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MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

CREATING A CIRCULAR FUTURE

Application of the Energy Cascade Model (MEC) on lettuce crop grown in controlled environment agriculture at two different scales : A small growth chamber and a vertical farm

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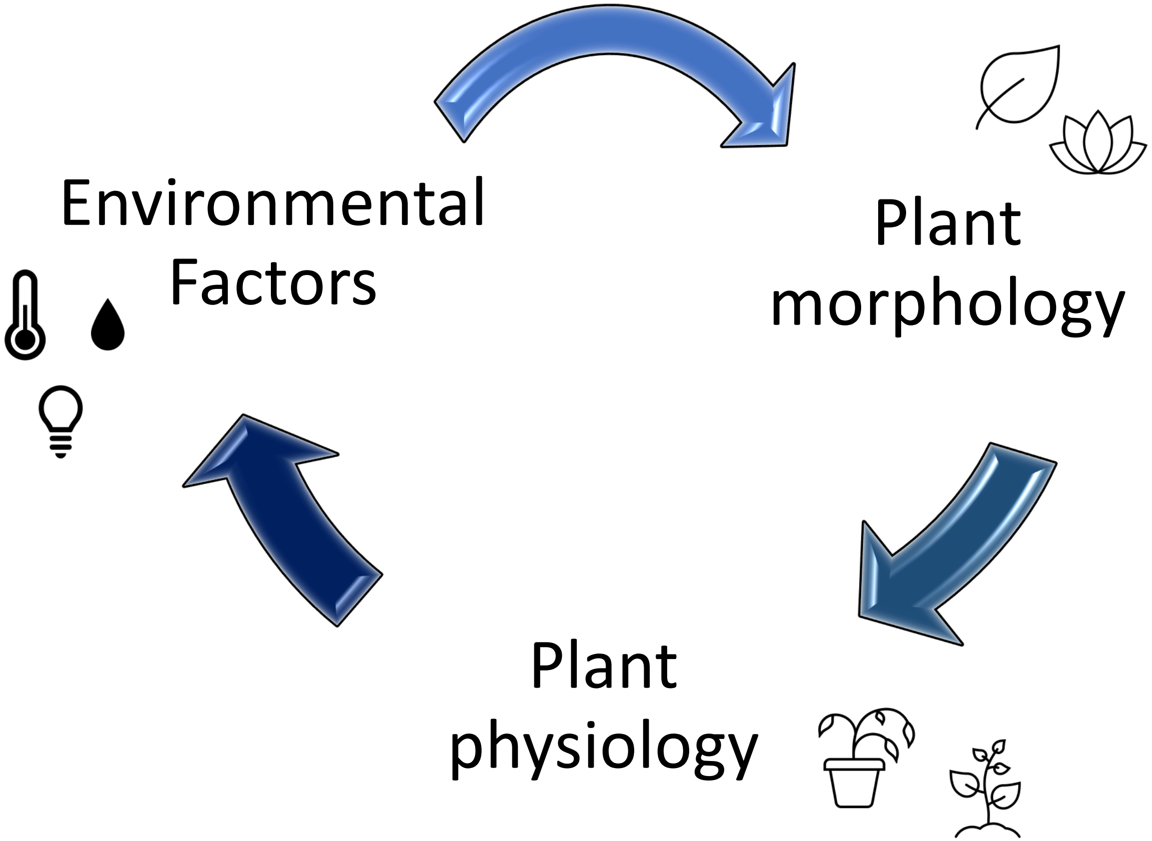
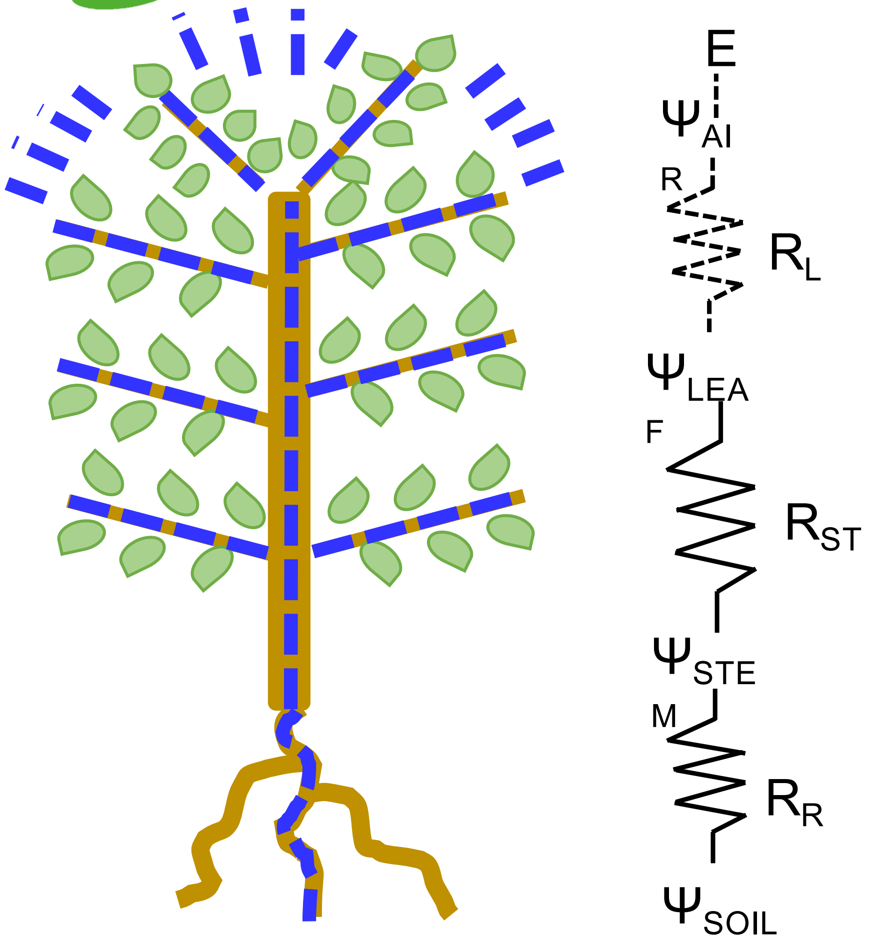
REQUIREMENTS

- Deep knowledge of how the micro-environment affects crop growth in Controlled Environment Agriculture
- Modelling and simulation for the remote management of environmental control and plant growth
- Implement ttechnological innovation in agriculture, in the direction of sustainability and automation to be applied also on Earth at larger scales (intensive agriculture)


Environmental
Factors
Plant
morphology
Plant
physiology


Temperature
Relative humidity
CO_2
light
clouds
wind
snow
heat
cold
rain
hailstorm
drought
pollutants
radiation

$VPD = e - es \quad (kPa)$



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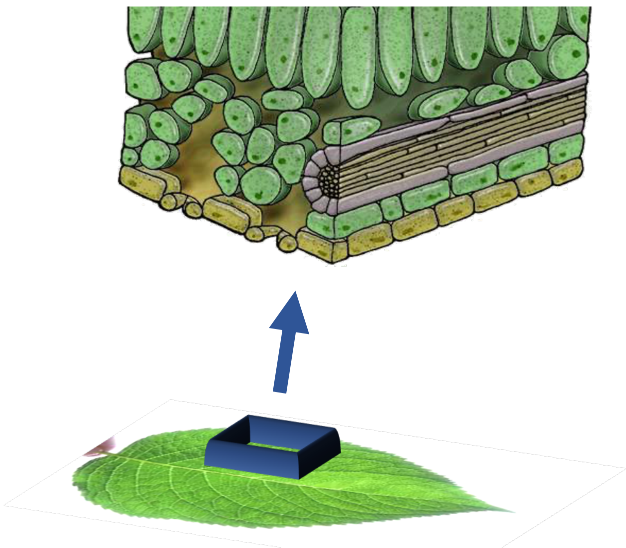
MINOR REVIEW

Annals of Applied Biology WILEY

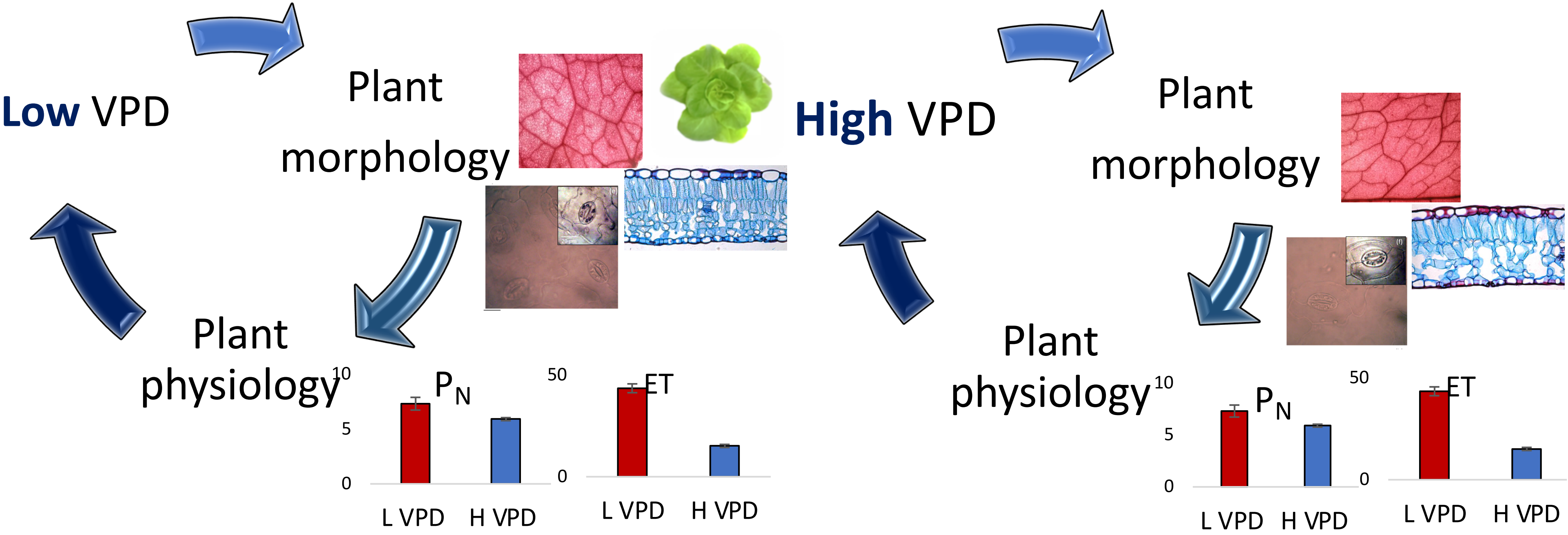
Vapour pressure deficit: The hidden driver behind plant morphofunctional traits in controlled environments

Chiara Amitrano[1] | Carmen Arena[2] | Youssef Rouphael[1] | Stefania De Pascale[1] | Veronica De Micco[1]



Leaf Anatomy has a central role in the evaporative process

VPD


Low VPD
Plant
morphology
Plant
physiology
P_N
10
5
0
L VPD
H VPD
ET
50
0
L VPD
H VPD
High VPD
Plant
morphology
Plant
physiology
P_N
10
5
0
L VPD
H VPD
ET
50
0
L VPD
H VPD

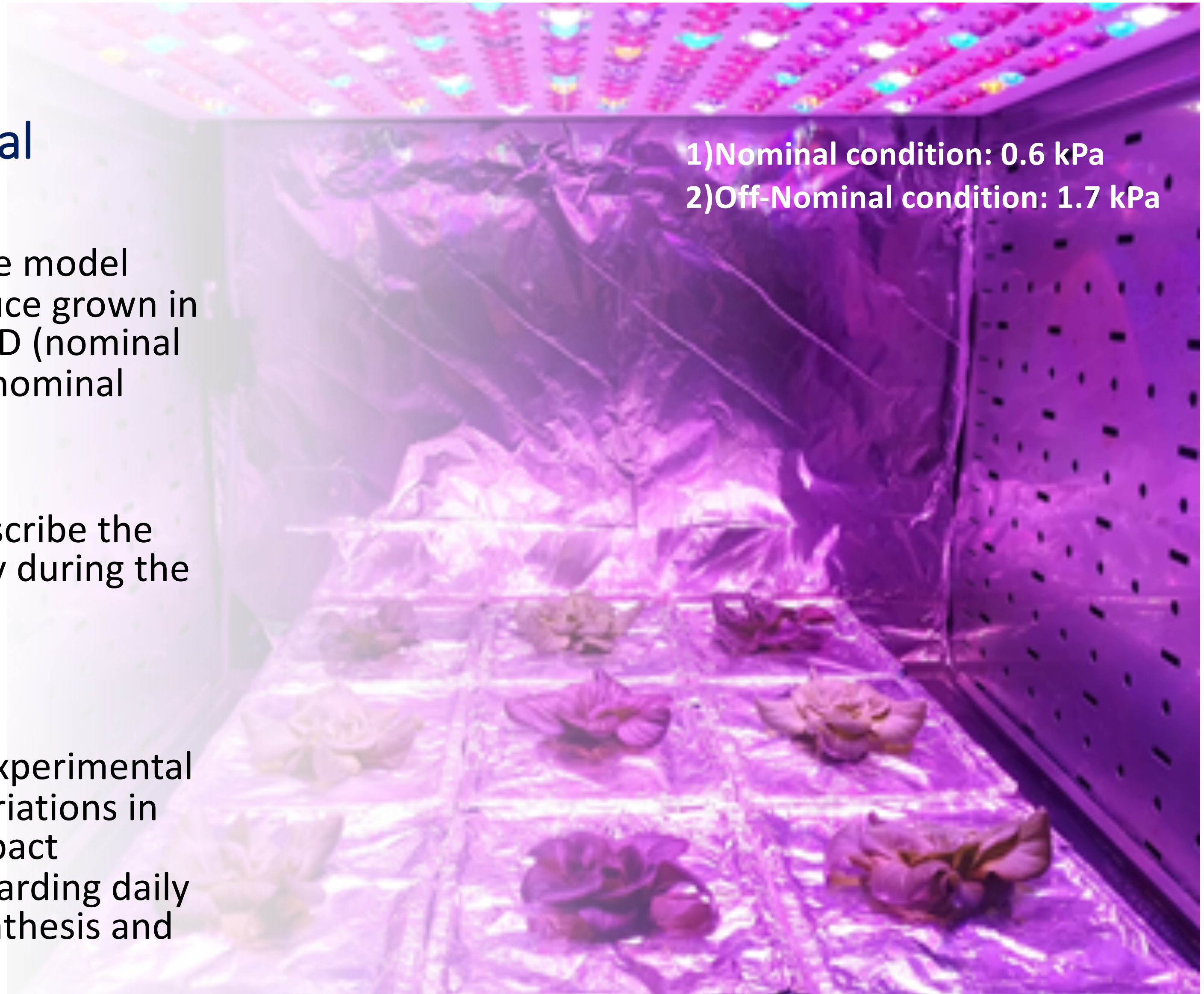
GOALS

1. **Apply** an explanatory model (MEC model) which, by using environmental factors as input, can predict crop biomass, photosynthesis and energy balance. **Implement** the model to simulate plant responses due to environmental disturbances (different VPDs).

2. **Evaluate** whether the Energy Cascade Model (MEC) can be equally and reliably applied on lettuce cultivation trials conducted in facilities at different scales (growth chamber and vertical farm).

3. **Test** whether the Energy Cascade Model (MEC) can still be reliable under the influence of other environmental conditions (different light intensities in the vertical farm trial).

Growth chamber Trial



In the present study:

1. We applied an Energy cascade model (MEC) to green- and red-leaf lettuce grown in a climatic chamber under low VPD (nominal condition) and high VPD (off-nominal condition).

2. We tooled up the model to describe the changing leaf functional efficiency during the growing period

3. We validated the model against experimental data to predict how possible variations in the cultivation factors impact plant performance, especially regarding daily biomass accumulation, photosynthesis and evapotranspiration.

The MEC model algorithm

The net photosynthesis (P_N) µmol CO2 m^{-2} s^{-1}

P_N = (24-H) / 24 + H · CUE / 24·PG

Where P_G is the gross photosynthesis:

P_G = A · CQY · PPFD

The stomatal conductance (g_S)

g_S = 1.717 · T – 19.96 – 10.54 · VPD · P_N/ [CO_2]

Total edible biomass (TEB) gm^{-2}:

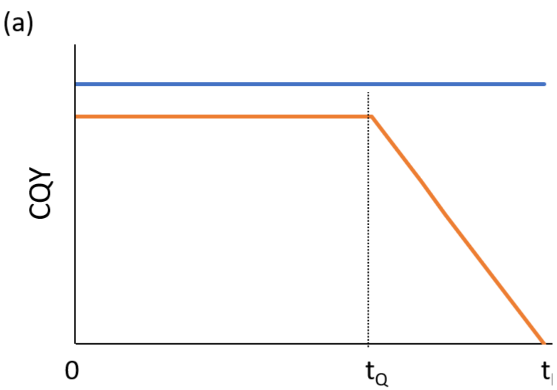
$$TEB = \int_{TE}^{TM} XFTR \cdot CGR \cdot dt$$

The daily canopy transpiration (DTR)

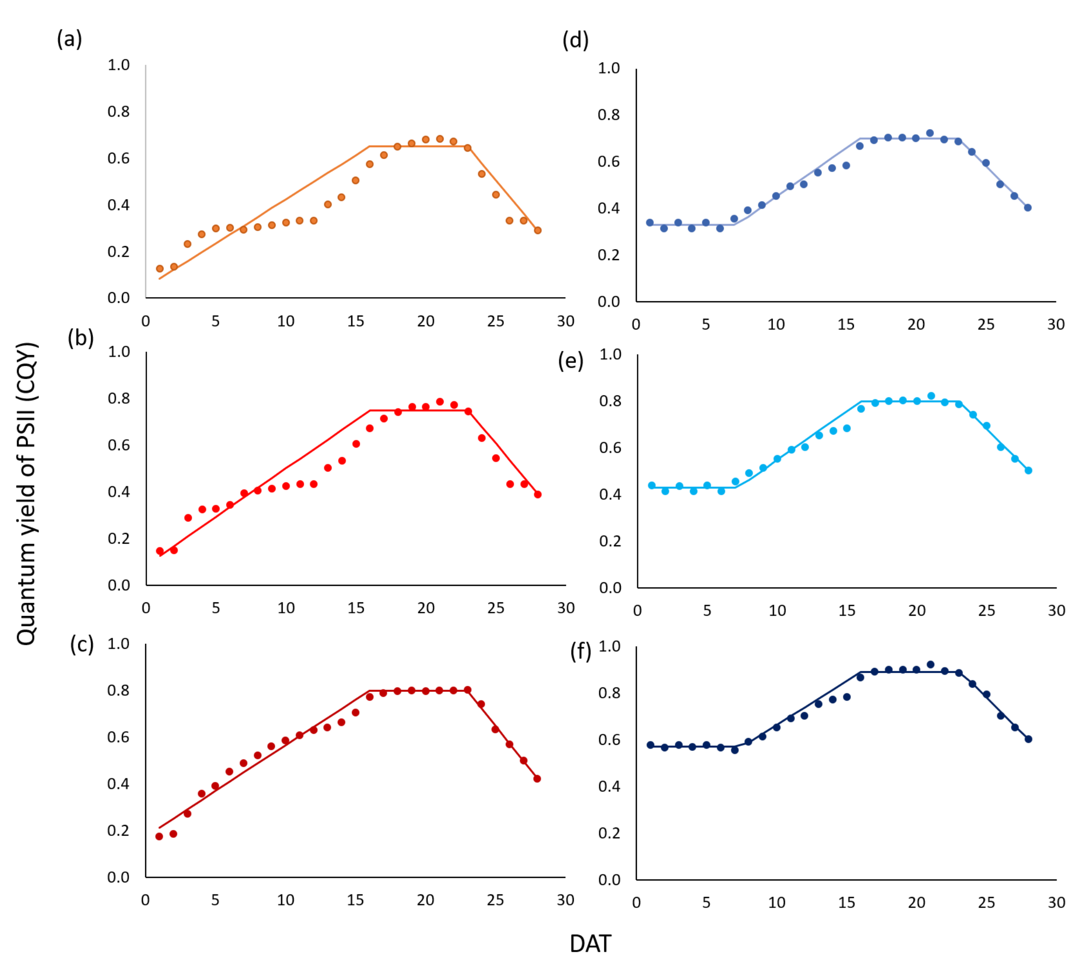
DTR = 3600·H· (M_{WW}/ ρ_W) · g_c · (VPD/P_{ATM})

Parameter	Definition	Value	Source
H	Photoperiod	12	Experimental data
A_{MAX}	Maximum fraction of PPF absorbed by the canopy	0.04	Experimental data
PPF	Photosynthetic photon flux	315	Experimental data
CUE	Maximum carbon use efficiency	0.65	Dougher and Bugb ee (1997)
CQY	Maximum canopy quantum yield	0.02	Dougher and Bugbee (1997)
t_A	Time at canopy Closure	8	Experimental data
t_M	Time of harvesting	28	Experimental data
t_E	Onset of edible biomass	1	Jones et al., 2000
BCF	Biomass carbon fraction	0.4	Jones et al., 2000
XFRT	fraction of DCG allocated to edible biomass	0.95	Jones et al., 2000
OPF	Oxygen production fraction	1.08	Jones et al., 2000
g_A	Aerodynamic conductance for water vapour transfer	2.5	Cavazzoni, 2003

The MEC model –Troubleshooting-



Original MEC model time profile of CQY … other crops (orange line). *Amitrano et al.* …



…rescence measurements with Opti- … three leaves of different ages per

The MEC model –Troubleshooting-

The three variables **A, CQY** and **CUE** were reduced to the variable:

α = CUE ·A ·CQY

β = A · CQY.

sensors

MDPI

Article

Crop Management in Controlled Environment Agriculture (CEA) Systems Using Predictive Mathematical Models †

Chiara Amitrano, Giovanni Battista Chirico *, Stefania De Pascale, Youssef Rouphael and Veronica De Micco *

The net photosynthesis (P_N) µmol CO_2 m^{-2} s^{-1}

$P_N = [H \cdot \alpha / 24 + \beta (24-H) / 24] \cdot PPFD$

Where P_G is the gross photosynthesis:

$P_G = \beta \cdot PPFD$

The stomatal conductance (g_S)

$g_S = (1.717 \cdot T – 19.96 – 10.54 \cdot VPD) \cdot P_N / [CO_2]$

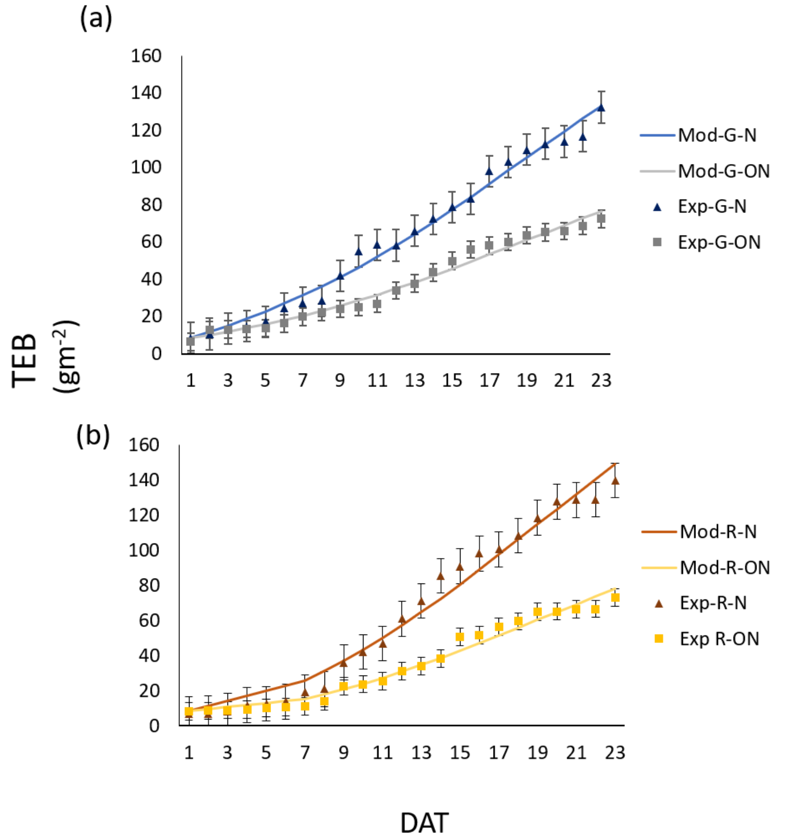
Total edible biomass (TEB) gm^{-2}

$TEB = \int_{TE}^{TM} XFTR \cdot CGR \cdot dt$

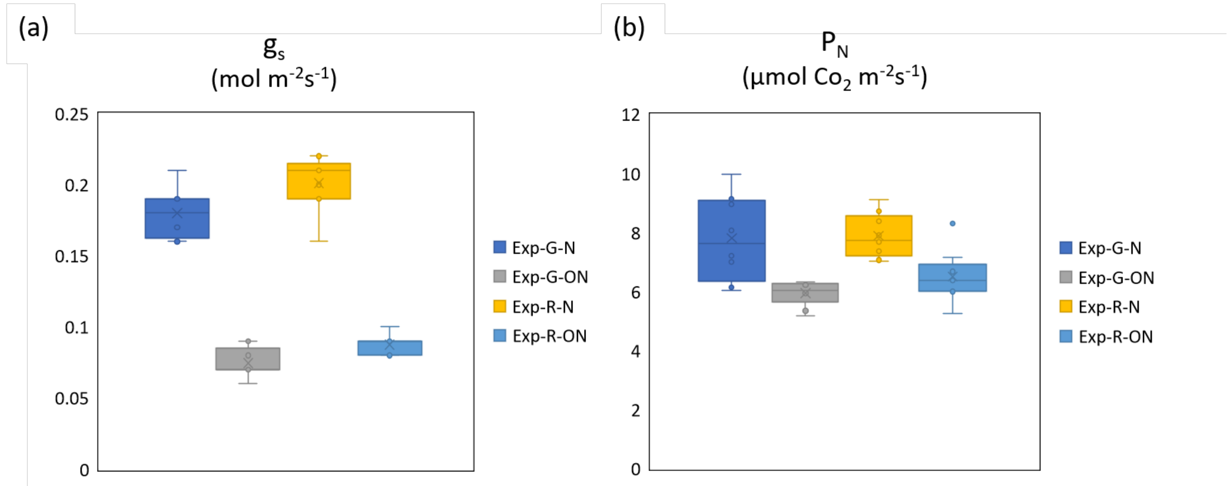
The daily canopy transpiration (DTR)

$TR = 3600 \cdot H \cdot (MW_W / \rho_W) \cdot g_c \cdot (VPD/P_{ATM})$

Results



Theoretical (line) and experimental (dots) profiles of TEB (Total edible biomass) for green- (G) (a) and red-leaf (R) (b) plants under nominal (N) and off-nominal (ON) scenarios. *Amitrano et al. 2020 Sensors, 20(11), 31*

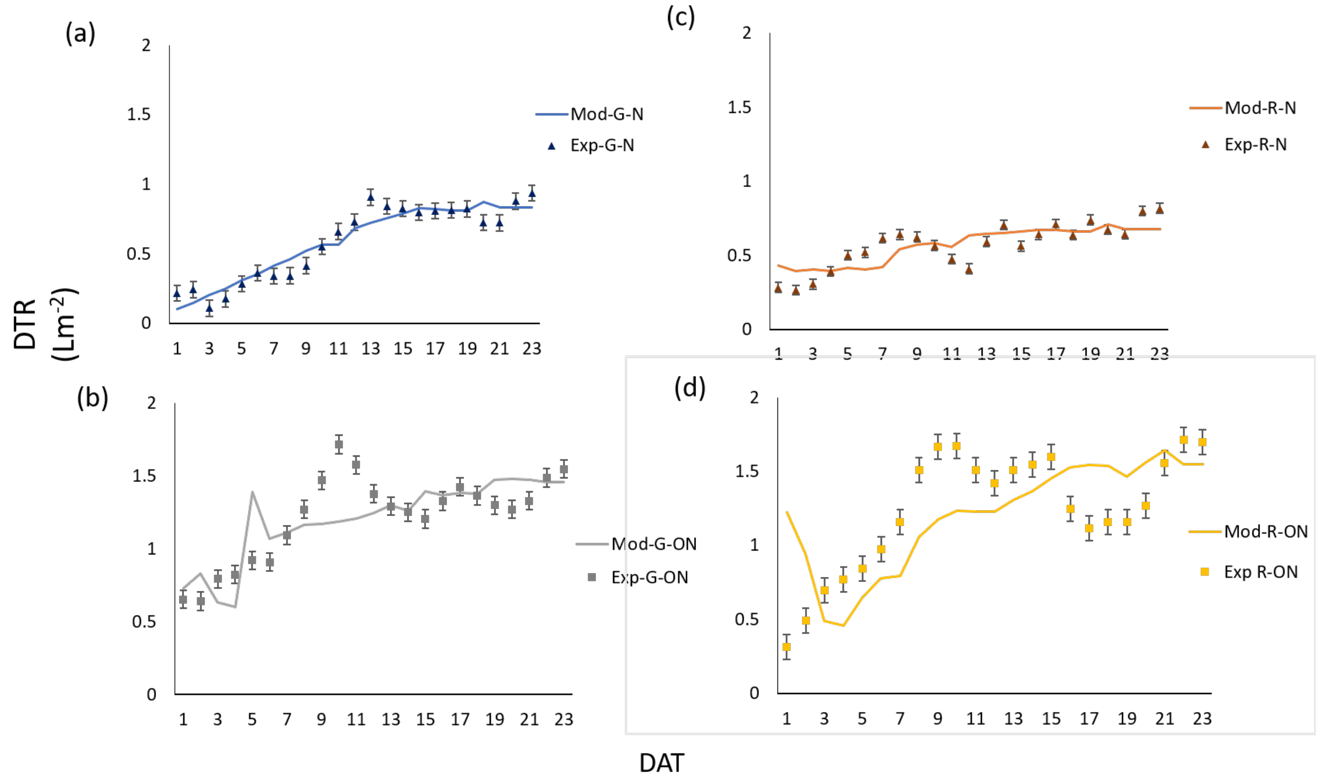


Box-plot distribution of g_s (Stomatal conductance) (a) and of P_N (Net-photosynthesis).
Amitrano et al. 2020 Sensors, 20(11), 31

Growth chamber experiments	DAT	rBIAS g_s	predicted g_s (mol $m^{-2}s^{-1}$)	rBIAS P_N	predicted P_N (µmol Co_2 $m^{-2}s^{-1}$)
G-N	23	39.4%	0.26	34.1%	9.80
G-ON	23	68.2%	0.13	75.9%	10.38
R-N	23	-0.1%	0.21	-10.7%	7.79
R-ON	23	48.6%	0.13	70.9%	11.12

Relative BIAS (rBIAS) and model predictions of stomatal conductance (g_s) and net photosynthesis (P_N). *Amitrano et al. 2020 Sensors, 20(11), 31*

Results



Profiles of DTR (Daily transpiration) for green- (G) (a,b) and red-leaf (R) (c,d) plants undernominal (N) (a,c) and off-nominal (ON) (b,d) scenarios; model simulations (line) and experimental data (dots) are reported. *Amitrano et al. 2020 Sensors, 20(11), 31*

Vertical Farm Trial

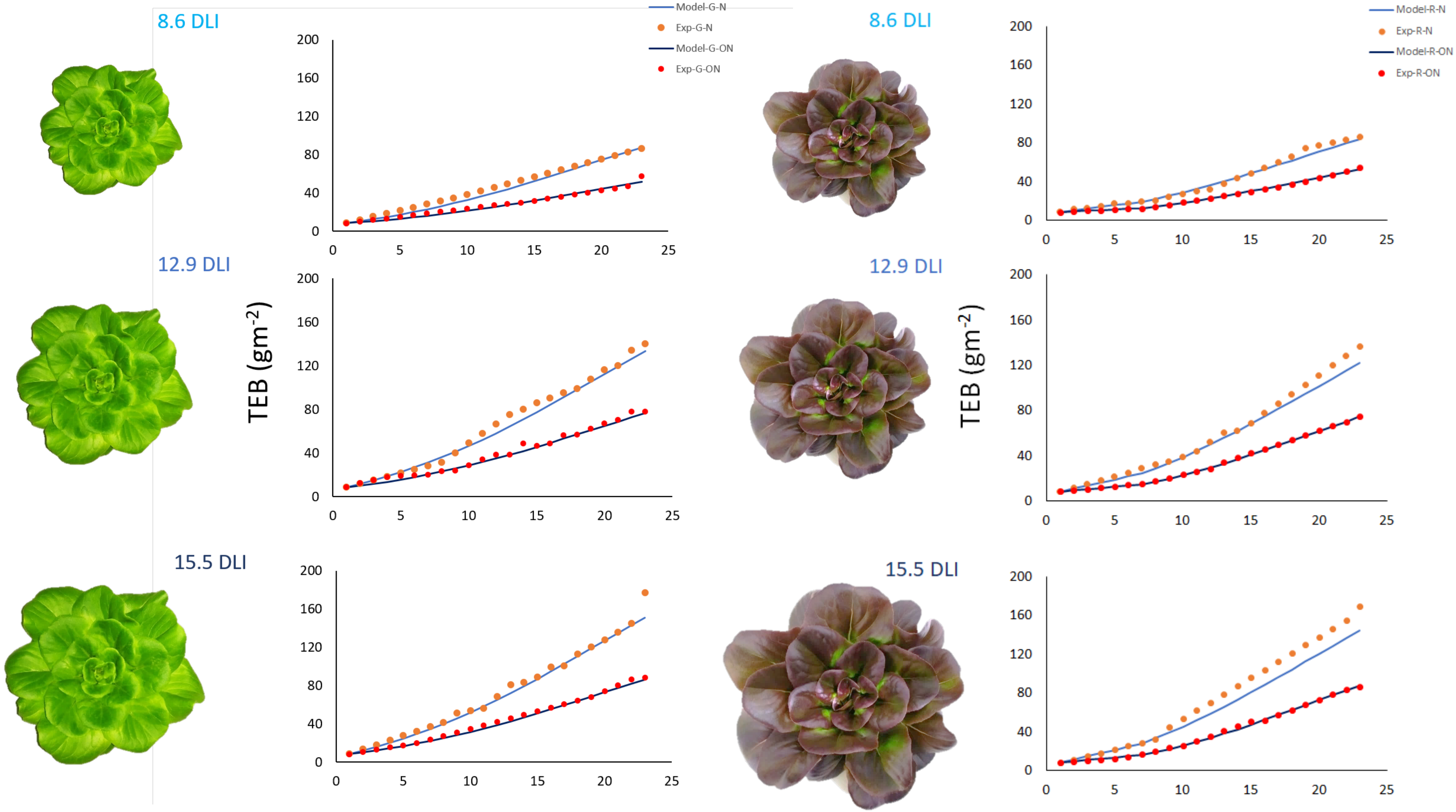
In the present study:

1. We grew green- and red-leaf lettuce grown in a Vertical farm under low VPD (nominal condition) and high VPD (off-nominal condition).

2. We used three different light intensities (8.6, 12.9 and 15.5 DLI), one for layer.

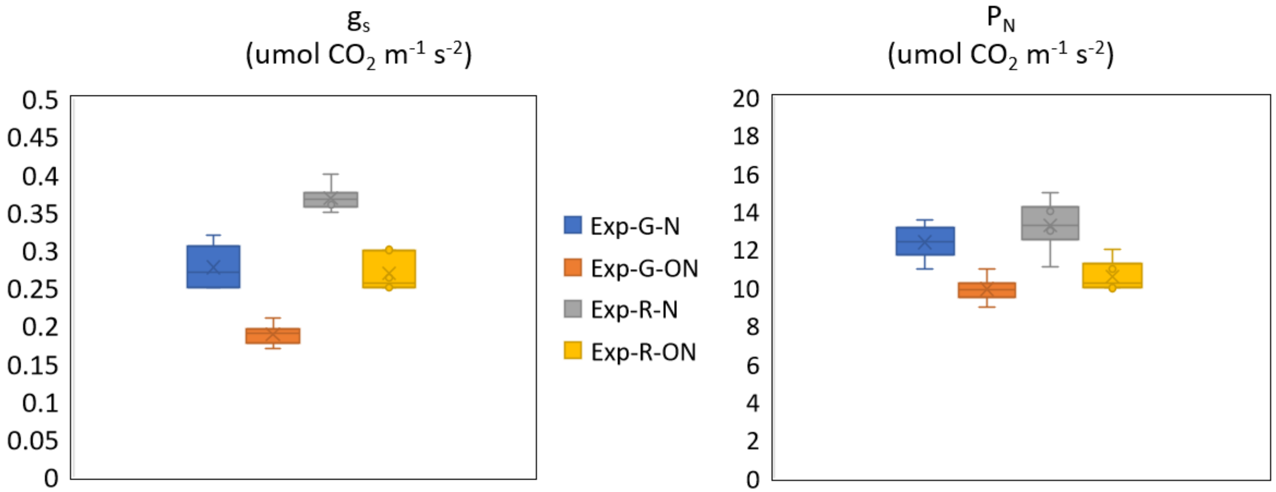
3. We validate the MEC model against experimental data.

Results


8.6 DLI
12.9 DLI
15.5 DLI
TEB (gm-2)
Model-G-N
Exp-G-N
Model-G-ON
Exp-G-ON
Model-R-N
Exp-R-N
Model-R-ON
Exp-R-ON
0
40
80
120
160
200
0
5
10
15
20
25

Results

12.9 DLI



Vertical farm experiments	DAT	rBIAS g_s	predicted g_s (mol $m^{-2}s^{-1}$)	rBIAS P_N	predicted P_N (µmol Co_2 $m^{-2}s^{-1}$)
G-N	23	22%	0.24	16%	9.80
G-ON	23	20%	0.11	17%	10.37
R-N	23	19%	0.32	12%	10.61
R-ON	23	15%	0.12	15%	6.84

Conclusions

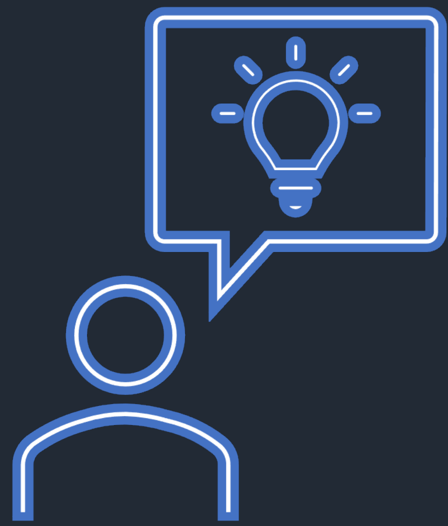
The MEC model reasonably predicts edible biomass, in both green and red ‘Salanova’ lettuce under nominal and off-nominal conditions being also reliable at the vertical-farm level, with lettuces under different light intensities. However, the model slightly underestimates stomatal conductance and net photosynthesis in both trials.

Challenge ahead

1.To increase the functionality of the model a further step will be to specific parameters that will consider the possible intrinsic morpho-physiological variability of plants, especially developed under off-nominal conditions.

2. A compartment that consider other environmental variables such as drought or CO_2 enrichment should be added to the model.

3. Explanatory models are promising tool for forecasting growth variations caused by anomalies in the environmental control and should be taken into account not only in Space-related research, but also to manage crop production throughout the year and to cultivate under climate change scenario.



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THANK YOU.

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