°C higher or lower than air temperature under rather moderate environmental conditions. Microclimate affects crop growth and development as well as crop architecture. In its turn crop architecture influences microclimate, resulting in complex interactions between microclimate, crop architecture, plant growth, and disease infection. This presentation will describe some approaches for mechanistically simulating growth, development and plant architecture of greenhouse crops, such as tomato and roses, in response to abiotic and biotic constraints. It will be discussed how these models may be used for prediction and planning of production, decision support systems, control of the greenhouse climate, supply of water and nutrients, and phenotyping. It will be discussed how models help us in exploring new avenues, and how the combination of models and sensors is powerful in both monitoring and phenotyping

Keywords: crop simulation, growth, development, plant architecture

MODELLING SULPHUR ALLOCATION AND PARTITIONNING IN HIGH S-DEMANDING SPECIES OF THE BRASSICACEAE FAMILY

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Sulphur (S) is a meso element in plants ranking in need next to after N, P and K. Due to its presence in a wide range of organic compounds (proteins, glucosinolates, glutathione, phytochelatins, vitamins…), it plays a central role in essential functions such as essential amino acids and hormone syntheses, defense mechanisms against (a)biotic stresses, heavy metal chelation, regulation of redox status. Vegetables of the *Brassicaceae* family, like cauliflower, broccoli, cabbage, and Brussels sprouts, are high S-demanding species because of their high contents in S-rich compounds (glucosinolates, methiine and their by derivatives) which also influence organoleptic properties and were shown to reduce the risk of several degenerative diseases. The importance to monitor S fertilisation in these high S demanding species, have emerged for the last decades when drastic environmental policies have led to soil S oligotrophy mainly due to reductions in industrial SO_2 emissions (protocols of Helsinki, 1985; Oslo, 1994; Kyoto, 1997). In this context, an optimised management of S nutrition can be supported through a modelling approach of plant S requirements. This approach has recently been developed in rapeseed, a crop species of the *Brassicaceae* family which is particularly sensitive to S limitation during the vegetative phase. Therefore, modelling S requirements and allocation within the main plant compartments could be a helpful tool to correct early deficiencies. The model *SuMoToRI (Sulfur Model Towards Rapeseed Improvement*, Brunel-Muguet et al., 2015) was built to predict rapeseed growth, S allocation (between plant parts) and S partitionning (organic vs. mineral) until the onset of pod formation in relation to S availability. It introduces novel features compared to other mineral-driven crop models because it considers the specificities of S mineral storage in leaves during the vegetative phase. It could be further adapted for Brassica vegetables by taking into account their specific temporal and spatial dynamics of S fluxes.

Keywords: Brassica, Sulfur, Sulfate, Model, Remobilization

SIMULATION OF A REFERENCE LINE FOR PLANT GROWTH IN ROSA CHINENSIS CV. AND FICUS BENJAMINA

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Microclimate (CO_2, light, temperature and relative humidity) and irrigation are important factors for plant growth, development and quality in ornamental horticulture. To optimize plant growth, actual plant growth can be measured and compared with a desired growing pattern. Using the deviation between measured and simulated growth, growers can decide whether and in which way the microclimate or irrigation needs to be adjusted. In this decision, costs associated with climate control and irrigation must also be taken into account. This will help growers to find a proper balance between cultivation costs and plant growth. In this study, flowering pot roses (*Rosa chinensis* cv.) and non-flowering *Ficus benjamina* were grown from cutting to mature plant in a controlled greenhouse environment. Growing conditions, microclimate as well as plant spacing, closely resembled the ones used in commercial greenhouses. Microclimate, soil water content and potential, leaf temperature, sap flow, stem diameter and leaf thickness were continuously measured on three plants of both species. In addition, discontinuous measurements of leaf and stem water potential, photosynthesis, transpiration and stomatal conductance were performed. These measurements were used to optimize a mechanistic plant model, which allows simulation of a plant growth reference line.

Keywords: ornamental horticulture, mechanistic modelling, plant monitoring, sap flow, stem diameter, leaf thickness

PREDICTING THE DORMANCY AND BUD BREAK DATES FOR GRAPEVINES

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Bud-Break is one of the most critical stages in grapevines because it is the beginning of active growth and its prediction is useful for more accurate scheduling of activities in the field. However, to predict that stage is tough for growers due to unobservable transition points in phenology of dormancy. In that way, the objective of this study is to predict the bud break determining the induction and release of dormancy stages in Grapevine for cultivars Cabernet Sauvignon and Chardonnay. For this purpose, samples of 18 nodes were collected during three years, from 2013 to 2015, twice per week for each variety since July 7th until the bud-break in the field. The nodes were placed at forcing conditions at 24 °C and the number of days among sampling and bud-break were recorded. The dormancy stage was identified according to the time from sampling and bud-break (endo-dormancy more than 30 days and endo-dormancy less than 30 days). It was found that the onset of dormancy was at the same time for both cultivars. However, different requirements of thermal time and chilling units were observed between cultivars. The lack of differences in dormancy induction suggested that this process could be driven by photoperiod changes and is associated with the minimum rate of change in day length, which coincided with the beginning of dormancy. Chilling unit accumulation led the prediction of the endodormancy release and growing degree days accumulation can explain ecodormancy release and bud break. In conclusion chilling and thermal unit requirements and thresholds were identified for evaluated cultivars allowing the prediction of the dormancy release and bud break.

Keywords: Chilling units, thermal time, base temperature, prediction, Cabernet sauvignon, Chardonnay

SIMULATING GROWTH, FRESH WEIGHT AND SIZE OF INDIVIDUAL FRUITS UNDER WATER AND NITROGEN LIMITATIONS WITH THE CROPGRO-TOMATO MODEL

Raquel Rybak [1], Kenneth Boote [2], James Jones [2], Lincoln Zotarelli [2]

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Crop growth models are valuable tools to understand the impact of water and N fertilization management on tomato production. The CROPGRO-Tomato model simulates fruit fresh weight and size based on simulated dry weight per fruit, a dry matter concentration that varies as a function of fruit physiological age, and a diameter function dependent on fresh weight per fruit. But there are insufficient connections of these functions to the model's simulation of water or N stresses. The existing water and N stress factors in the model were linked to new equations that affect timing and rate of dry weight growth per fruit and dry matter concentration of individual fruits. The model with these modifications and the reducing factors SWFAC, TURFAC and NSTRES was successfully used to predict the stress-induced variations in dry matter concentration, and reductions in dry and fresh weight growth and size of single fruits, as well as reductions in total crop growth and fruit yield. The newly-added subroutine for predicting dry matter concentration, fruit fresh weight, and size, along with coupling to water and N stresses make the improved model a valuable risk assessment tool for predicting fresh market production and quality of tomato.

Keywords: Tomato, crop modeling, fruit growth, fresh weight size, water deficit, nitrogen deficit

THE EFFECTS OF DIFFERENT LED COLOURS ON TOMATO CROP GROWTH AND PRODUCTION

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The rates of photosynthesis and light use efficiency for Solid State Lighting (SSL) modules that produce white, green, red, blue, amber and red+blue have been determined in the EU-funded HI-LED project. The effects of different LED light colours and levels on crop photosynthesis and seasonal growth and production were quantified with the INTKAM crop growth model. INTKAM was extended with 1) wavelength distribution of different LED colours, 2) light extinction profiles for LED lights of different wavelengths, 3) energy content of different wavelengths, and 4) photosynthetic efficiency of different LED colours. Various scenarios were examined, in which different LED colours were or were not combined with solar radiation, and varied over the day. The scenario studies made use of a greenhouse climate, varietal characteristics and crop management information that were realized in a tomato experiment in 2013 at the experimental facilities of Wageningen UR in Bleiswijk, The Netherlands. The relative efficiency of the photosynthesis rate was a dominant factor, as was the duration of the LED lighting. The differences in transmission and reflection (combined in extinction) were of relatively lower importance. The effects of relative efficiency of the photosynthesis rate became apparent when comparing simulation results assuming exposure to LED without and with background solar radiation. The differences in total crop growth were strongly associated with the relative efficiency of the photosynthesis rate. The effects of duration can be explained by the non-linearity of the photosynthesis-light response curve.

Keywords: LED lighting, Intkam model, tomato growth and production

MODELLING THE INFLUENCE OF LIGHT QUALITY AND QUANTITY ON LETTUCE LEAF LENGTH

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Light plays a major role in regulating all aspects of plant morphology and development via a range of photoreceptors. The photoreceptors can be roughly grouped in to three groups based on the colour of light they are most responsive to blue (phototropins and cryptochromes), red:far-red ratio (phytochromes) and UVB (UVR8). In a series of experiments we grew lettuce two lettuce varieties, Amica and Alega, under 24 different LED light treatments and measured the influence of light quality on growth and leaf morphology. The LED light treatments examined four light variables 1) red:blue ratio, 2) red:far-red ratios, 3) light intensity and 4) proportion of green light in the spectrum. A model was developed to calculate leaf length under any light mixture containing red, blue, green and far-red light. The model was based on a series of assumptions. There is theoretical dark-leaf-length, which is the length a leaf would grow in darkness if there were no energy or carbohydrate restrictions. Both blue and red light photoreceptors impose an additive restriction on leaf growth that reduces leaf length as light intensity increases. Far-red light acts to reduce the growth restriction imposed by red light via its influence on phytochrome, causing leaf length to increase. Green light reduces the growth restriction imposed by cryptochromes causing leaf length to increase. The parameterised models had good fits with the measured data (R^2 0.86). The model can be applied to all morphological parameters and will be useful for designing light treatments and predicting/testing plant light responses. The differences in model parameters between varieties can be used to quantify light responses to different regions of the spectrum, information that may help plant breeding.

Keywords: LED, Lettuce, photoreceptors, leaf morphology

A COMPARTMENTAL EPIDEMIOLOGICAL MODEL FOR BROWN ROT SPREADING IN STONE FRUITS ORCHARD

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Brown rot is one of the main polycyclic diseases in stone fruits and in absence of chemical treatments and presence of favorable environmental conditions it can decimate peach crops. A better understanding of the mechanisms underlying its spreading in orchards is therefore mandatory to promote a reduction in the use of pesticides and adapt agronomic practices to possible climate change scenarios. We developed a simple ordinary differential equation model to describe temporal dynamics of brown rot spreading in a fruit tree orchard. We parametrized the model by using field and laboratory data gathered in 2014 and 2015 from a peach (*Prunus persica*) orchard at Avignon (southern France). Data show temporal trajectory of fruit status (i.e. resistant, susceptible, infected) and size and of pathogen densities. Comparisons with empirical evidence show that the simulated dynamics are consistent with reality. We eventually used the model to study epidemiological consequences of cultural practices such as fruit thinning and fertilization.

Keywords: model ; peach ; brown rot; moniliosis ; control .

A MULTI-SEASONAL MODEL OF PLANT-NEMATODE INTERACTIONS AND ITS USE FOR DURABLE PLANT RESISTANCE DEPLOYMENT

Samuel Nilusmas , Mathilde Mercat, Thom Perrot, Suzanne Touzeau, Vincent Calcagno, Caroline Djian Caporalino, Philippe Castagnone Sereno, Ludovic Mailleret

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Root-knot nematodes of the genus *Meloidogyne* are soil-borne, little mobile, polyphagous pests which threaten important sheltered crops such as vegetables or small fruits. They attack plant roots to feed and reproduce and have a major impact on crop yield. Most eco-friendly plant protection strategies are based on the use of resistant crops. The emergence of virulent nematode variants, which are adapted to the resistance, challenges the durability of such methods. Because virulent root-knot nematodes exhibit a reduced fitness on non-resistant crops, combining both resistant and non-resistant plants can help increase the efficacy and sustainability of resistance-based nematode control. Since nematodes have poor intrinsic dispersal ability, the association between resistant and non-resistant plants should rely on crop rotation over cropping seasons, rather than on spatial arrangements. We proposed a semi-discrete model describing the population dynamics of plant roots and of nematodes within and over cropping seasons. This model, inspired by epidemiological concepts, was fitted to literature data on the within cropping season dynamics of non-resistant plants and avirulent nematodes; it was then extended to also account for resistant plants and virulent parasites. The model was used to compute optimal crop rotation strategies with respect to the maximization of different proxies for crop yield over different horizons of time (typically 5 to 40 cropping seasons). Robustness of the results to parameter values was assessed using sensitivity analyses. Further combinations of resistance based control of nematodes with other agronomic practices (solarization, rotations with non-host, trap or poison plants…) were also discussed.

Keywords: epidemiology; nematode; resistance

TOPIC 3

Methodological issues for plant systems modeling

This topic will address important issues concerning methodological advancements for model calibration, selection and integration.
This session will present novel strategies or applied examples in model comparison and evaluation, model calibration (numerical estimation of parameters, identifiability studies, methods for automatic image analysis…), model simplification (quasi-steady state approximation, variables or reactions lumping, sensitivity analysis…) and model integration (connection and communication among existing models or different time/space scales, meta-model).

Oral presentations (21th September am)

REDUCTION OF PARAMETER UNCERTAINTY AND GENOTYPIC DIFFERENTIATION IN PLANT GROWTH MODELS

Paul-Henry Cournède

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In the recent years, plant growth models have opened new perspectives to unravel the genotype x environment interaction. Generally speaking, plant growth models are formalized as parametric dynamic systems with general state-space representation. Ideally, a genotype should be characterized by one unique set of parameters, at least for some range of environmental conditions (corresponding to the famous “one genotype=one set of parameters” of Tardieu, Trends in Plant Sciences, 2003), but reversely, two different genotypes should also be characterized by two different sets of parameters.

To achieve this goal, it is generally considered that models should describe with enough precision the involved biological processes (Yin et al., J. Exp. Bot., 2010). With this objective in mind, there has been an important tendency to refine plant growth models. For example, the traditional crop or process-based models have been transformed to take into account plant architecture, in order to refine the physiological functioning as well as the description of plant-environment interaction by considering more local scales (Vos et al., J. Exp. Bot., 2010). Another perspective is to integrate cellular regulatory networks into plant models (Baldazzi et al., In: Crop Systems Biology, 2016). The objective is for example to deduce physiological functions from the enzyme concentrations predicted by the network.

A classical consequence of this refinement process is that parameterization can become a very complex issue, resulting in model uncertainty impeding both the predictive capacity of models and their ability to properly differentiate between genotypes.

Our talk will present a few methodological approaches that can be used to face these difficulties. First we will recall a few elements on the assessment of uncertainty in modelling, particularly in relation to Bayesian parameter estimation (Cournede et al., MMNP, 2013). Then, we will show how sensitivity analysis can be used in the parameterization process of complex models to help develop a parsimonious approach and reduce both the uncertainty on the most influential parameters and uncertainty on model prediction. Finally, we will show how inter-genotype variability can be accounted for in plant models via proper statistical test procedures. The different methods will be illustrated on several examples.

Keywords: parameter estimation, model uncertainty.

APPLICATION OF STRUCTURAL EQUATIONS MODELING (SEM) IN HORTICULTURAL STUDIES

Ebrahim Hadavi

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Structural equations modeling (SEM) is among new statistical tools. While it had found a large application in other research fields like social science it is considered new to agriculture and horticulture science. It can help to uncover and visualize the key important points of interest out of the results in a concise manner. It can suggest us the path of observed effects in ANOVA analysis. SEM analysis gives more weight to the correlation between variables than does ANOVA. By putting both analyses together, we can obtain a more comprehensive output. We have used this analysis tool in many works together with ANOVA analysis, and some of them are already published. We conclude that SEM could be used as a powerful tool to apply path analysis to data sets in different disciplines in Horticulture science. We will provide some samples among our works in which SEM analysis is applied in evaluation of response of cut flowers to vase solutions to response of plants to applied foliar treatments to show some possible applications for this technique.

Keywords: structural equations modeling (SEM), path analysis, horticulture

UNCERTAINTY ANALYSIS OF MODIFIED VEGSYST MODEL APPLIED TO A SOILLESS CULTURE TOMATO CROP

Antonio Martinez-Ruiz, Irineo López Cruz, Augustín Ruíz-García, Joel Pineda-Pineda, Armando Ramírez-Arias

Universidad Autónoma Chapingo, Chapingo, Mexico

Over the last decades, the soilless culture technique has rapidly progressed in several developed countries linked to control environment and automation. Several crop growth models have been developed for decision support systems, so it is important to estimate the uncertainty associated to the predicted variables of these models previously to their application. An uncertainty analysis aims to know quantitatively the variability of model components for a specific situation and the derivation of an uncertainty distribution for each state variable and model output. Recently, the VegSyst model was developed to assist the Nitrogen (N) supply and irrigation management for some horticultural crops. The basic input data are measurements of air temperature, relative humidity, and solar radiation which are climatic data that are commonly measured, by growers, in the greenhouse. The model was developed assuming non-limiting conditions of water and N use. The aim of this research was to modify the VegSyst model including crop transpiration (ET) and leaf area index (LAI) in order to improve the prediction of dry matter production (DMP), N uptake, and transpiration rate for a soilless culture using plastic bags filled with “tezontle” (volcanic sand) as substrate. Crop transpiration was simulated by the Baille model. LAI was modeled using accumulated normalized thermal time and photosynthetically active radiation. An experiment with a tomato crop was carried out during the autumn-winter 2015 in a greenhouse located at University of Chapingo, Mexico. The collected data were used to carry out an uncertainty analysis in which the inputs were the model parameters and the outputs were the predicted ET, DMP, LAI, and crop N content. Probability Density Functions were defined for each model parameter to calculate the corresponding statistics and histograms of the model outputs. Results showed that ET, DMP and LAI can be predicted better by the model than N content.

Keywords: Mineral nutrition, Simulation model, Water uptake, Decision Support System

GRAPHICAL REPRESENTATION OF MODEL FIT AS AN AID FOR INPUT SELECTION

Luis Carlos Miranda Trujillo[1], Irineo López Cruz [2], Bruno Lara [3], Uwe Schmidt [1]

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The selection of input variables is the most sensitive stage of model building, involving technical skills as well as expert knowledge of the problem to be addressed by the model. One way to improve model fit is to provide it with more input information, i.e. more input signals. However, depending upon the model's type and the specific algorithms involved, adding a large number of inputs can also lead to bad model fit. An additional reason to keep the model simple is the computation cost, both during training and running simulations. It also implies a higher cost in sensors and equipment, if the inputs are expected to be measured.

This work proposes a new type of graphical method which can be an aid to visualize the relative contribution of a single input to the model fitting. The diagram consists of two reference lines, representing the simplest (less input variables) and most complex (all available inputs) models. A number of points represent the model fit of the models created by the addition (in the first case) and subtraction (in the second) of a single input variable. In several examples, the model fit is calculated as MSE after 500 training epochs of an Artificial Neural Network. The examples include 4 different models inside a tomato greenhouse: Climate prediction, crop leaf temperature, crop transpiration rate and crop photosynthesis rate. The distances from the individual points to the two reference lines give a clear hint on which input signals have the best contribution to model fit and should be considered to be included in the final model. Although these examples make use of the MSE as measure of model fit, the prosposed graphical procedure allows to compare models using any quantitative measure.

Keywords: Greenhouse models, Input selection, Graphical methods, Goodness of fit

DETERMINATION OF CELL WALL ELASTIC MODULUS USING A MICRO-MECHANICAL COMPRESSION MODEL OF APPLE TISSUE

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The mechanical properties of fruit tissue determine quality attributes such as firmness, and susceptibility to mechanical damage. Fruit tissue is a heterogeneous material, composed of a microscopic cell wall network under tension by turgid cells. Consequently, the mechanics of the cell wall network determines to a large extent the mechanical properties of the tissue. However, measurement of the cell wall properties in situ is difficult and a large uncertainty exists about the value of the cell wall's elastic modulus. In this contribution, a methodology is presented to estimate the elastic modulus using computer models of the histology of tissue. Compression experiments were performed in silico using a hygro-mechanical model that computes the stress development in the cellular tissue during deformation in the compression test. The elastic modulus of cell walls was estimated by fitting the simulated stress-strain curves to experimental curves of apple parenchyma tissue. Uing the model, the effect of different parameters (turgor pressure, cell size, porosity) on the compressibility of the tissue was then also simulated. Compression resistance of apple parenchyma increases with increasing turgor pressure of the cell wall, and decreasing cell size and porosity.

Keywords: micromechanical properties, Stress-strain, virtual tissue generator, mathematical modeling, postharvest

A COMPARISON OF BAYESIAN AND CLASSICAL PARAMETER ESTIMATION METHODS IN GREENHOUSE CROP MODELS

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Parameter estimation in crop growth models not only is useful in improving predictions but also it is necessary. However, some theoretical questions related to the improvement in predictions accuracy by model calibration need to be answered. Furthermore, there are also several unanswered practical questions on parameter estimation of crop models. For some researchers the issue of what data should be used in model calibration is still an open question. There is not general consensus on what goodness-of-fit criterion should be used. Also researchers do not know what sequential or simultaneous calibration should be preferable. Which and how many parameters should be adjusted and how, the information coming from the individual processes and overall system behaviour should be combined. Two main paradigms are identified regarding crop growth models calibration: parameter estimation with classical methods and Bayesian parameter estimation. In spite of that the last approach has several advantages on the classical one only few studies have been applied in crop growth models and there are no studies at all in case of greenhouse crop models. In the present work a comparison between the classical procedure of nonlinear least squares and Bayesian parameter estimation is carried out. This paper is focused on methodological issues concerning classical and Bayesian parameter estimation approaches. A two state variable greenhouse crop model is used in order to show both strengths and also weakness of both paradigms. First, the classical parameter estimation the lettuce model was calibrated by a well-established nonlinear least squares procedure. Next, for the Bayesian method, a prior parameter distribution was specified for the model parameters. After that, the posterior parameter distribution was computed by using the Bayes' theorem. The second step implies the use of numerical solutions due to the complexity of greenhouse crop models. Thus, both the importance sampling and

the Metropolis-Hastings algorithms were implemented. Results showed indeed several advantages for Bayesian parameter estimation method.

Keywords: Greenhouse lettuce crop, Nonlinear Least Squares, Importance sampling, Metropolis-Hastings algorithm

A MODEL-BASED APPROACH FOR PEACH FRUIT TRANSPIRATION PROCESS AND ITS GENETIC VARIABILITY

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Transpiration plays key role in fruit growth through water losses and thus can impact fruit quality through sugar concentration. Here, we propose to complement the Virtual Fruit model so that it can describe the genetic variability of fruit transpiration through the relationship between cuticular surface conductance and fruit growth. Data of cuticular conductance and corresponding fruit mass were collected on 14 genotypes. These observations data were selected to estimate the values of all the parameters of the fruit surface conductance sub-model. A multiple stage approach was adopted for parameter estimation. First, different Global Sensitivity Analysis methods were carried out to assess the importance of the parameters of the Virtual Fruit Model describing the link between fruit surface conductance and fruit fresh mass. Next, for the model calibration, as traditional estimation methods (gradient-based) fail to arrive at satisfactory solutions, a stochastic Differential Evolution optimization algorithm was applied regarding its ability of solving such problems. Several estimation steps were conducted and compared through model validation. The approach combined sensitivity analysis, correlation analysis and variability analysis results, and optimization algorithms. It was conducted recursively to find feasible solutions for all genotypes. The obtained results show the interest of such as approach.

Keywords: optimization algorithm, fruit surface conductance, Sensitivity Analysis

NEURO-FUZZY MODELING OF WEEKLY HARVEST RATES OF GREENHOUSE TOMATOES

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Year-round production of greenhouse tomatoes have the challenge of balancing the crop between vegetative and regenerative growth-modes, to fulfill the short and long term production goals. The status of the crop, the management of the climate and crop directly affects the crop development, which in turn affects the production rates. Knowing the expected production it is useful for growers for steering the crop and make decisions on crop, climate and labor management. However, weekly harvest rates of tomatoes have a non-steady fluctuating pattern that it´s challenging to predict accurately. An adaptive neuro-fuzzy (ANFIS) model with a Sugeno-type inference system was implemented to predict weekly harvest rates as a function of environmental parameters and plant morphological features, usually recorded by growers. The output of the model are the variables of interest including weekly harvest rates (kg/m^2) and fruit size (g). The inference system was derived from data from a two year experiments with beefsteak tomato. The results of the model are improved when compared to those obtained with dynamic neural networks.

Keywords: Black-box model, controlled environment agriculture, decision support, harvest rates

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TOPIC 4

Multi-scale, integrated approaches

The integration of processes and mechanisms measured at different scales from gene to organ are a main issue to understand and predict the complexity of biological systems. This section will focus on novel approaches and example that integrate the genetic and physiological controls into mechanistic process-based models, or that link plant/organ structure and functions.

BOTTOM-UP AND TOP-DOWN APPROACHES ' THE VALUE OF MODELLING IN TRAIT DISSECTION AND PHENOTYPIC PREDICTION

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Substantial genotype x environment interactions impede yield improvement of many crops. The value of complex traits such as yield, and their associated genetic controls typically vary across environments (‘*context dependent*’), thus impeding breeding progress. Here, we outline how ecophysiological modelling and functional whole-plant/crop modelling can be used to dissect complex traits and identify component traits more stable across environments (‘*context independent*’). Such a top-down approach, by breaking down complex context-dependant traits into simpler context-independent traits, allows the identification of genetic controls which are more stable across environments and genetic backgrounds. Using a complementary bottom-up approach is also relevant for crop improvement, as models allow quantitative evaluation of trait performance across a broad range of environmental conditions. Models incorporating physiological understanding of traits have been used to scale-up known effects of ‘simple’ traits from the organ to the crop level. Applying such models to the targeted environments has allowed the identification of key traits associated with drought adaptation in Australia. Examples will be presented to illustrate the relevance of modelling in trait dissection and phenotypic prediction

Keywords: crop model, multi-scale model, gene-to-phenotype model, genotype x environment interactions, drought, wheat, maize, target environments, crop improvement.

A KINETIC MODEL OF SUGAR METABOLISM IN PEACH FRUIT ALLOWS THE EXPLORATION OF GENETIC VARIABILITY

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The organoleptic properties of peach, as fruit in general, largely depend on the accumulated sugars and acids. From sucrose, glucose and fructose, main sugars found in peach, fructose is the sweetest one. While commercial peach has equivalent fructose and glucose concentration, some wild or ornamental accessions display an imbalanced fructose-to-glucose ratio with a very low fructose concentration. In addition to genetic control, sugar metabolism is driven by fruit development and environment. The relative role of biochemical strengths and gene regulation in the elaboration of fruit sugar content at maturity is not well known. As the complex interplay between synthesis, degradation, transport and storage held in the cell is difficult to formulate, mathematical modelling appears to be an effective tool to challenge the issue. Thus, on the basis of profiling data, we developed a kinetic model of sugar metabolism in peach fruit. It simulates the evolution of sucrose, glucose, fructose and sorbitol concentrations during fruit development. A particular attention has been given to represent cellular compartmentation (cytosol and vacuole) in order to modulate the availability of the metabolites for the enzymatic reactions. The model was parameterized for different peach genotypes including a particular phenotype with low fructose-to-glucose ratio. It described well genetic variability. It was then used to further explore the system including the mechanisms driving genotypic differences.

Keywords: mathematical model, P.persica, sugar concentrations, enzyme capacities, compartimentation

MODEL-BASED ANALYSIS OF THE GENETIC VARIABILITY IN TOMATO FRUIT GROWTH UNDER CONTRASTED WATER CONDITIONS

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Drought stress seriously limits plant and crop productivity and is one of the major abiotic stress factors, which represents the primary cause of crop loss worldwide. Understanding mechanisms governing plant adaptation to water deficit and identifying genes, QTLs and phenotypes that will enable a plant to maintain yield under water deficit (WD) conditions is a crucial challenge for breeder and growers, in the light of current issues concerning climate change. In the present work, 119 recombinant inbred lines of a population of *Solanum lycopersicum* were phenotyped under control and WD condition. Data of plant water status, fruit growth and composition were used to calibrate a process-based model describing water and carbon fluxes in growing fruit as a function of plant and environmental factors, in order to analyse the principal mechanisms involved in the plant adaptation to WD. The model calibration was performed assuming the same value for each parameter in controlled and WD conditions. Six parameters selected through a sensitivity analysis, were estimated using the NSGA2 evolutionary algorithm in order to minimize model prediction error of fruit dry and fresh masses. The variability in model parameters allowed us to explore diverse genetic strategies in response to water deficit.

Keywords: fleshy fruit, quality, ideotype, Solanum lycopersicum, Virtual fruit model, water stress

MODELLING THE VASCULATURE OF APPLE FRUIT

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To improve the shelf life and postharvest quality of apple fruit, numerical simulations, for example with finite element modelling or computational fluid dynamics, are often used. An example is a simulation of water transport throughout the fruit, which is linked to several storage disorders. Crucial in these simulations is the shape of the studied produce and the vasculature, which is the fruits transport system for liquids. While the general shape of these structures is known, there is a lack of realistic 3D models of vasculature incorporating biological variability. Here we present a method to generate variable structures of vasculature for apple fruit. The generated geometries are based on statistical evidence, obtained by using X-ray Computed Tomography. The main vascular bundles in the generated geometries were constructed using a shape description method onto the corresponding vascular bundles in the scanned produce. The smaller branches were generated with a space colonisation algorithm. The resulting models can directly be used as Computer-aided design input in numerical simulations of water transport.

Keywords: postharvest, finite elements, vasculature

CELL DIVISION, ENDOREDUPLICATION AND EXPANSION PROCESSES: SETTING THE CELL AND ORGAN CONTROL INTO AN INTEGRATED MODEL OF TOMATO FRUIT DEVELOPMENT

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The development of a new organ is the results of coordinated events of cell division and expansion. Fruit growth starts immediately after bloom with intensive cell division. As development proceeds, the proliferative activity of cells progressively slows down giving way to a phase of pure cell enlargement, during fruit growth and ripening. In many species including tomato, the transition from cell division to expansion phases is accompanied by a repeated DNA duplications without mitosis, a process called endoreduplication. The exact role of endoreduplication is still unknown, but a strong correlation between cell ploidy (i.e number of DNA copies) and final cell size has been observed in different species (Bertin, 2005; Lee et al., 2004; Melaragno, Mehrotra, & Coleman, 1993; Rewers, Sadowski, & Sliwinska, 2009) , suggesting a role of endoreduplication into the control of organ growth (Breuer, Ishida, & Sugimoto, 2010; Chevalier et al., 2011). Modeling the way cell division, endoreduplication and expansion processes interact together is crucial to understand the emergence of specific morphological traits (fruit size, weight, shape and texture) and their dependence on environmental factors. Historically, a big debate has opposed two constrasting views, the cellular theory vs the organismal, that set the control of organ growth, respectively, at the level of the individual cell or of the whole tissue (Beemster, Fiorani, & Inzé, 2003; Harashima & Schnittger, 2010; John & Qi, 2008). Recently, a consensus view (neo-cellular theory) is starting to emerge according to which, although individual cells are the units of plant morphology, their behavior (division, expansion) is not autonomous but coordinated at the organ level by specific growth-related substances, thus creating an effective interaction between cellular and whole-organ control (Beemster et al., 2003). A first integrated model of tomato fruit has been recently developed that explicitly accounts for the early phase of fruit development, coupling cell proliferation and expansion phases (Baldazzi et al., 2013; Baldazzi, Bertin, Genard, & Génard, 2012). Here we propose an improved version of this model that includes cells endoreduplication and the possible effect of the ploidy level onto cell expansion capabilities. The model is used to investigate the interaction among the cell division, endoreduplication and expansion processes, in the perspective of the new cellular theory. In particular, different control schemes (either cell or organ-controlled) are tested regarding specific model parameters and simulation results compared to observed data. The model shows that a pure cell-based control is not capable of reproducing the observed cell size distribution, and an organ -based control is needed in order to get realistic cells and fruit size.

Keywords: division, expansion, endoreduplication, development, tomato, multi-scale

MULTICELLULAR MODELLING OF PLANT TISSUES AS HYDRAULIC SYSTEMS

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At the cellular level, plant growth results from the competition between the so-called turgor pressure and mechanical resistance from the cell walls. The turgor pressure itself results from a difference of osmotic pressure between the interior and the exterior of the cell: the plasmic membrane is semi-permeable, so that a higher solute (sugars, ions) concentration inside the cell leads to a water flux towards the cell and to a pressure rise; if the pressure exceeds a given threshold, the cell walls extend and the cell grows. Recently, different models of plant growth have attempted to incorporate mechanics of cell walls in tissue development [Boudon et al. 2015], but all of them make the assumption that turgor pressure is constant with time. In this work, we go one step further and include a model of the regulation of turgor pressure in a multicellular framework. The cell wall material is modeled as a continuous visco-elasto-plastic material characterized by an elastic modulus, a yield deformation, and a rate of synthesis of matter as in [Boudon et al. 2015]. Flows between cells occur through their membranes according to non-equilibrium thermodynamics, as a result from a difference in turgor and osmotic pressures. The value of pressure is not prescribed but emerges from the coupling of all these phenomena. Numerical simulations exhibit a highly non linear behaviour with respect to the governing parameters. We have identified two clearly distinct growth regimes: one regime that allows large growth

heterogeneities by amplifying the effect of differences between cells, and conversely another regime that smoothes differences out and yields a homogeneous growth. On the biological level, the first regime is well adapted to morphogenesis, whereas the second one is well adapted to homothetic growth after the differentiated tissues have been created. .

Key words: fruit growth, structural-functional model, cell mechanics, multicellular model

CHALLENGES IN MODELLING CLIMATE CHANGE EFFECTS ON THE PRODUCTIVITY OF VEGETABLE CROPS

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Research in applied plant sciences focusses on understanding plant performance and crop productivity under various environmental conditions. Major research goals are improving crop production systems and meeting the challenges of future food security. Yet, the prediction of plant performance and crop productivity remains a challenge. On the one hand, this is due to the variability of environmental conditions during plant growth and development. On the other hand, there is a large multiplicity in plant responses as well as interactions with the environment. Models aim at analysing such complex systems systematically. Here, we outline and discuss particular challenges in modelling climate change effects on the productivity of vegetable crops. First, we briefly show that predicting vegetable crop productivity requires more than just a straightforward knowledge transfer from results of climate change research on major agricultural crops to vegetable crops. E.g., these crops may differ in harvest organ and phenological stages at harvest. Second, we discuss the need of considering plant architecture for an accurate prediction of resource use efficiency. Crop models primarily aim at predicting dry matter production and, therefore, they use data on plant architecture only to a limited extend. However, plant architecture contributes significantly to the resource use efficiency of crops. Finally, we discuss how to cope with challenges in model parameterization, such as the source of model parameters, and model evaluation with respect to climate change impact research.

Keywords: vegetable, crop modeling, productivity, yield, climate change, plant architecture, virtual plant model, functional-structural plant model

INTRODUCING TURGOR-DRIVEN GROWTH DYNAMICS INTO FUNCTIONAL-STRUCTURAL PLANT MODELS

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Functional-structural plant models (FSPMs) offer the potential to explore the response of mutually interacting plants under conditions that are experimentally difficult to achieve. However, this requires a mechanistic understanding of plant development dynamics as influenced by their environment, which presents no trivial task. To date, FSPMs mainly focus on the plant-carbon relations and largely disregard the importance of plant-water status on organogenesis. Consequently, incorporating a turgor-driven growth concept, coupling carbon and water dynamics in an FSPM presents a significant improvement towards capturing plant development in a mechanistic manner. This was achieved by implementing an existing water flow and storage model interwoven with plant carbon dynamics in the GroIMP modelling platform. GroIMP provided the framework for combining the standard graph structure of FSPMs with differential equations solvers as well as a rate assignment operator, which enables the model to automatically adjust to networking plant structures and production of new plant organs. Furthermore, it allows visual exploration of the diel patterns of organ water content and growth. Integrated with existing FSPMs, this new concept opens an array of possibilities for FSPMs, as it presents a different formulation of growth in terms of local processes, influenced by local and external conditions. Additionally, it will allow an in-depth evaluation of plant developmental responses to drought scenarios.

Keywords: Sapflow, Modelling, Functional-Structural Plant Models, Mechanistic Growth.

MODELING THE GROWTH AND QUALITY OF GRAPE BERRY IN CHANGING ENVIRONMENTS

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Grape quality is a complex trait that mainly refers to berry chemical composition, including sugars, organic acids, phenolics, aroma and aroma precursor compounds. It is known that the composition and concentration of chemical compounds dynamically change along berry development and can be affected by genotypes (rootstock and scion), environment (light, temperature and water) and nutrient status (carbon and nitrogen). Moreover, the ongoing climate change is affecting the physiology of grapevine and ultimately wine quality and typicity. Therefore, a better understanding of the mechanisms controlling the accumulation of quality-related metabolites (both primary and secondary) in grape berry is essential to choose or maintain the vine and viticultural practices best adapted to a given growth region. Process-based models can mechanistically integrate various processes involved in fruit growth and composition, and reproduce the plant responses to weather and management practices, making them a promising tool to study the response of berry quality to those factors. Our research activities in modeling the growth and quality of grape berry in changing environments will be summarized. First, we will present

models for berry growth, sugar concentration, and anthocyanin composition over berry development in response to various growth conditions. Second, approaches how to model organic acids and other metabolites will be discussed. Finally, a functional-structural plant model offering the possibility to integrate all afore-mentioned models in a single conceptual frame, as well as soil water status and leaf gas exchange, will be presented. This will provide an overview of recent progress in models of grapevine and open discussions about how to use models to better predict the effect of climate on fruit quality.

Keywords: vitis, grape quality, model

AN INTEGRATED PLANT AND FRUIT MODEL FOR GRAPEVINE (VITIS VINIFERA L.)

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Irrigation is of crucial importance for grapevine cultivation in many wine regions, and will most likely become even more indispensible with the pending doom of climate change. While sufficient irrigation is desirable for the plant's water status, water is scarce, and furthermore grape quality usually benefits from slight to moderate drought conditions, especially for wine grapes. To optimise irrigation, in depth knowledge of plant and fruit development, as well as their underlying mechanisms is imperative. In this study, this knowledge is sought through a combination of intensive plant and fruit measurements and mechanistic modelling. The modelling part consists of a plant model combined with a fruit model. While plant water status models exist, and attempts have been made to mechanistically model grape berry growth, no integrated model for plant and fruit development in grape is available. Here we use an extensive field dataset on Chardonnay grapevines (*Vitis vinifera* L. 'Chardonnay') to develop and test for the first time a coupled plant and fruit model to simultaneously simulate plant and fruit development. Through this modelling approach, we aim at further unravelling the delicate relationship between water availability and fruit growth and quality. This way, in the long run, irrigation scheduling and other vineyard management practices can be backed up by our mechanistic model, and optimised to obtain the preferred grape quality.

Keywords: Vitis vinifera L.; mechanistics modelling; fruit growth; water potential; sap flow; stem diameter

DESIGNING MIXED FRUIT-VEGETABLE CROPPING SYSTEMS BU INTEGER QUADRATIC PROGRAMMING

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Mixed fruit-vegetable cropping systems (MFVCS) are a promising way of ensuring environmentally sustainable agricultural production systems in response to the challenge of being able to fulfill local market requirements. Indeed, they combine productions and they also make a better use of biodiversity. These agroforestry systems are based on a complex set of interactions modifying the utilization of light, water and nutrients. Thus, designing such a system must optimize the use of these resources, by maximizing positive interactions (facilitation) and minimizing negative ones (competition). To attain these objectives, the system's design has to include the spatial and temporal dimensions of these interactions, taking into account the evolution of above-and below-ground interactions over a time horizon [1]. However, considerable amount of research has been conducted, on the one hand, to prove the interest of agroforestry [1], and on the other hand to propose models supporting cropping plan and crop rotations decisions [2], but to our knowledge, no model supports the spatial and temporal allocation of both vegetable crops and trees in agroforestry system. Therefore, we initially built a first MFVCS prototype using Weighted Constraint Satisfaction Problem but the resolution was limited to small scale systems (~25m²) [3]. In this paper, we explore larger MFVCS models (100m², 3 tree stages, four seasons/year) mixing up to 10 vegetable crops and one tree production using different solvers based on Integer Quadratic Programming. The limit of exact methods in solving the MFVCS problem, after tuning the solver parameters to improve convergence speed, are presented showing the need for approximation methods able to solve a large scale system with solutions of good quality in reasonable time, which could be used in interactive design with farmers and advisers.

Keywords: agroforestry, mixed fruit-vegetable cropping system, above-and below-ground interactions, spatial and temporal dimensions, integer quadratic programming

A CROP SIMULATION MODEL SUPPORTING MULTIPLE ECOSYSTEM SERVICES ANALYSIS IN APPLE ORCHARDS

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Ecological intensification holds the dual task of providing acceptable food production levels and preserving natural resources and functions. This duality can be analyzed with the concept of ecosystem services (ES), from which humans draw potential benefits. Apple tree orchards are agroecosystems and as such they deliver not only a fruit production but several other ES. ES present different types of relations that depend on the interactions occurring between their underlying ecosystem functions and on the agricultural management that impact them. The study of these relations is necessary to adjust agroecosystem management towards specific multiple ES profile goals.

We therefore suggest describing the functional transformations occurring in the apple orchard agroecosystem and the resulting services for a range of agricultural practices and pedoclimatic conditions using a crop simulation model: STICS. The model was parameterized and evaluated on two experimental apple orchard sites in the south-east of France, each consisting of three different agricultural management systems. The ES considered were nitrogen soil availability, climate regulation by GHG mitigation, fruit production and water cycle regulation. ES indicators and ecosystem function indicators derived from the model were then used to analyze the relations between multiple ES under the influence of existing or fictive agricultural management systems, in order to compare different apple orchard systems with respect to their multiple ES profile.

Keywords: apple orchards, multiple ecosystem services, STICS, indicators, agricultural management systems, pedoclimatic conditions.

POSTER PRESENTATIONS

CLIMATE CHANGES IMPACTS ON VALUES OF PHOTOSYNTHETIC PARAMETERS IN KIMCHI CABBAGES

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The objective of this study was to determine the effects of climate changes on physiological responses of Kimchi cabbages using the photosynthetic and biochemical models. The Kimchi cabbages were grown by climate changes scenarios, representative concentration pathway (RCP) 4.5 (Temp.; +3.4°C and CO_2 con.; 540 µmol mol^{-1}) and RCP 8.5 (Temp.; +6.0°C and CO_2 con.; 940 µmol mol^{-1}), respectively, using the extreme weather simulators. The control of Kimchi cabbages were transplanted using a soil bin at the field at 8th September, 2015. The photosynthetic light-response and A/Ci curves were observed and the photosynthetic parameters were estimated by the regression analysis or biochemical model. The maximum net CO_2 assimilation rate of control was the highest among all the treatments, while respiration rate showed the lowest. The light compensation and saturation points of control were 21.7 µmolm^{-2} s^{-1} and 727.7 µmolm^{-2} s^{-1}, respectively, which were the greatest. Maximum carboxylation rate, maximum rate of electron transport, and triose phosphate utilization rate of leaves applied with RCP 8.5 were 27.7 µmolm^{-2} s^{-1}, 67 µmolm^{-2} s^{-1}, and 6.6 µmolm^{-2} s^{-1}, respectively, those were lower than control. However, the mitochondrial respiration in the light of RCP 8.5 was 2.5 µmolm^{-2} s^{-1}, which was higher than approximately 1.3 times compared with control. Results indicated that RCP 4.5 and RCP 8.5 scenarios decrease assimilation rate and those were negative impacts on photosynthesis efficiency of Kimchi cabbages.

Keywords: photosynthetic model, biochemical model, carboxylation, photosynthesis, regression analysis

IMPACTS OF CLIMATE CHANGES ON LEAF MORPHOLOGIES, GROWTH, AND YIELD OF KIMCHI CABBAGE

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This study was to evaluate the impacts of climate changes on leaf morphologies, growth, and yield of Kimchi cabbage. The Kimchi cabbages were cultivated by climate changes scenarios, representative concentration pathway (RCP) 4.5 and RCP 8.5, respectively. RCP 4.5 and RCP 8.5 treatments were set with higher 3.4°C and 6.0°C air temperatures compared with field weather conditions and maintaining 540 µmol mol^{-1} and 940 µmol mol^{-1} CO_2 concentrations, respectively, using the newly developed extreme weather growth-chambers. The Kimchi cabbages were grown using a soil bin at the outside as control during autumn time, which they were transplanted at 8th September, 2015. The leaves in RCP 4.5 and 8.5 showed the tipburn disorders and those were much more rugged compared to leaves of control. There were better developed leaf nerves, thicker the mesophyll tissues, and greater cell sizes grown by RCP scenarios. The palisade tissues of control leaves were developed rectangle, while that of RCP 4.5 and RCP 8.5 were represented the abnormal type like as the difformis and rounds. Leaf length and width was not significant, while leaf area and yield of control were 29,355cm^2/plant and 10,496kg/10a, respectively, which was the greatest among all the tested treatments. The yield of RCP 4.5 decreased by 65% compared with that of control, however, the yield was not possible to calculate in RCP 8.5 causing head formation were collapsed. Results indicated that RCP 4.5 and RCP 8.5 scenarios retarded growth and those were negative impacts on leaf morphology and yield of Kimchi cabbages.

Keywords: Brassica campestris L., extreme weather, abotic stress, physiological disorder, environmental control

COMPUTATIONAL STUDY OF THERMAL PERFORMANCE OF AN UNHEATED CANARIAN-TYPE GREENHOUSE: INFLUENCE OF THE OPENING CONFIGURATIONS ON AIRFLOW AND CLIMATE PATTERNS AT THE CROP LEVEL

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The increasing cost of electricity often drives the farmers of the southern Mediterranean countries, to adopt the natural ventilation in order to provide greenhouse aeration. During the daytime, the roof and sidewall vents were opened to allow the excess heat to escape and cooler outside air to enter. Whereas, during the night time, these openings are mainly used to regulate the excess humidity in greenhouse which causes damage on plants due to the development of Botrytis cinerea.
In order to assess the effect of these roof and sidewall ventilation openings on climate inside the greenhouse, we have used a Computational Fluid Dynamic (CFD) to simulate the airflow circulation and climate distribution during the day and night.This study was conducted in a one hectare canarian-type greenhouse, the most widely used in Morocco, with a mature tomato crop.
The simulations were performed with the CFD model based on solving partial differential equations, which represent conservation laws for the mass, momentum, and energy, using CFD Finite Volume Method (FVM).
The model takes into account the virtual crop as a porous medium using the Darcy-Forchheimer model restricted to its inertial terms.
The results show that opening configurations strongly affects the airflow circulation under the studied greenhouse, which can generate a heterogeneous climate at the canopy level, especially during the daytime. Results have illustrated also, that there is a reverse flow from the leeward to windward side of the greenhouse at the crop level. Closing the north-south sidewall ventilation openings contributes significantly to the inside air velocity increase and to air temperature decrease at the crop level. Conversely, during the night time, climate distribution at the crop level is homogeneous on the whole greenhouse.

Keywords: greenhouse, CFD, tomato crop, insect screen, ventilation openings, airflow, microclimate

IMPROVEMENT AND VALIDATION OF A CFD MODEL TO SIMULATE THE THERMAL AND AIR ENVIRONMENT IN GREENHOUSES INSTALLED WITH HEAT PUMPS

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It is widely recognized that heat pumps have higher energy efficiency compared to oil fan heaters. Since heat pumps can be used not only for heating but also dehumidification and cooling, they are suitable for the Japanese climate, which is characterized by high temperatures and humidity during summer and low temperatures during winter. Many heat pumps are needed for warming the inside of a greenhouse as compared to oil fan heaters, which are usually used in Japan because the temperature and volume of the air exhausted from heat pumps were lower than that of the oil fan heaters. However, there is no guideline to install heat pumps at adequate places. We have developed a computational fluid dynamic (CFD) model to reproduce the air flow, heat, and gas dispersion in urban areas to evaluate the thermal environment. In this study, we improved and validated the CFD model for evaluating the thermal air environment in greenhouses installed with heat pumps. First, we added the model, which simulates the convective and radiative exchanges at greenhouse glasses and steel frames to the conventional CFD model. The validity of the modified CFD model was confirmed by comparing the results from the field observation. The temperature distribution in a greenhouse without vegetation was well reproduced with the actual measured value with an error range of 1-2 ˚C. Second, to evaluate the thermal condition in a greenhouse with vegetation, we added a function to the CFD model to consider the fluid dynamics influence of plants (an increase of wind velocity drop and turbulence), solar radiation (shortwave radiation), the long wave radiation attenuation, latent heat, sensible heat emission, water vapor, and CO_2 exchange. The spatially-averaged temperature and specific humidity around the vegetation obtained using the second modified CFD model were in good agreement with the 19 cases of measurements of the greenhouse. Further, the evaluation of the thermal and air environment in a large-scale tomato greenhouse will be discussed.

Keywords: Greenhouse, Heat pump, Computational fluid dynamic, Thermal and air environment

SHOULD THE FEED-BACK INHIBITION OF PHOTOSYNTHESIS AND THE ROOT-ZONE RESPIRATION BE INCLUDED IN CUCUMBER PRODUCTION MODELS?

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Mechanistic models, even highly sophisticated ones, that describe the growth of commercial greenhouse crops in order to improve climate control and plant management include neither a possible feedback mechanism of sink limitation on photosynthesis nor a loss of carbohydrates by root exudation. In order to address this problem, the effect of sink-source relations on photosynthesis and the CO_2 release in the root zone of hydroponically grown cucumber was investigated. Mature fruit-bearing cucumber plants were grown in aerated nutrient solution. The root containers were designed as open chambers measuring the CO_2 gas exchange in the root zone. A similar arrangement in a gas exchange cuvette enabled simultaneous measurements of the CO_2 gas exchange in the shoot and root zones. Reducing the sinks for carbohydrates by removing all fruit from the plants always resulted in a doubling of the CO_2 gas exchange in the root zone within a few hours. However, respiration of the shoot remained unaffected, and photosynthesis was only marginally reduced, if at all. The reason for this increasing root zone respiration could be the exudation of organic compounds by the roots and their decomposition by micro-organisms. This hypothesis requires further experimental evidence. Root exudation as carbon losses may have become a considerable factor in the carbon balance in the range below 20 g fruit dry matter per plant, *i.e.* below a plant fruit load of approximately 700 g. It would therefore make sense to include carbon leakage by root exudation in cucumber production models. In contrast, the inhibition of photosynthesis was measurable only at zero fruit load, which does not occur in cucumber production systems. Models that estimate production can therefore ignore an (end-product) inhibition of photosynthesis.

Keywords: Cucumber, exudation, fruit, sink-source relations

STOMATAL RESISTANCE MODELLING UNDER WATER RESTRICTION CONDITIONS BY MEANS OF DESIGN OF EXPERIMENTS, COMPARISON WITH THE JARVIS METHOD

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In greenhouses, reducing water consumption by increasing water efficiency is of high interest. Water need is linked to the plant transpiration, which itself depends on the stomatal resistance Rs. Up until now however, prediction of Rs through models was mainly conducted for open field conditions and very few models exist for greenhouse plants grown in pots. The aim of this work is to develop a dynamic model of Rs based on the full factorial design FFD under restriction conditions. Then, the model will be validated and its performance will be compared against the Jarvis model inside a greenhouse. The FFD is based on an optimization process to establish a polynomial relationship between Rs and the radiation, humidity and temperature. To implement the model, a set of experiments was conducted inside a 10 m^2 growth chamber equipped with Impatiens New Guinea pots under comfort condition. Rs was measured with a porometer and nine scenarios were tested. First the FFD model was implemented for comfort conditions. Then it was adapted to calculate Rsunder water restriction, through the introduction of a new multiplicative function depending on the growing medium matric potential. Once these parameters had been determined, the obtained FFD model was validated against experimental data recorded inside a greenhouse Impatiens crop, and compared with the Jarvis model. The FFD showed its ability to correctly simulate Rs under water restriction conditions. Its main advantage is that just few data was enough to fit this model contrary to the Jarvis method and it provided even better results. Hence, it could be useful to predict accurately the evolution of transpiration.

Keywords: Full Factor Design, stomatal resistance,matric potential

A FACILITY FOR MEASURING THE CO2 GAS EXCHANGE IN COMPLETE CROPS

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In many ecological and agricultural studies, the instantaneous response of plants to environmental effects is of fundamental interest. Many models have been developed to describe the effects of environmental conditions on plant growth and yield. The CO_2 gas exchange of the plants is a key process in these models. This is usually derived from measurements in leaf and plant cuvettes and then scaled up to crop level. However, conditions in the cuvettes differ from those in a fully developed crop. Moreover, measurements of the gas exchange in the root environment are mostly lacking or included in that of the shoot. Therefore, a system for measuring the CO_2 gas exchange in complete crops in eight almost airtight greenhouse cabins was designed. In addition to the aboveground components of plants, the gas exchange in the root zone can be measured in four troughs per cabin where temperature can be controlled (heating and cooling) independently of the greenhouse climate. In this facility, outside air is pumped into the cabins at air supply rates between 3 and 60 $m^3 h^{-1}$ per m^2 of ground area using mass flow controllers. Air can be heated before supplied if necessary. A second system pumps out the cabin air maintaining a pressure difference of 20 Pa to the environment. Technical pure CO_2 is supplied to the cabins using mass flow controllers in order to meet the required CO_2 concentration. In addition, outside air or air from the cabins can be pumped into the troughs at defined supply rates. Excess air leaves the troughs through the leakage in the coverage. A pump alternately conveys ambient air and air from the troughs into the CO_2 sensor. The CO_2 gas exchange of the root environment can be estimated from the CO_2 concentration of the air supplied externally and in the troughs, and the air supply rate. Finally, the CO_2 gas exchange of the shoots is calculated from the inlet

and exhaust air CO_2 concentration, the air and the CO_2 supply rates, and the CO_2 concentration and air flow rate originating from the root environment.

Keywords: Greenhouse, model, photosynthesis, root-zone respiration

MODELLING TOMATO PLANTS GROWN UNDER SON-T AND LED LIGHT

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In order to produce tomatoes during winter-time, when natural light intensity is low, there is a need for assimilation lighting. In the past, SON-T lamps mostly fulfilled this need for additional light. The major drawback with these lamps is that the light intensities that can be applied in practice are limited because of the associated heat production, which negatively affects the growth of tomato plants. This is one of the main reasons why more research is dedicated to the use of LED lamps. These lamps use less energy and produce less heat. But implementation of LEDs in practice is not very straightforward, because effects on plants are not yet fully understood. There is a lack of knowledge on how long and at which light intensities the plants have to be exposed. In order to get more insights in the effects of LED lamps, tomato plants (*Solanum esculentum*, cv. Foundation) were grown under either SON-T lamps (169 µmol m^{-2} s^{-1}) or a combination of SON-T (169 µmol m^{-2} s^{-1}) and LED (80 µmol m^{-2} s^{-1}) lamps. Plants were equipped with plant sensors and simultaneously measured sap flow and diameter variations of the fruit and the stem. Data from these sensors was used in a mechanistic plant model to simulate effects of assimilation lighting on water and carbon balances of the plants. A combination of sensors and models can be very useful in future management of assimilation lighting and in particular LED lamps.

Keywords: Tomato, Solanum esculentum, cv. Foundation, assimilation lighting, SON-T, LED, mechanistic plant modelling

TIPBURN DEVELOPMENT AND LEAF CALCIUM CONCENTRATION IN BUTTERHEAD LETTUCE AFFECTED BY ENVIRONMENTAL FACTORS AND CALCIUM ABSORPTION

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Tipburn is a severe problem in producing butterhead lettuce under artificial lighting and frequently develops as a consequence of decreased calcium concentrations in leaves. In this study, butterhead lettuce was grown in a plant factory equipped with artificial light and was subjected to different light intensities. Fresh and dry weight of shoots, the number of whole leaves, and the number of tipburned leaves were determined, and the relative growth rate was calculated. Furthermore, the rate of calcium absorption by roots and calcium concentration in leaves were determined to characterize the dependence of tipburn development on leaf calcium concentration and plant growth rates at varying light intensities. Fresh and dry weights of shoots, relative growth rate, the number of whole leaves, and the number of tipburned leaves significantly increased with light intensity. Associations existed between growth and tipburn occurrence. However, calcium absorption rate per plant also increased with light intensity in association with water absorption rate. This dependency of calcium absorption by roots on the ion mass flow was characterized by differences in the two parameters involved in the transpiration integrated model. Consequently, calcium concentrations in the entire plant and outer leaves increased with light intensity. In contrast, calcium concentration in the inner leaves remained approximately the same among different light intensities. This pattern can be attributed to the higher mass flow of calcium to outer leaves than to inner leaves, driven by transpiration, under high light intensities. Thus, a lack of calcium in the inner leaves resulting from rapid growth may contribute to the frequent tipburn development.

Keywords: artificial lighting, plant factory, soil-less cultivation, root calcium absorption, root water absorption

IMPROVEMENT OF IRRIGATION AND CROP PROTECTION IN A CUCUMBER GREENHOUSE CROP USING DECISION MAKING TOOLS

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Cucumber crops under heated greenhouses represent 72% of the total surface areas in France. Decision-support modelling tools have to be provided and adapted for growers to increase efficiency of climatic and irrigation parameters in greenhouse. Using physiological investigation and innovative tools, we proposed to improve cucumber crop management in the North-West of France. In order to improve water use efficiency of cucumber crop in greenhouse, decision making tools including vapor pressure deficit (VPD) analysis has been studied. The aim is to manage irrigation triggering not only by the amount of radiation perceived by the greenhouse (usual practice), but by the estimated transpiration rate of a cucumber crop. Transpiration rate could be appreciated through the calculation of $VPD_{leaf\text{-}air}$, deriving from leaf temperature measurements using infra-red camera, temperature of the greenhouse and air humidity. A threshold of irrigation triggering has been proposed for cucumber, and validated during two crop periods in a commercial greenhouse in the North-West of France. In a second experiment, the use of infra-red camera in association with fruit transpiration modeling is proposed to monitor fruit temperature during crucial day periods where dehumidification must be required to protect plant from condensation. This technique is essential in heated greenhouse due to sanitary risks

(*Dydimella bryoniae*, *Sphaerotheca fuliginea*,…) associated with the presence of free water in the surface of plant organs, notably fruits, as it could largely affect yield and fruit quality. Dehumidification could be driven by fruit temperature in the early morning critical phase, and results from a commercial greenhouse are discussed here.

Keywords: Cucumber, greenhouse, transpiration, vapour pressure deficit, irrigation, crop protection

SIMULATING LETTUCE PRODUCTION IN MULTI LAYER MOVING GUTTER SYSTEMS

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Cultivation of leafy vegetables as e.g. lettuce is nowadays often done in moving gutter systems (MGS). The MGS cultivation system maximises yield by using the optimum spacing in relation to plant size and light interception at all times in the cultivation cycle. While with MGS optimal spacing during the cultivation period is guaranteed and the maximum possible yield per square meter attained, cultivation with MGS in double layers including modern LED lighting and air conditioning units is the next step. For optimal cultivation planning a model of a double layer MGS was designed with lettuce as model crop, and implemented in an existing greenhouse simulator Virtual Greenhouse (VG). The model as based on deterministic equations of lettuce physiology using three different lettuce cultivars, and validated with data attained from a commercial lettuce producer with single layer MGS in Slovenia. The double layer cultivation was implemented based on single layer data. A comparing simulation study of regular cultivation (non MGS) and MGS with single and double layer was done. For that the VG model was used. Simulations were performed for a complete year taking the specific cropping measures into account. Each batch was simulated with set points between 0 and 20 daily light integral (mol light photons m^{-2} crop area day^{-1}) for the top compartment and the lower compartment separately. Due to lower natural light in the bottom compartment, the realised DLI was different between the top and bottom when setting DLI between 0 and 20 mol m^{-2} day^{-1}. Refraining from supplementary light results in average at levels higher than 14 DLI between March and September in the top compartment, while a maximum of 10 DLI is attained in the lower compartment. The different lettuce cultivars were cultivated with the same climate set points, where only the heat- and latent heat exchange differs. Simulations show that the MGS with double layer can strongly improve cultivation output, but a thorough planning of layer positioning moving speed of the gutters needs to be taken care for. In addition, large amounts of surplus heat energy from lamps when using high DLI set points needs to be removed. Dry weight growth for cultivation over a year depends on the amount of lighting used and differs only little between the three cultivars, while due to a different dry matter content fresh weight was different.

Keywords: lettuce, modelling, greenhouse, multi layer production, exhaust heat, DLI, moving gutter system, greenhouse simulator, virtual greenhouse, temperature sum

A SIMPLE MODEL TO PREDICT AIR TEMPERATURE INSIDE A MEDITERRANEAN GREENHOUSE

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The main purpose of this work was to develop a simplified dynamic energy balance model to predict the air temperature inside greenhouses naturally ventilated. The model was validated comparing simulated and experimentally measured temperatures of inside air, plants and soil. Measurements were carried out during two tomato crop cycles (autumn-winter and spring-summer) in a multi-span greenhouse equipped with insect-proof screens in the openings and variable cover transmittance (different whitewashing along the season). The current model was based on previous models that has been adapted for use in the conditions of the Southern Spain. The input data of this model were the outside weather conditions, physical parameters of crop and greenhouse characteristics. The outputs of this methodology were the inside air, cover, crop and soil temperatures. Ground temperature was obtained calculating the heat flux through the woven polypropylene film covering the soil. The simplification of the model was achieved using multiple regressions for predict the crop and soil film temperatures. Furthermore, we included an empirical coefficient to consider the effect over light distribution inside the greenhouse caused by the diffusivity of the plastic cover. The energy balance model was established by mean of ordinary differential equations solved numerically using the algorithm LSODA. A program was written in the statistical software R for solving these equations. Statistical comparison between the predicted inside air temperature by the model and the measured results showed good agreement with a Relative Root Mean Squared Error (RRMSE) lower than 10%. The model shows moderate sensitivity to variations regarding the calculated temperature of the film covering the ground.

Keywords: greenhouse, numeric model, temperature, natural ventilation, heat transfer.

FRUIT YIELD AND CAPSAICINOIDS PRODUCTION OF CAPSICUM CHINENSE GENOTYPES GROWN IN THE GREENHOUSE AND SHADEHOUSE CONDITIONS

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Hot pepper (*Capsicum chinense* Jacq.) is an excellent source of capsaicinoids for many industries. It has been

demonstrated that a higher carotenoid content is found in greenhouse and shade house pepper fruits as compared to open-field production. However, there are limited studies on dry yield and pungency of *C. chinense* under protected cultivation. This study evaluated fruit number, fruit dry yield, capsaicinoid amounts, and capsaicinoid yields in nine *Capsicum* genotypes grown under greenhouse and shadehouse environments. 'Akanee Pirot', 'Phet Mordindang', 'Tubtim Mordindang', HB1, HB2, HB3, and HB4 were developed at Khon Kaen University, Thailand for high pungency and fruit yield, while 'Orange Habanero' and 'Superhot' were commercial cultivars used as cultivar checks. The results confirmed that the environmental factors between the greenhouse and the shadehouse were very different, and they affected fruit number, fruit dry yield, capsaicinoid amounts, and capsaicinoid yields. In general, the pepper plants grown under greenhouse environment produced greater fruit numbers, higher fruit dry yield, higher capsaicinoids content, and higher capsaicinoids yield than those plants grown under shadehouse conditions. However, hot pepper genotypes showed different responses to each environment. 'Phet Mordingdang' and 'Akanee Pirot' produced the highest capsacinoid yields under greenhouse condition (1,031.6 and 1,009.6 mg/plant, respectively), while those plants under shade house produced 307.6 and 125.1 mg/plant, respectively. The capsaicinoid production under protected environments obtained here is good information for *Capsicum* production for high value market of pharmaceutical products.

Keywords: Capsaicin, dihydrocapsaicin, protected agriculture, pharmaceutical

A NAPA CABBAGE MODEL BASED ON COUPLING OF GAS EXCHANGE AND ENERGY BALANCE OF LEAF LEVEL

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For developing a napa cabbage model, Soil-Plant-Atmosphere-Research (SPAR) experiment with 6 different temperature schemes were conducted to investigate temperature-growth and temperature-photosynthesis responses. After transplanting of 30-day young plants in SPAR chambers, numbers of leaves, leaf areas, growth rates of plants were measured 6 times during growing season. We also measured leaf-level photosynthesis rates in each chamber using LI-6400 Potable Photosynthesis System. For model construction, FvCB model for photosynthesis process was applied and parameters for FvCB model were gotten from measured A-Ci data. The big-leaf model was applied for scaling up from leaf-level to canopy-level. Daily leaf area index were calculated from 6 leaf area data. As a result, a coupled model of gas exchange and energy balance of napa cabbage was developed. There are linear relationships between the simulation results of FvCB model and measured data in leaf assimilates of all SPAR chambers. The model can also simulate hourly photosynthesis and growth rates of canopy-level using meteorological elements as inputs. And simulated results of total assimilate were also linearly related measured total dry weights of each SPAR chambers. We concluded this coupled model can be used for explaining the hourly changes in photosynthesis and also physiological parameters in leaf level of napa cabbage.

Keywords: napa cabbage, gas exchange model, leaf-level photosynthesis, SPAR

TEMPERATURE DROP IMPROVED RESPONSES OF GREENHOUSE FRUIT VEGETABLES TO LONG PHOTOPERIOD OF SUPPLEMENTAL LIGHTING

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It is well known that long photoperiods of supplemental lighting cause photo-injury such as leaf chlorosis and necrotic spotting in greenhouse fruit vegetables such as tomatoes and sweet peppers. This photo-injury has limited the application of long photoperiod of supplemental lighting and the yield increase by supplemental lighting, in year-round greenhouse vegetable production. In our previous study, we have found that a temperature drop with dynamic temperature integration (TI) can promote the translocation of photo-assimilates from leaf to fruit and thus has the potential to reduce photo-injury and improve the response of greenhouse fruit vegetables to long photoperiods of supplemental lighting. Therefore, we initiated this study in 2013 with the aim to investigate the interactions between photoperiods and temperature control strategies for improving the response of greenhouse vegetables to long photoperiods of supplemental lighting including both HPS (high pressure sodium) and LED intra-canopy lighting. The study was conducted over 3 winters (from 2013 to 2016) in 8 greenhouse compartments, each with 50 m^2 of growing area. Two photoperiods (Control - 16 or 17h and Long Photoperiod- 20 or 21h) of overhead HPS lighting and two temperature integration strategies (Control TI – no temperature drop and Dynamic TI with temperature drop to 13.5°C for tomatoes or 15.5°C for sweet peppers at the end of photoperiod) were applied in the 8 compartments (2 complete replications). Four intra-canopy LED photoperiods (0, 16h, 20h and 24h) were applied to the 4 plots inside each compartment. Dynamic TI with temperature drop had the same 24-h average temperature as Control TI; the low temperature during the drop period was compensated with higher temperature in other periods over a day (24-h period). Dynamic TI with temperature drop significantly reduced photo-injury and increased fruit yield at the long photoperiods for both tomatoes and sweet peppers. It also reduced the heating energy use during the cold

months in winter. Therefore, dynamic temperature integration with temperature drop is an energy-efficient climate control strategy for improving the response of greenhouse tomatoes and sweet peppers to long photoperiods of supplemental lighting in year-round greenhouse fruit vegetable production.

Keywords: Photoinjury, energy, yield, fruit quality, microclimate, LED, HPS

EFFECTS OF DIFFUSED PLASTIC COVER MATERIALS ON GREENHOUSE MICROCLIMATE, PLANT GROWTH, FRUIT YIELD AND QUALITY, AND ENERGY USE IN GREENHOUSE FRUIT VEGETABLE PRODUCTION

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Greenhouse cover materials affect not only the light quantity and quality entering the greenhouse but also heat loss to the outside, which in turn have a large influence on greenhouse microclimate, plant growth, fruit yield and quality, and heating energy use. Diffused cover materials have the potential to improve the light distribution within crop canopy and reduce high temperature stress and increase fruit yield and quality in the summer. Therefore, this study was initiated in 2013 with the aim to evaluate the performance of newly developed plastic cover materials by the industry on energy use, microclimate, plant growth, fruit yield and quality of greenhouse fruit vegetables. Four greenhouse trials were conducted from fall 2013 to summer 2015 using 6 greenhouses covered with standard (STD) or newly developed diffused, double-layers & air-inflated polyethylene film (DPE), or twin-wall polycarbonate sheet (DPC), two greenhouses for each cover material. The STD, DPE and DPC all have the same calculated direct (perpendicular) light transmission (79%) while the proportion of diffused light is 50, 75 and 100%, respectively. It was found that the diffused cover materials (DPE and DPC) improved the vertical temperature and light distribution within crop canopy, increased light use efficiency, and reduced the fruit disorders or improved fruit grades in the summer. The improvement in light use efficiency could only compensate for a small/few percentage of decrease in total light transmission. Therefore, DPE greenhouses had similar marketable fruit yield as STD even if its total light transmission was 3-5% lower than STD. DPE greenhouses also used similar amount of energy as STD greenhouses. DPC greenhouses saved over 10% energy in comparison to STD and DPE greenhouses. However, its fruit yield was not as high as STD and DPE because of its much lower light transmission (10-15% less than STD), especially at lower solar angles during fall/winter production. Therefore, when plastic cover material manufacturers/developers try to increase the proportion of diffused light with their cover materials, the total light transmission should not be compromised.

Keywords: Cucumis Sativus, Capsicum annuum, Solanum lycopersicum, light transmission, vertical microclimate distribution, fruit disorders

USING MODELLING TO TARGET REPRESENTATIVE DROUGHT PATTERNS BY MANAGING THE IRRIGATION SCHEDULING

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To be valuable for the industry, traits need to translate to greater crop value in the target environments. Assessing the benefit of adaptive traits in field conditions is challenging as climatic conditions are variable and unpredictable. Year-to-year variability makes reliable screening difficult and large genotype-by-environment interactions impede progress of breeders and pre-breeders in crop improvement for complex traits, such as drought adaptation.

By capturing the interactions of plants with their environment, crop models have been demonstrated as efficient tools to characterise the nature of water-limited environments as experienced by the crops. In a recent study, crop modelling was used to identify four major drought environment types representing the stresses encountered in the Australian wheatbelt (Chenu et al., 2013, New Phytologist 198:801-820). To target those specific drought patterns in field trials, a web-based application (‘StressMaster’) was developed based on the APSIM crop model. Using soil, climate, genotype, and management information, StressMaster simulates in “real time” the drought pattern experienced by a crop up to the current date. The application also simulates future drought patterns for the rest of the season based on historical climatic records, allowing users to assess the influence of different irrigation scenarios on ‘future’ levels of water stress for the rest of the season.

StressMaster is used as a decision-making tool to define irrigation regimes at the Australian Managed Environment Facilities, where wheat benchmarking germplasm and populations differing for adaptive traits are being phenotyped. In addition to assisting in-season management, information from the seasonal drought characterisation is used in covariate analysis to interpret genotype-by-environment interactions across multiple trials and in assessing the value of genotypes, traits and genes for representative environment types.

Keywords: crop model, irrigation, drought, managed environment facility, phenotyping, target environment, crop improvement, breeding

MODEL-ASSISTED GREENHOUSE MANAGEMENT: AN EXAMPLE FOR SUPPLEMENTAL LIGHTING IN CUCUMBER PRODUCTION

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In the greenhouse cultivation, supplemental lighting is commonly used to increase photosynthetic active radiation (PAR) and daily canopy assimilation (DCA). How should supplemental lighting be applied efficiently is also of concern, i.e. the balance between the energy input and its benefit on productivity should be taken into account. This work uses modelling approach to test the response of canopy photosynthesis and light use efficiency (LUE) to the supplemental lighting under different natural light conditions in combination with scenarios of supplemental lighting. A multi-layer model representing a cucumber canopy was constructed to simulate DCA. Each layer was different in leaf area, nitrogen concentration, photosynthetic nitrogen partitioning, photosynthetic parameters and light intensity. Using this model, DCA and LUE on a daily basis were simulated for winter (10 mol PAR m^{-2} d^{-1}/9 hr day length) and summer seasons (40 mol PAR m^{-2} d^{-1}/15 hr day length) in combination of two supplemental top-lighting scenarios: 2 hr during dawn and 2 hr during dusk (DDI), and during the whole natural light period (NLI). In both scenarios, a total additional PAR of 7.2 mol m^{-2} d^{-1} was applied above the canopy. In winter, supplemental lighting increased DCA by DDI and NLI scenarios by 61% and 58%, respectively. In summer, DDI and NLI showed 19% and 13% increase in DCA, respectively. In winter, DDI increased DCA by 0.198 mol d^{-1} $plant^{-1}$, equivalent to about 0.15 kg d^{-1} $plant^{-1}$ fresh weight of cucumber. By applying the same daily amount of supplemental lighting, DDI had 2% and 5% higher LUE than NLI in winter and summer, respectively. This model can be used to investigate the effect of lighting scenarios on canopy photosynthesis and assist the decision making in crop management.

Keywords: Daily canopy assimilation, light use efficiency, supplemental lighting scenarios

FACTORS AFFECTING THE AERATION STATUS OF THE ROOT ZONES IN DRIP-IRRIGATED ORCHARDS

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We extensively surveyed the soil aeration status in the root zone of 35 commercial, drip-irrigated Israeli orchards in order to evaluate the extent and severity of soil hypoxia in drip-irrigated orchards. The survey involved measuring soil gaseous O_2 concentrations at depths of 0 to 60 cm, 20 cm to the side of the emitter. Oxygen concentrations at active root depths were usually higher than 15% (vs. 21% in the atmosphere) and decreased approximately linearly with increasing depth. During the cold, rainy winter the soil O_2 concentrations were usually higher than in the warm irrigation season, but after heavy rain they usually dropped for a few days. Low O_2 concentrations were mostly found in intensively irrigated, clayey soils. The negative gradients of O_2 concentration vs. depth were highly correlated with soil water content which, in turn, was highly correlated with the soil clay content. Thus, the concentration gradients were also higher in orchards irrigated with a single drip line per tree row than in those with two lines per row. The O_2 concentrations decreased with increasing temperature. In a few sites those in plots irrigated with recycled effluent water were similar to or slightly lower than those in plots irrigated with fresh water at similar rates. Within each irrigation cycle the O_2 concentrations decreased after water application and increased as the soil dried. A few observations showed that O_2 concentrations near mature trees were lower than those near young trees or in uncultivated soil. Rough evaluation of the diffusive vertical O_2 flux, averaged over all orchards, based on the mean O_2 concentration gradient and on the mean O_2 diffusion coefficient yielded a value of 15 g m^{-2} day^{-1}, which is consistent with reported respiration rates of cultivated soils at 25 °C. It is likely that in some circumstances this O_2 diffusion rate may be a limiting factor with regard to root respiration, photosynthesis, water and nutrient uptakes, plant growth and yield, especially under intensive irrigation and fertigation and at elevated soil temperatures.

Keywords: soil aeration, hypoxia

REAL-TIME DYNAMICAL MONITORING OF WATER STATUS IN PLANTS: LOW FIELDS NMR AND MRI INVESTIGATIONS

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Today, understanding how plants respond to water stress is essential to meet the challenge of developing new cultivars and new irrigation strategies, consistent with the maintenance of crop productivity in the context of global change. In this context, the study of plant water relations is of central interest for modeling plant and organ responses to biotic and abiotic constraints. Paradoxically, there are very few direct and non-invasive methods to quantify and measure the level and the flow of water in plants. For this purpose, we report on the development of an innovative methodology based on Nuclear Magnetic Resonance relaxometry and imaging at low and high magnetic fields,respectively, to measure the water contents and fluxes in tomato and sorghum plants. The combination of these approaches allows us to seek new eco-physiological biomarkers and to design experiments in the laboratory and even in field conditions1. A dedicated

NMR device for living plants has been implemented in a climatic chamber which allows a careful control and modification of the environmental parameters during the experimentation over long periods of time. One particular interesting result concerns the investigation of the spatial distribution of water in stems and fruits from T1- T2 and Diffusion weighted MRI 3D images. The modification of the NMR relaxation parameters during day / night cycles will be presented in normal and abiotic stress conditions. A direct application could permit to extract eco-physiological biomarkers which allow to explore and model water fluxes during heat and water stresses and analyze their impact on the development of young reproductive organs.

Keywords: radio frequency antenna, transportable NMR setup , NMR climatic chamber, NMR relaxation and imaging, eco-physiological biomarkers, biotic and abiotic stresses in plants

MODELING THE POLLEN TUBE GROWTH FOR GALA AND FUJI APPLES

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Pollen tube growth is one of the most important processes in the floral biology, because a successful fruit set depends on the pollen tube kinetics. In that way, predicting when the pollen tube reach the stylar base and the flower is fertilized can be a useful tool to manage the fruit load especially using chemical bloom thinners that inhibit the pollen tube growth (like Lime Sulphur) in the right timing. Thus, the objective of this study is to model the pollen tube growth based on temperature and percentage of penetration in the style (%P). For this purpose, flowers of two apple varieties (Fuji and Gala) were emasculated, hand pollinated and placed in growth chambers at eight different temperatures (4, 7, 11, 14, 20, 22, 28 and 30 °C). Then, flowers were sampled and processed at five different times or hours after pollination (HAP) distinctly for each temperature; the pollen tube length was measured with a fluorescent microscope. For each temperature, the pollen tube length in function of the %P was adjusted to exponential and sigmoidal models depending on the behavior of the data. Then, the models were derived for getting the hourly growth rates, which were adjusted to a response surface model where temperature and %P are the predictors and rate is the response. Finally, total pollen tube length was simulated through Euler's method, cumulating the hourly rate at HAP=t (according to the response surface model predictors) with the total length reached in the last hour HAP=t-1. Other valuable information provided by the model are non-growth conditions, like low temperatures (below 11 °C) when the %P is above 50% or very low temperatures like 4 °C. In conclusion, this model can be used for Gala and Fuji apples to predict the pollen tube penetration in the style which is a decision support tool for thinning timing

Keywords: Thinning, response surface, Euler's integration, Malus domestica

MODELLING IRRIGATION WATER REQUIREMENTS AT PHYSIOLOGICAL GROWTH STAGES OF OKRA LIFE CYCLE USING CROPWAT MODEL FOR DERIVED SAVANNAH AND HUMID FOREST ZONES OF NIGERIA

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Accurate quantification of irrigation water requirement at different physiological growth stages of okra (*Abelmoschus esculentus* L.) life cycle is important to prevent over or under irrigation. Field experiments were therefore initiated to model okra irrigation water requirements at the four physiological growth stages of okra life cycle using CROPWAT model. Derived savannah 1 (DS1), derived savannah 2 (DS2) and humid forest (HF) occupying 493.36 ha, 69.83 ha and 305.25 ha respectively were used. Some selected soil physical properties coupled with weather parameters were used to develop irrigation water requirements for okra crop. In DS1, the estimated crop co-efficient (K_c) values were 0.30, 0.52, 0.84 and 0.7 for the germination, crop growth, flowering and fruiting stages, respectively. Corresponding K_c values in DS2 were 0.30, 0.54, 0.90 and 0.84 and in the HF were 0.30, 0.56, 0.87 and 0.86 respectively. Daily crop evapo-transpiration values ranged from 1.16 to 3.36, 1.17 to 3.64, and 1.2 to 3.38 mm day^{-1} for DS1, DS2 and HF respectively with significant ($p=0.05$) peak at the flowering stage for the three locations. Sustainable okra cultivation would require maximum daily irrigation water at flowering stage (reproductive phase) to meet the crop physiological needs and evapo-transpiration demand of the atmosphere.

Keywords: crop co-efficient, crop evapo-transpiration, irrigation schedule, okra

INVESTIGATING EFFECTS OF PRECISE IRRIGATION ON GROWTH AND YIELD OF POTATO (SOLANUM TUBEROSUM L.) CROP UNDER DIFFERENT PLANTING CONFIGURATIONS

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Freshwater is truly the lifeblood of agriculture that can promise sustainable and consistent food production. Chronically water shortage is a major constraint for sustainable production of food and fiber crops in many arid and semi-arid regions where production of crops relies on supplementary irrigation. To address this issue a two years of field experiment on autumn potato was conducted at Water Management Research Centre-UAF, Faisalabad, Pakistan to assess the effects of different irrigation approaches and irrigation regimens on potato yield and growth parameters along with potato physical and chemical characteristics under altered planting configurations during 2014-15 and 2015-16. Two planting patterns with irrigation treatments were ridge-furrow sowing with furrow irrigation (F) and bed-furrow sowing under drip irrigation with three irrigation regimens (I_1) irrigation to retain the available water for crop, (I_2) irrigation when 20% of the available water was consumed and (I_3) irrigation when 35% of the available water was consumed and it was replicated thrice. Results revealed that irrigation regimens influenced tuber while on the behalf of water saving, water productivity in kg/m^3 was documented as 7.23, 12.50, 13.83 and 15.74 in F, I_1, I_2 and I_3 respectively in the first year. Other growth parameters i.e. percentage plant emergence, plant height, no. of tillers, no. of compound leaves and no. of tubers plant^{-1} were also measured. Results disclosed that different MAD levels poses severe effects on physical properties while didn't have any significant effect on chemical properties of potato. It was observed that treatment F showed higher average tuber length, thickness, weight, actual and calculated volume, particle density, bulk density and repose angle that were registered as 7.65 cm, 4.31 cm, 97.34 g, 86.25 cm^3, 80.44 cm^3, 1.13 g/cm^3, 563.36 kg/m^3 and 33°50' respectively while I_1 showed 1.75 shape index and I_3 showed higher tuber diameter 6.37cm and yielded more spherical shaped potatoes. However chemical properties included tuber moisture (%), TSS and starch content (%) that were registered as 79.3, 5.37 and 18.6 respectively in F. It was concluded that potato was severely affected by water stress and planting configuration didn't have any significant effect on different traits.

Keywords: Irrigation, Potato, Physical Characteristics, Planting Configurations, Scheduling.

IMPACT OF CLIMATE CHANGE ON PRODUCTION OF SESAME IN WESTERN ZONE OF TIGRAY

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Sesame is one of the most important cash crops which is mostly grown in the western and north western zone of Tigray region. The impact of climate change on sesame yield were not addressed yet particularly in the study area. Therefore, this study was aimed at assessing the impact of climate change on production of Sesame in the Western lowlands of Tigray, with the specific objective of climate characterization and modeling the impact of climate change on production of sesame. Climate of the study area was analyzed using Instat and Mann-Kendall software's. Using the observed climate data (1980 to 2009), historical sesame yield was obtained and climate outputs from HadGEM2-ES, ACCESS1-0 and GFDL-ESM2M models were projected for the near (2010-2039), mid (2040-2069) and end (2070-2099) term periods to evaluate future impacts of climate change. The annual rainfall in the study area revealed a decreasing trend with an inter-annual variability of 16.7%. Of all the historical climate data (30 years), 70% of the onset date was on first week of June, while the cessation date was on September 15. The Markov chain first order model indicates that the probability of 7 and 12 days dry spell on May (80%) and September (90%) were very high. The mean minimum temperature ranges between 10.20C and 12.6 0C, while, the mean maximum temperature varies between 23.2 0C and 26.70C. In the end term RCP 4.5 all models revealed that the increase in minimum temperature will be below 1OC. Moreover, GFDL-ESM2M predicted rainfall to increase by 8.2% in the near term RCP4.5. Similarly, the GCM ACCESS1-0 revealed rainfall to increase by 5.2% in end term RCP8.5. In all periods (near, mid and end term) normal sowing date was better than early and late sowing dates in terms of yield. In late sowing date, yield was simulated to reduce from -5.88% to -23.31% in the end term RCP8.5 by GFDL-ESM2M and HadGEM2-EM climate models respectively. However, in the normal sowing date the yield was increased up to 33.1% by GFDL-ESM2M model in the midterm RCP4.5. Generally, higher yields were found in the normal sowing date. The response of sesame cultivars to the future climate changes should be studied under different management options. The impact should also be studied by different crop and climate models so as to capture the possible variability of sesame yield. Sensitivity to carbon dioxide, temperature, rainfall and other different management activities should be undertaken.

Keywords: Characterization, RCP, Mann-Kendall, GFDL-ESM2M, ACCESS1-0 & HadGEM2-ES

METHODOLOGY FOR THE USE OF DSSAT MODELS USING CUSTOMIZED TOOLS FOR CROP YIELD ESTIMATION

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An integrated approach involving customized tools to support Decision Support System for Agrotechnology Transfer (DSSAT) crop growth model to enabled crop yield estimation system scientific, timely and precise. Crop yield forecasting plays a crucial role for planners and policy makers for decision making regarding food production and early warning systems for agriculture. The customized tools has modules which support the user in preparing data for weather, Soil and experiment file in DSSAT models format and process the experiment files in batch mode automatically to simulate the yield. This paper describe the functionality of DSSAT customized tools for yield simulation and a case study to present the result output.

Keywords: DSSAT, Simulation, Customized Tools

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