Plant Growth Chamber Simulation using EcosimPro®

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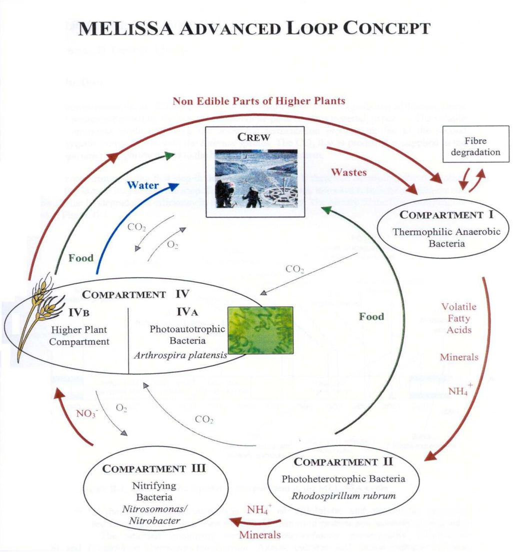
Presentation Overview

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

- CO_2 reduction, O_2 production
- Fresh food production (lowers logistics penalty)
- H_2O regeneration

+ Positive influence in crew psychology

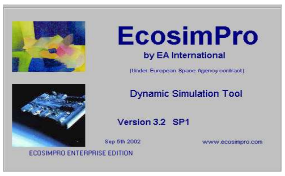
✓ Draw-backs

- 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

by EA International

(Under European Space Agency contract)

Dynamic Simulation Tool

Version 3.2 SP1

Sep 5th 2002

www.ecosimpro.com

ECOSIMPRO ENTERPRISE EDITION

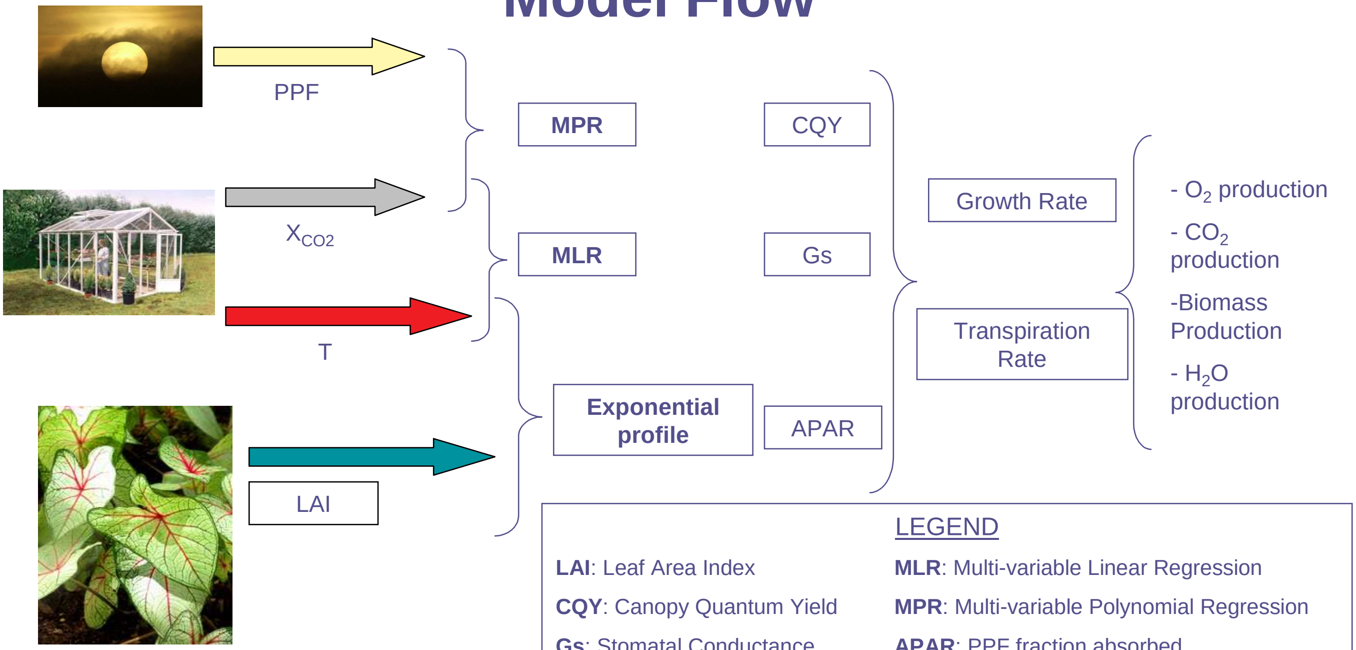
✓ **EcosimPro®**

- 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, CO_2 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

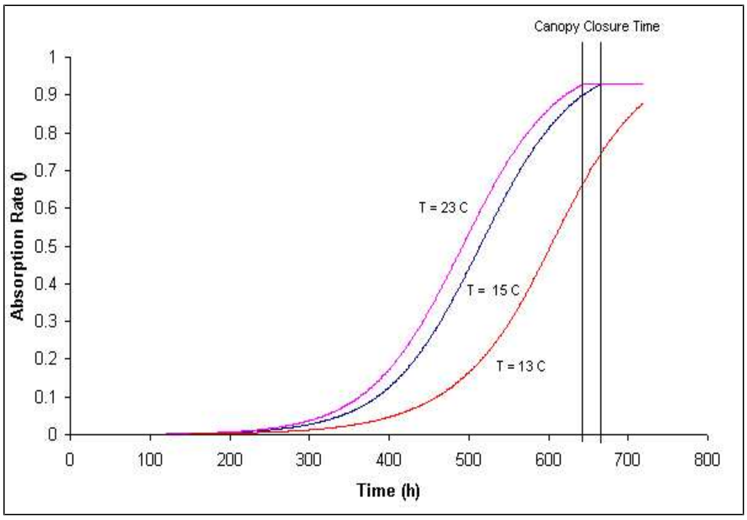


LEGEND

LAI: Leaf Area Index	**MLR**: Multi-variable Linear Regression
CQY: Canopy Quantum Yield	**MPR**: Multi-variable Polynomial Regression
Gs: Stomatal Conductance	**APAR**: PPF fraction absorbed
PPF: Photosynthetic Photon Flux	**X_{CO2}**: CO_2 Concentration
T: Temperature	

Light Absorption Model

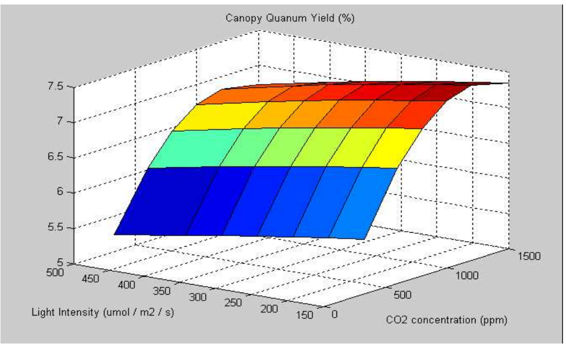
- The Absorption efficiency increases with leave area and is bound by canopy closure, which depends on the temperature of the growth environment



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_{CO2})

$$CQY = CQY(PPF, X_{CO2})$$



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:

$$TR = \alpha \cdot Gc \cdot \frac{VPsat - Pvap}{Patm}$$

α: Units Conversion Factor

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

Global conductance ⇒

$$Gc = \frac{gA \cdot Gs}{gA + Gs}$$

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 CO_2 concentration and relative humidity

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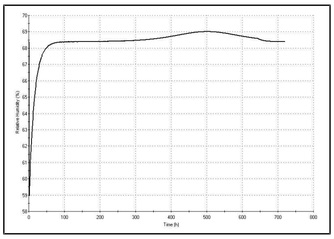
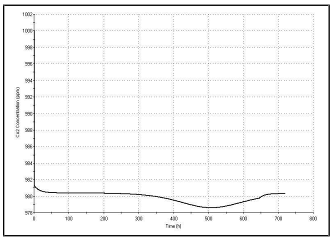
Case 1: Lettuce

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



Relative Humidity vs. Time



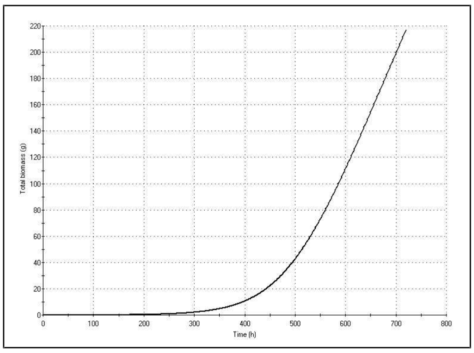
CO2 concentration vs. Time

- Mean production rates:

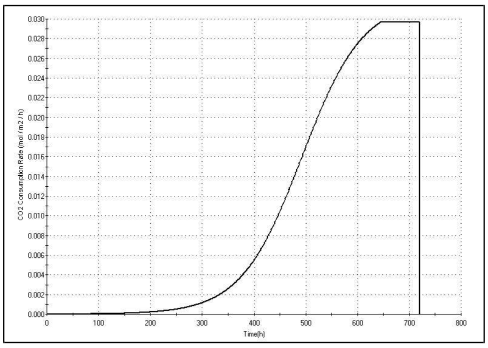
Biomass:	$7.24g_{dw}/m^2/d$
O_2:	$7.72g/m^2/d$
H_2O:	$0.47kg/m^2/d$

- Mean consumption rates:

CO_2:	$10.61g/m^2/d$



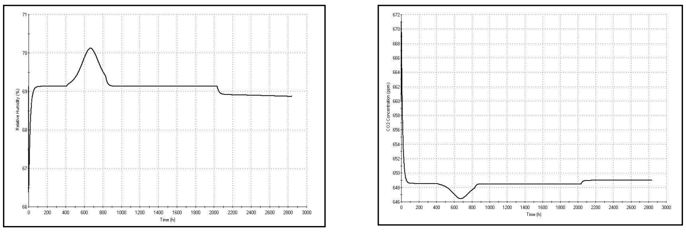
Biomass vs. Time



CO_2 production vs. Time

Case 2: Rice

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



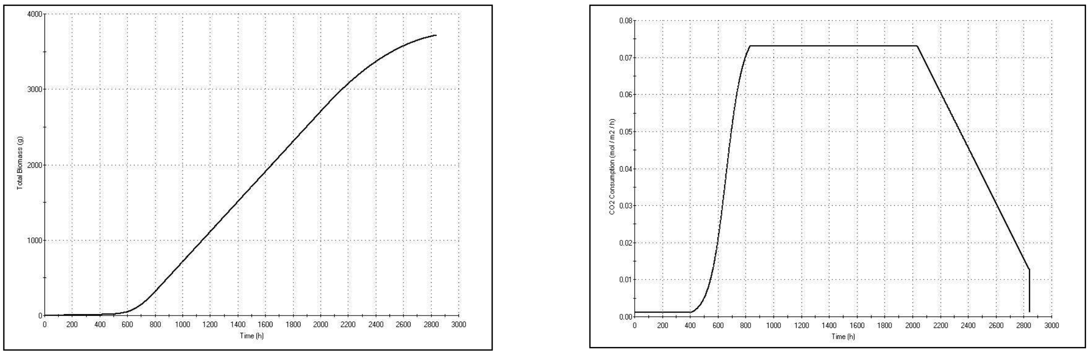
Relative Humidity vs. Time **CO2 concentration vs. Time**

- Mean production rates:

Biomass: 31.41g$_{dw}$/m^2/d
O_2: 36.85g/m^2/d
H_2O: 3.50kg/m^2/d

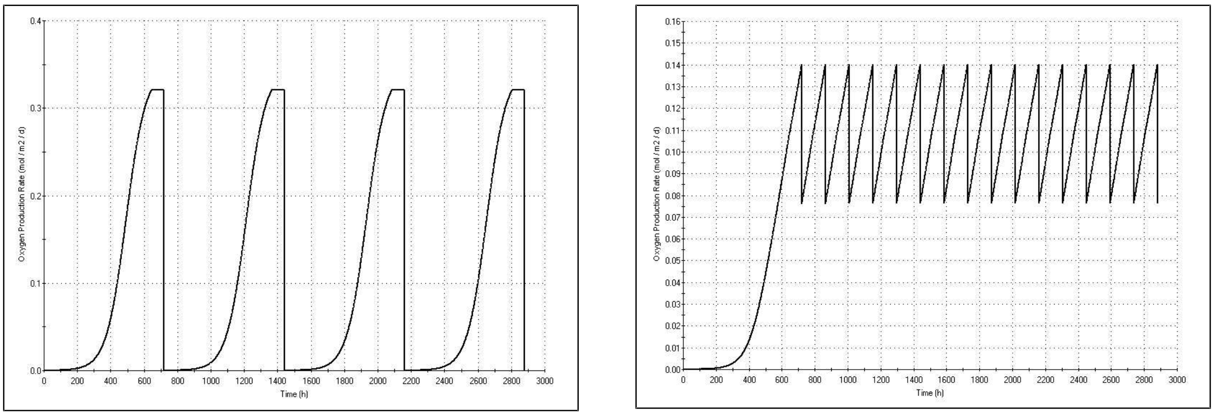
- Mean consumption rates:

CO_2: 50.67g/m^2/d



Biomass vs. Time **CO_2 production vs. Time**

Staggered vs. Non-Staggered: lettuce

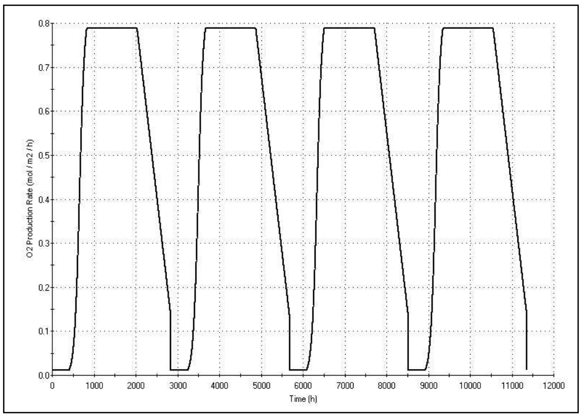


O_2 production vs. Time. Case N = 1 **O_2 production vs. Time. Case N = 5**

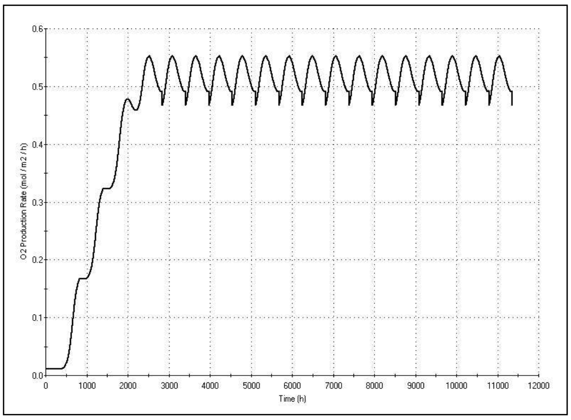
- The mean production rates are unchanged
- The instantaneous production rates fluctuate around the mean value.

⇒ Easier control, less buffer capabilities needed

Staggered vs. Non-Staggered: rice



O_2 production vs. Time. Case N = 1



O_2 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