

Plant Growth Chamber Simulation using EcosimPro[®]



17th European Thermal and ECLS Software Workshop
Noordwijk, 21st-22nd October, 2003

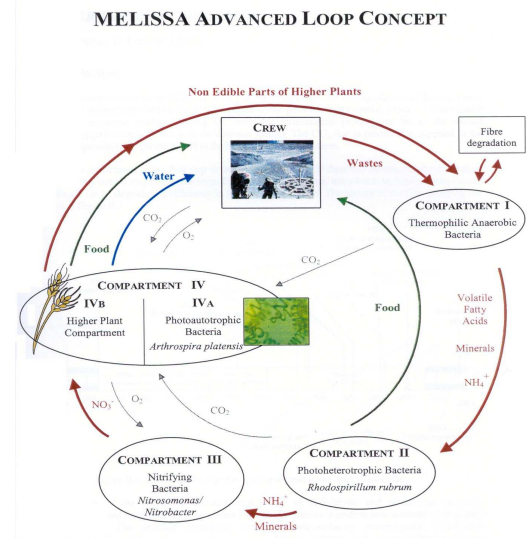
Presentation Overview

1. Introduction
2. Plant Model
3. EcosimPro[®] model
4. Results
5. Conclusions

Introduction (I)

✓ MELISSA

- Stands for Micro-Ecological Life Support System Alternative
- It is a closed ecosystem intended as a tool to gain understanding of artificial ecosystems and to develop new technologies for a long term manned mission life support system
- To facilitate the study, the system is divided in five compartments: three bacteria compartments, the photosynthetic compartment and the crew compartment
- The photosynthetic compartment is as well divided in two: photo-autotrophic bacteria and higher plants



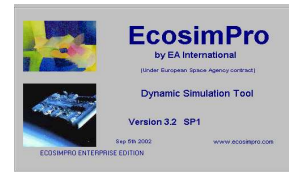
Introduction (II)

- ✓ Life Support functions of plants
 - CO₂ reduction, O₂ production
 - Fresh food production (lowers logistics penalty)
 - H₂O regeneration
 - + Positive influence in crew psychology
- ✓ Draw-backs
 - High power demand
 - High mass and volume penalties
 - Crew time intensive

To weigh the positive effects against the penalties trade-offs are required. Multiple sources indicate plants may be favorable for long term missions

⇒ **Simulations needed**

Introduction (III)



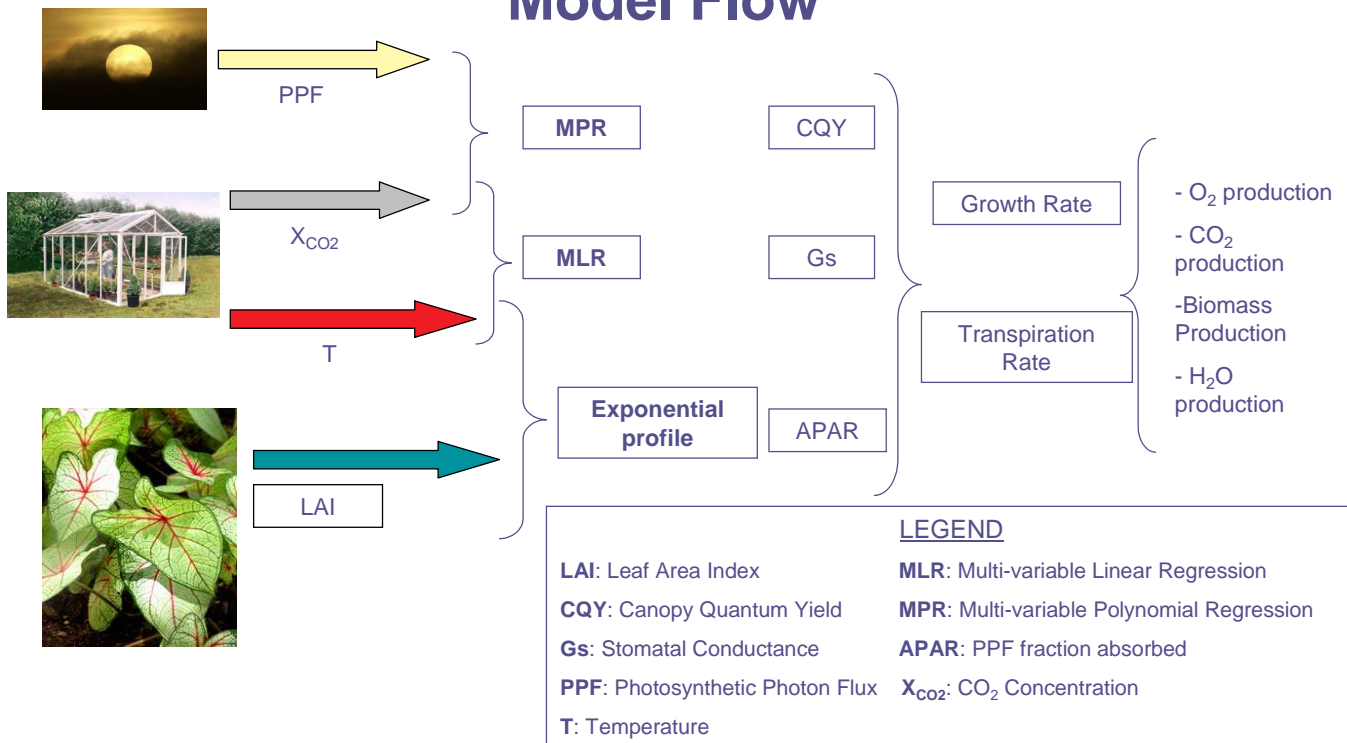
✓ EcosimPro®

- Multi-disciplinary simulation tool
- User-Friendly visual environment (similar to Microsoft Visual Studio®)
- Object oriented approach towards creating reusable libraries of components
- Allows the simulation of a given set of algebraic equations, ODEs and discrete events
- Avoids the need for the user to call the solvers, to order the equations, to handle numerical problems (algebraic loops, high index problems)
- Permits graphical modeling (drag and drop, connect components)
- Easy post-processing tool (EcoMonitor®)

Plant Growth Model

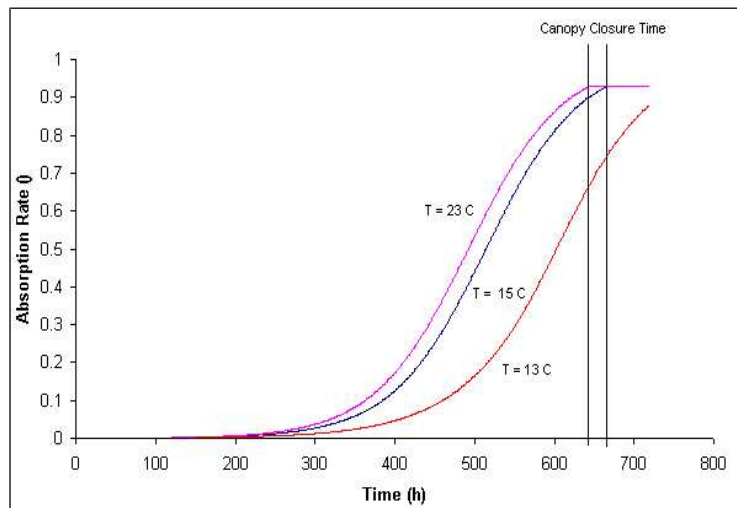
- The model selected for this investigation is the Modified Energy Cascade Model
 - It is a dynamic top level plant growth model
 - It considers:
 - Environmental conditions (light, CO₂ concentration, temperature and relative humidity)
 - Different periods in plant growth (juvenile phase, panicle initiation, heading, grain fill, canopy closure time, time of senescence)
 - Monoculture strategy
 - It does not consider:
 - Nutrient limitations
 - Water and nutrients uptake
 - Germination period of plants

Model Flow



Light Absorption Model

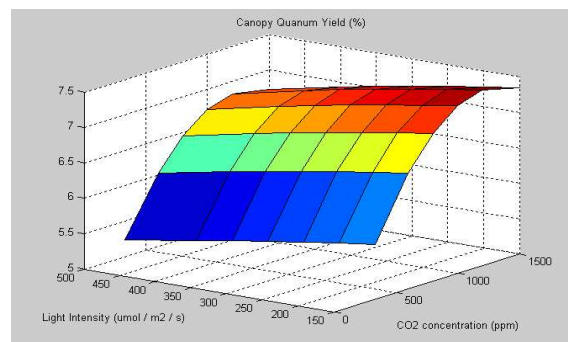
- The Absorption efficiency increases with leaf area and is bound by canopy closure, which depends on the temperature of the growth environment



Growth model

- The growth model is based in an overall efficiency of carbon fixation. The Canopy Quantum Yield (CQY) is defined as the ratio of carbon fixed (C-mol) over the total light absorbed (# of photons)
- CQY is calculated using a multivariable polynomial regression based on experimental data. It depends on the total light flux (PPF) and the carbon dioxide concentration (X_{CO_2})

$$CQY = CQY(PPF, X_{CO_2})$$



Transpiration Model

- The driving force for transpiration is the difference in H_2O saturation vapor pressure and H_2O vapor pressure in the chamber. Hence, the transpiration rate (TR) is given by the following equation:

$$TR = \alpha \cdot G_c \cdot \frac{VP_{sat} - P_{vap}}{P_{atm}} \quad \alpha: \text{Units Conversion Factor}$$

- Two conductances are defined:
 - g_A : Chamber aerodynamic conductance
 - G_s : Canopy stomatal conductance
- g_A is considered constant and does not pose a limitation on the transpiration
- G_s is a multivariable linear regression depending on carbon fixed, temperature and relative vapor pressure difference

Global conductance \Rightarrow

$$G_c = \frac{g_A \cdot G_s}{g_A + G_s}$$

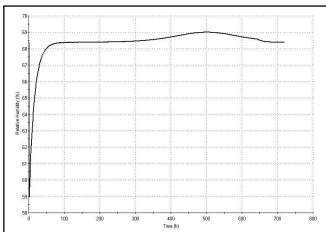
EcosimPro[®] Model

In the context of the previously developed MELiSSA library the model has been adapted to EcosimPro[®] with the following additional features:

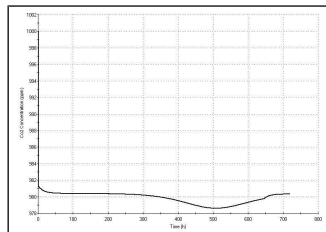
- General gas phase modeling considerations: mass balance, pressure dynamics, relative humidity
- Time events to introduce harvesting cycles and staggered culture strategy
- Conventional control strategy (PID) to maintain optimum and relatively constant values of CO₂ concentration and relative humidity

Case 1: Lettuce

- The controlled variables are maintained around the set-points of 1000ppm_{CO2} and 70% relative humidity

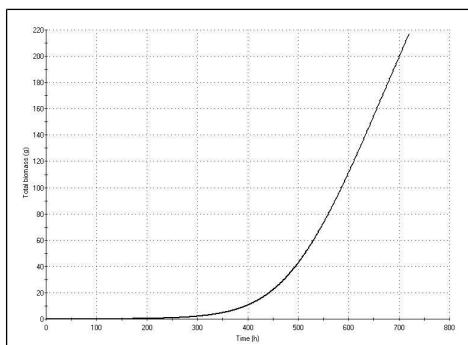


Relative Humidity vs. Time

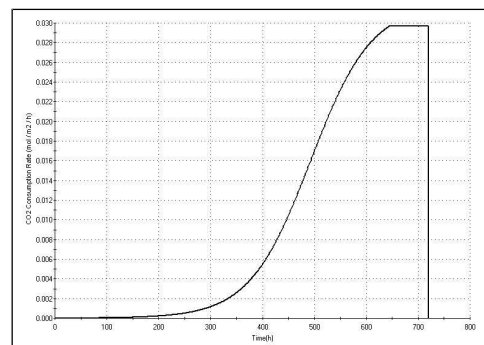


CO₂ concentration vs. Time

- Mean production rates:
 Biomass: 7.24g_{dw}/m²/d
 O₂: 7.72g/m²/d
 H₂O: 0.47kg/m²/d
- Mean consumption rates:
 CO₂: 10.61g/m²/d



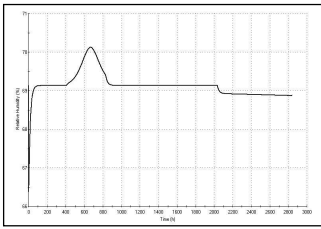
Biomass vs. Time



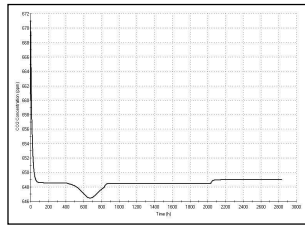
CO₂ production vs. Time

Case 2: Rice

- The controlled variables are maintained around the set-points of 660ppm_{CO2} and 70% relative humidity

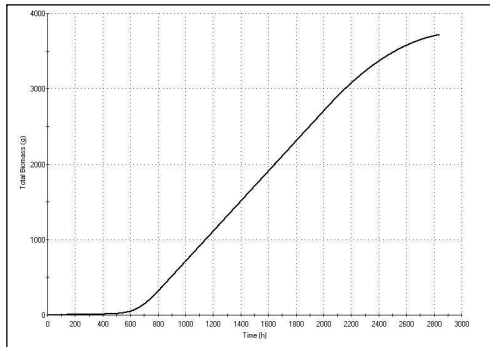


Relative Humidity vs. Time

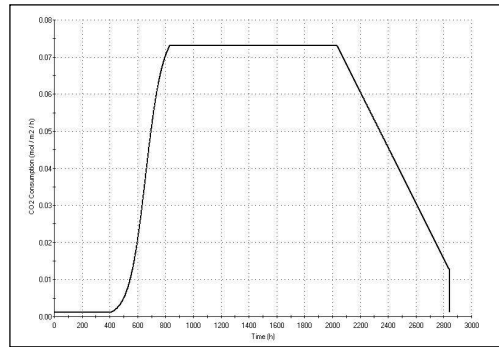


CO2 concentration vs. Time

- Mean production rates:
 - Biomass: 31.41g_{dw}/m²/d
 - O₂: 36.85g/m²/d
 - H₂O: 3.50kg/m²/d
- Mean consumption rates:
 - CO₂: 50.67g/m²/d



Biomass vs. Time

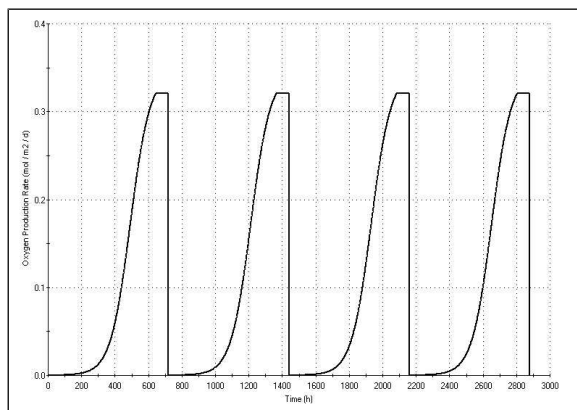


CO₂ production vs. Time

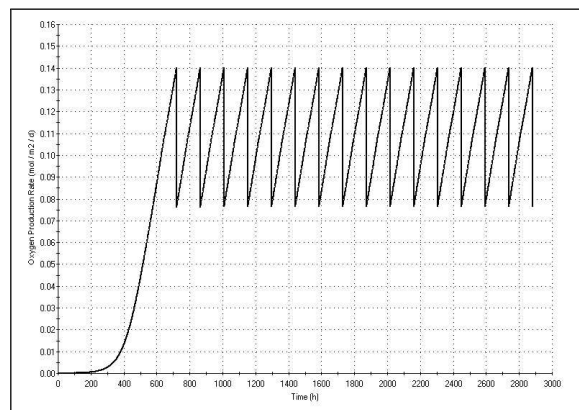
Luis Ordóñez. ESA/ESTEC TOS-MCV

- 13 -

Staggered vs. Non-Staggered: lettuce



O₂ production vs. Time. Case N = 1



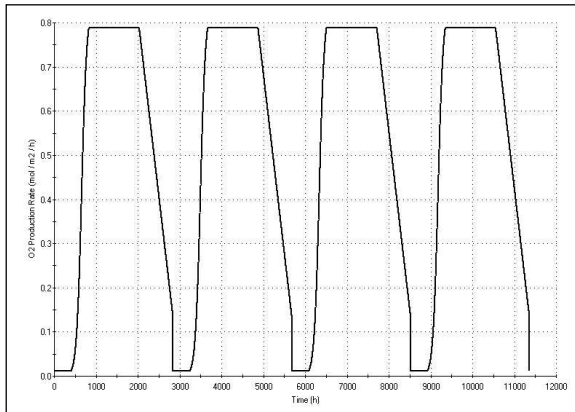
O₂ production vs. Time. Case N = 5

- The mean production rates are unchanged
 - The instantaneous production rates fluctuate around the mean value.
- ⇒ Easier control, less buffer capabilities needed

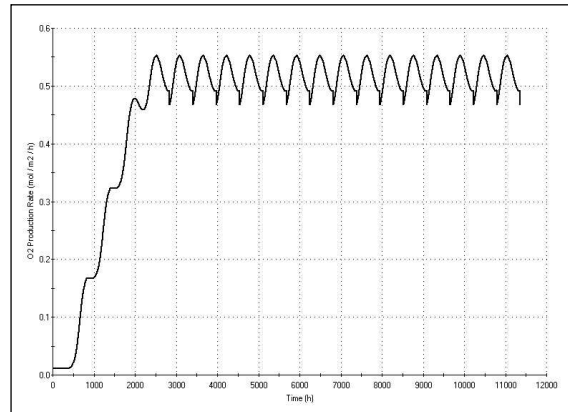
Luis Ordóñez. ESA/ESTEC TOS-MCV

- 14 -

Staggered vs. Non-Staggered: rice



O₂ production vs. Time. Case N = 1



O₂ production vs. Time. Case N = 5

- The mean production rates are unchanged
 - The instantaneous production rates fluctuate around the mean value
- ⇒ Easier control, less buffer capabilities needed

Conclusions

- The model is capable of simulating plant growth under variable conditions
- EcosimPro[®] permits the simulation of staggered culture strategy thanks to its capability of handling discrete events
- Additional experimental data is necessary to improve and adjust the model
- Model predictions may help implementing a predictive control strategy for a MELiSSA Higher Plants Compartment
- Upon completion of data collection for the remaining candidate crops (tomato, potato, soybean, spinach, onion and wheat), the model will allow sizing the MELiSSA Higher Plant Compartment

References

- Cavazzoni, J. "Crop Modeling Task, ALS Power Reduction NRA". Rutgers University. Department of Bioresource Engineering. September 1999.
- "MELiSSA" Yearly Report for 2002 Activity. Lobo, M. and Lasseur, Ch. ESA/EWP-2216. June 2003
- www.ecosimpro.com