MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

2022 MELISSA CONFERENCE
8-9-10 NOVEMBER 2022

CREATING A CIRCULAR **FUTURE**

Water Across the Plant Systems (WAPS)

ground tests on hydration and air humidity to model plant growth for space experiments

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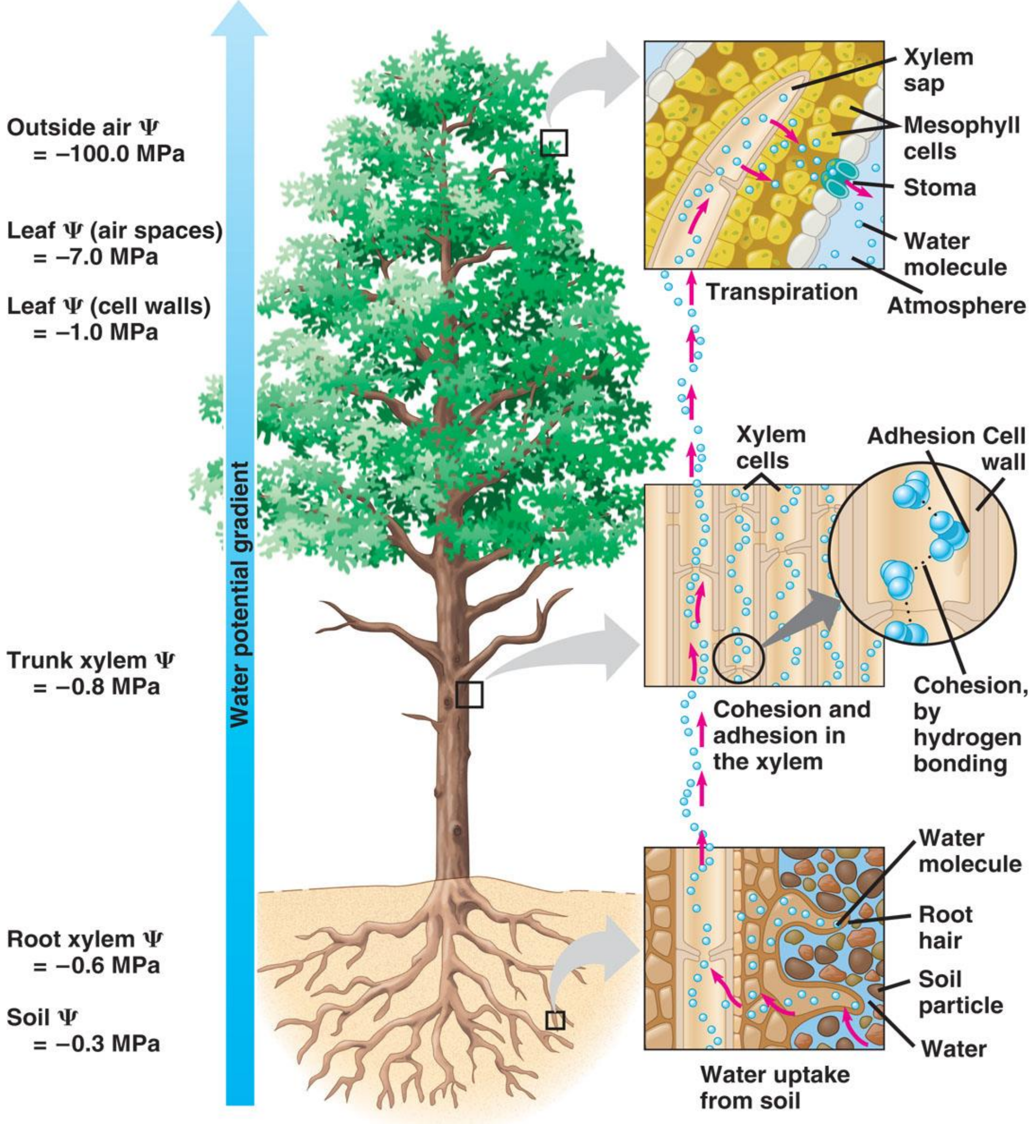


Plant growth depends on

- the water flow in-across-out of the plant
- the water potential gradient between the root and the air outside the leaf and consequently the rate of transpiration.

Environmental factors playing a major role in transpiration are:

- Soil water
- Light
- Temperature
- Air humidity
- Wind

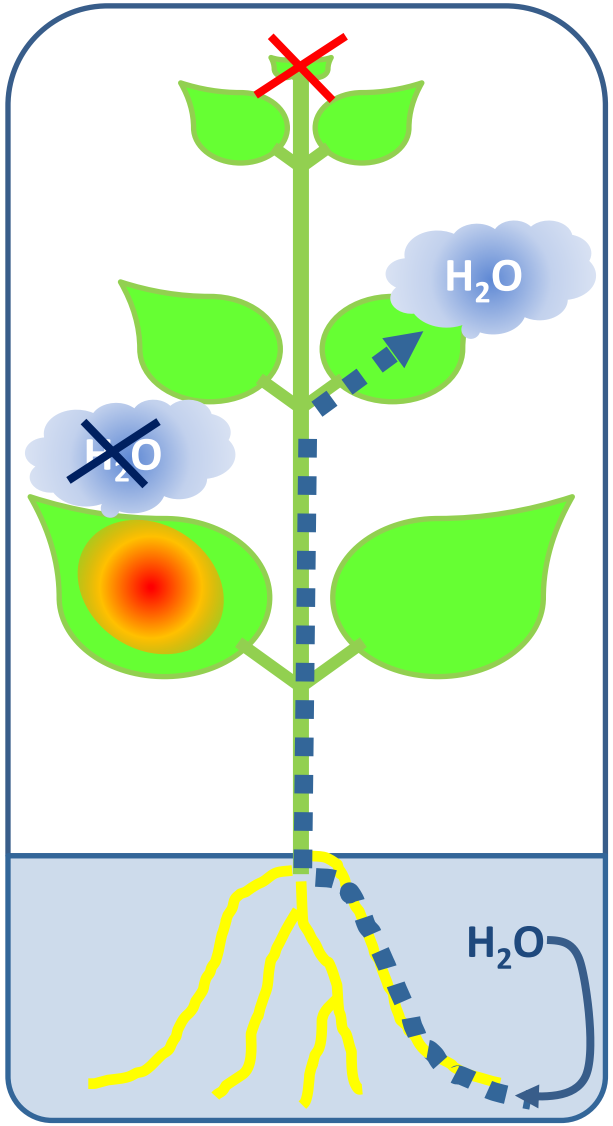
Leaf gas exchanges and Boundary layer

At leaf level, water transpiration and exchanges of other gases (CO_2, O_2) can be limited by stomata closure and thickness of boundary layer

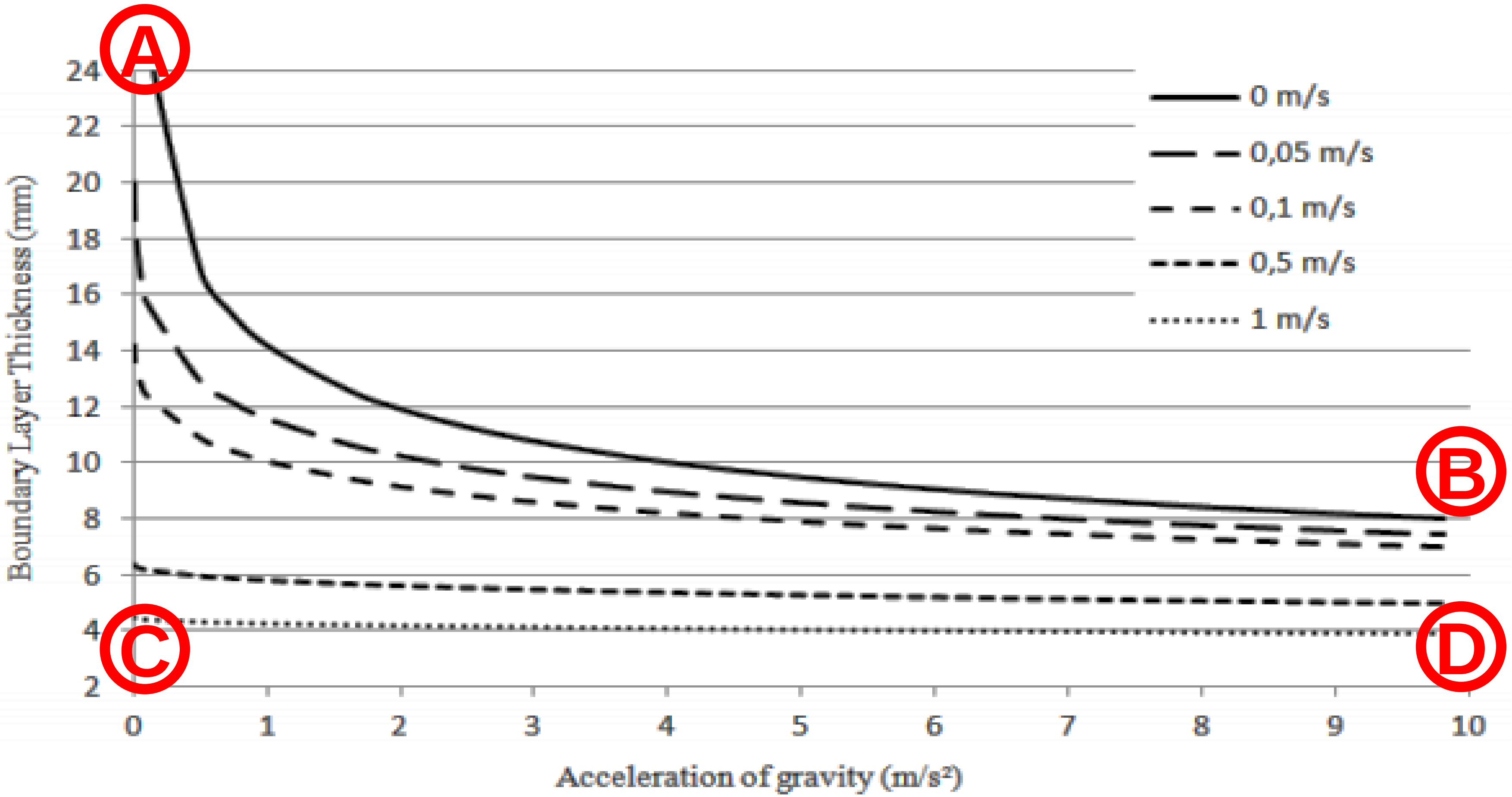
The **boundary layer** is a zone of stagnant air that surrounds plants organs.

Thick boundary layers

- Limit the gas exchanges
- Increase leaf temperature
- Decrease plant growth



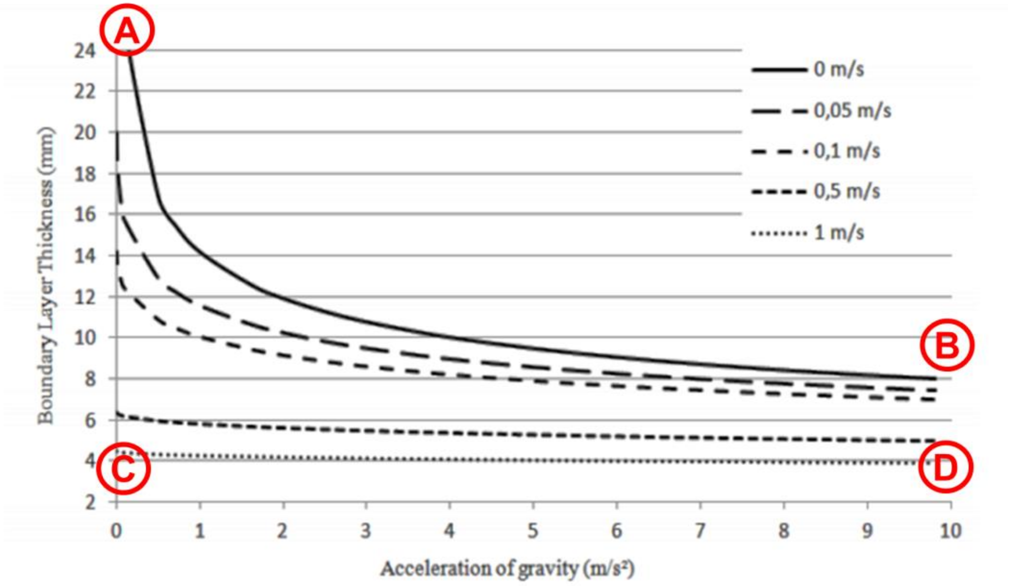
The boundary layer formation occurs both on Earth and in space.
Air flow around leaf surface affects BL thickness



by L. Poulet 2018

WAPS: scientific aims and experimental design

AIMS: To separate direct effects of microgravity on plant growth from the indirect effects caused by restricted free air convection



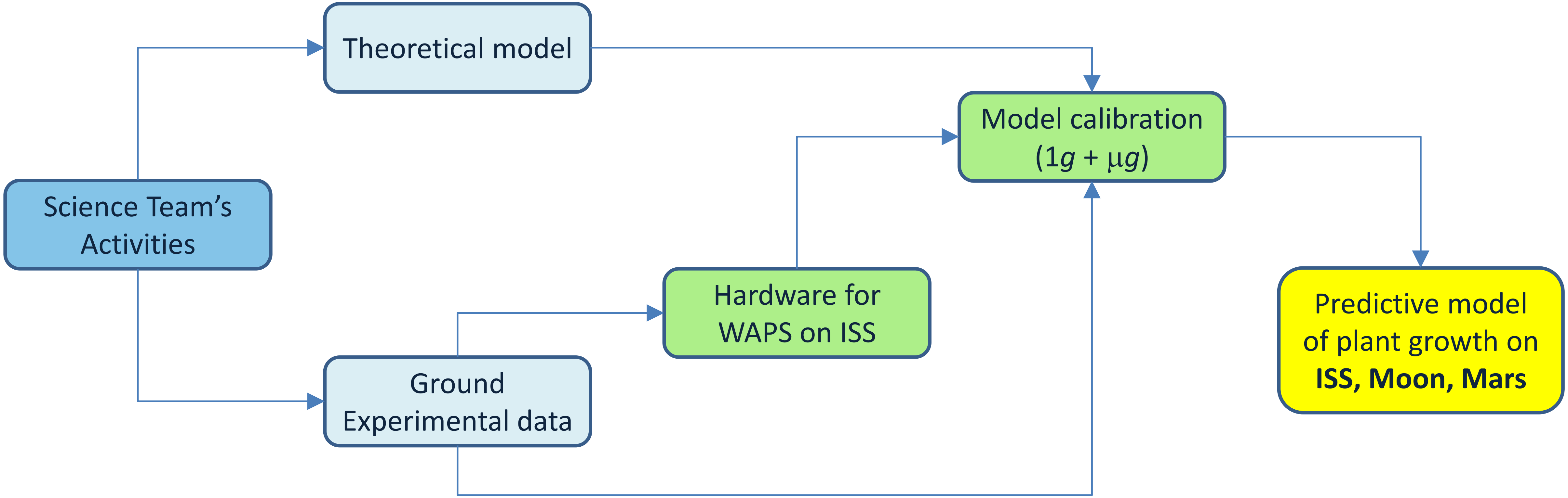
EXPERIMENTAL DESIGN:

- two levels of gravity
- two levels of boundary layers

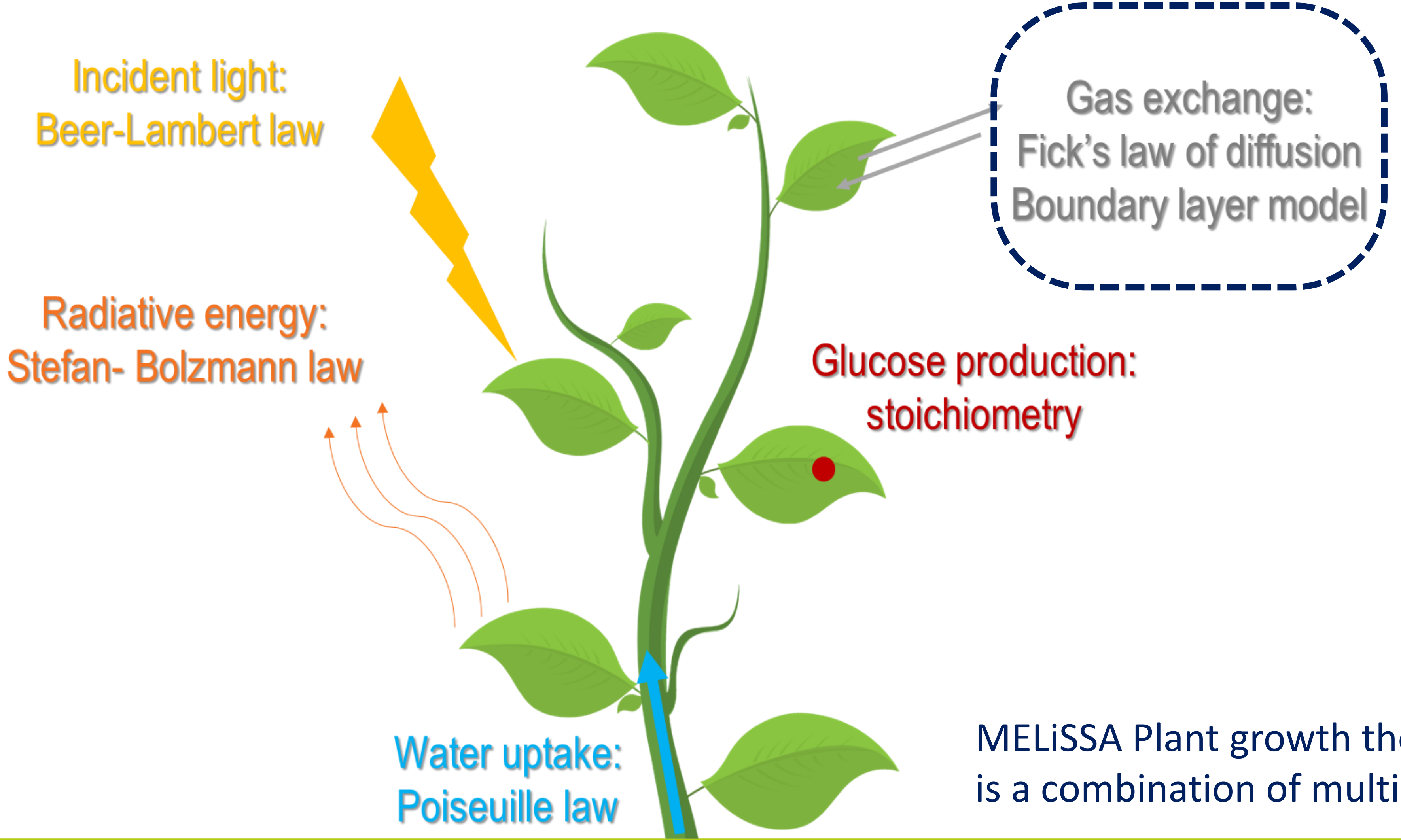
All other factors (temp., light, air humidity, …) to be kept equal in all CCs

	ISS microgravity	1g inflight control
Thick boundary layer (BL "present")	A - Worst scenario: both microgravity and stagnant atmosphere affect plant growth	B - This combination emphasize the effect of the boundary layer
Thin boundary layer (BL "absent")	C - This combination emphasize the effect of microgravity	D - Control-combination: plant growth is affected by neither microgravity nor boundary layer

WAPS Science Team: scientific approach



Plant growth theoretical model



MELiSSA Plant growth theoretical model is a combination of multiple sub-models

WAPS model: Entry Parameters and Output Variables

ENTRY PARAMETERS

Environment
- Chamber dimensions
- Gravitational acceleration
- Air
  - Pressure
  - Composition
  - Temperature
  - Relative Humidity
  - Velocity

Plant fixed parameters
- Initial fresh mass*
- Initial leaf temperature**
- Specific Leaf Area***
- Dry Mass Ratio****
- Transpiration Ratio*****

Computed from:
** Leaf Area on day 8 and 14 and Fresh Mass on day 14*
*** IR images*
**** Leaf Area and Fresh Mass*
***** Fresh and Dry Mass*
******Fresh and Dry Mass, and Water used by the plant*

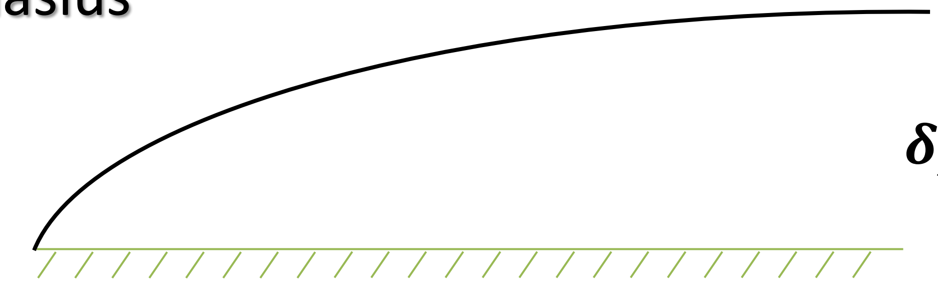
Plant adjustable parameters
- Stomatal Conductance
- Leaf Absorbance

OUTPUT VARIABLES

- Dry mass
- Free water in the plant
- Leaf temperature
- Transpiration rate
- CO_2 absorption rate

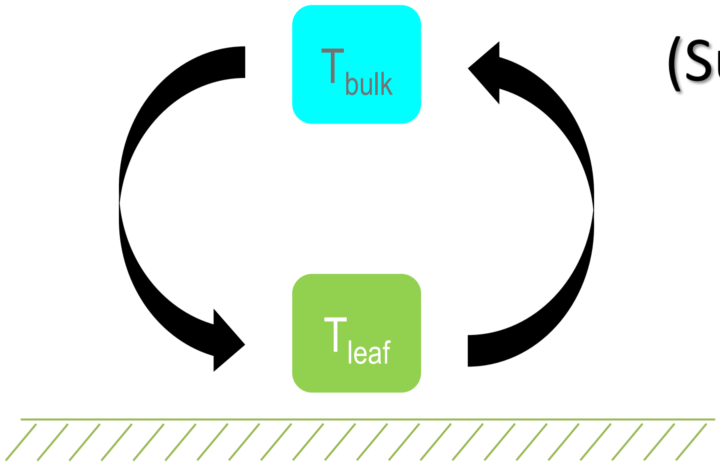
Boundary Layer: Surface Renewal Model

Blasius

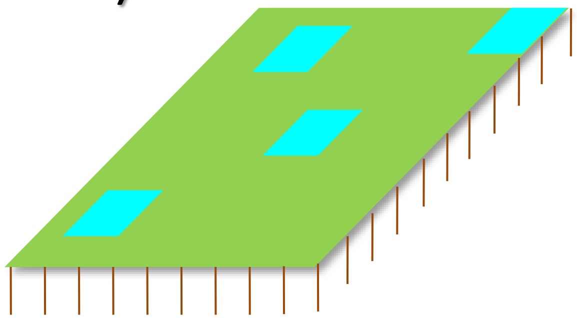


$$\delta_X = 4.64\sqrt{\frac{\nu\, L}{V_{bulk}}}$$

Danckwerts (Surface Renewal Model)



$$\delta_X = \frac{2}{\zeta}\sqrt{\frac{\nu\, L}{V_{bulk}}}$$



The SRM represents the BL in a more dynamic way

The BL thickness is linked to the friction between the air and the surface

Boundary Layer Surface Renewal Model

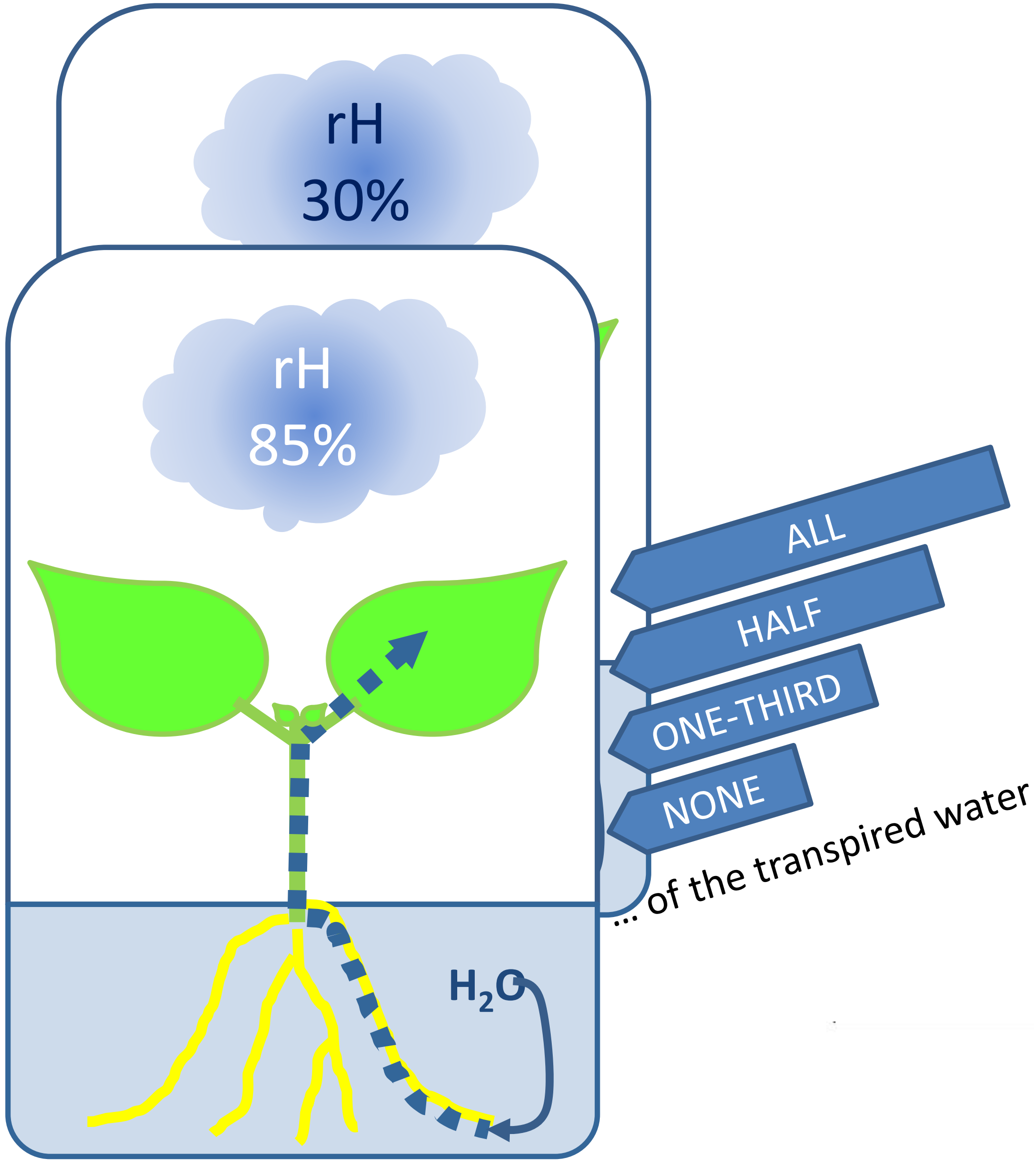
Time Scale	SECONDS	MINUTES / HOURS	DAYS
Behavior	Transient	Steady-State	Biomass production
Response	Physical	Biological	Growth
Model calibration and validation	Done on parabolic flight data ~20 s	On-going work on gas exchange data	Current work

Model calibration: experiment on plant watering

Experimental hypothesis:
Both water availability to root and air humidity influence plant growth and transpiration

Experimental design: 4x2
<u>4 watering regimes</u>:
- ALL
- HALF
- ONE-THIRD
- NONE

<u>2 environmental conditions</u>:
- rH 30%
- rH 85%

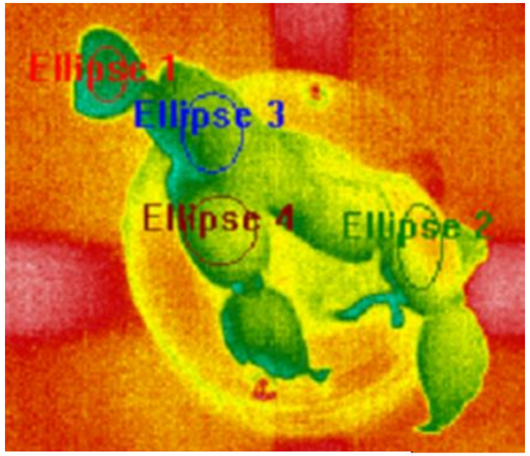


Types of Experimental data

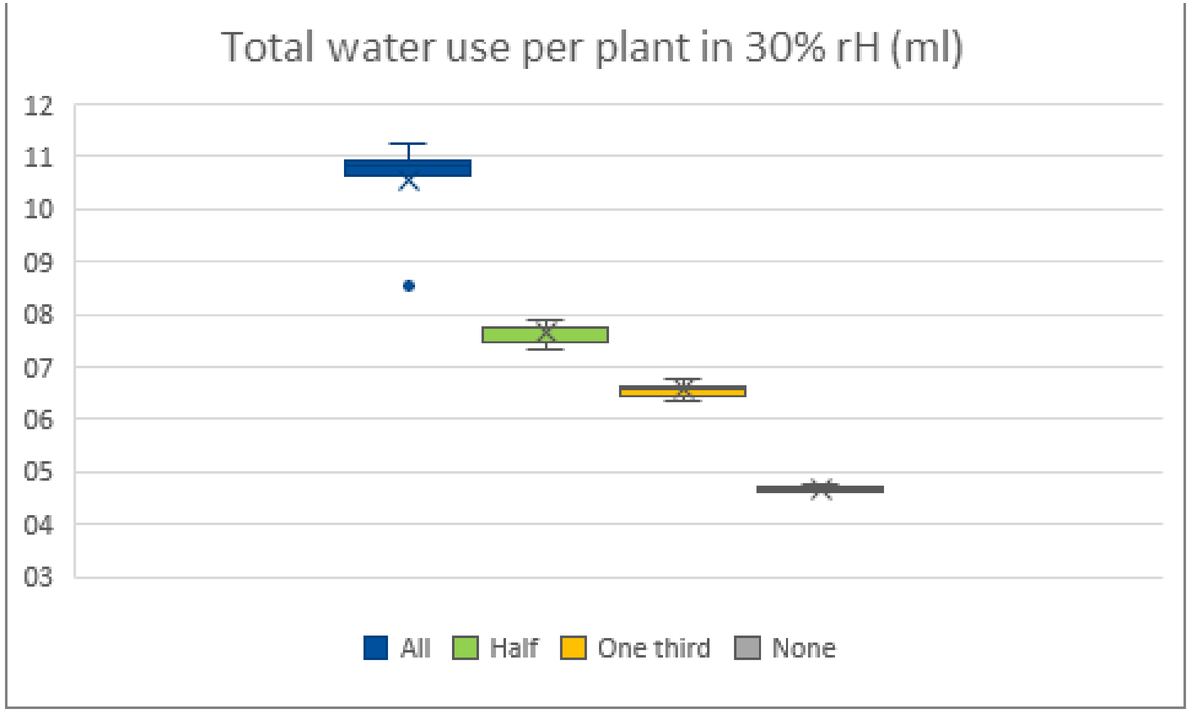
Biometric measurements
Including:
- Stem length
- Leaf Area

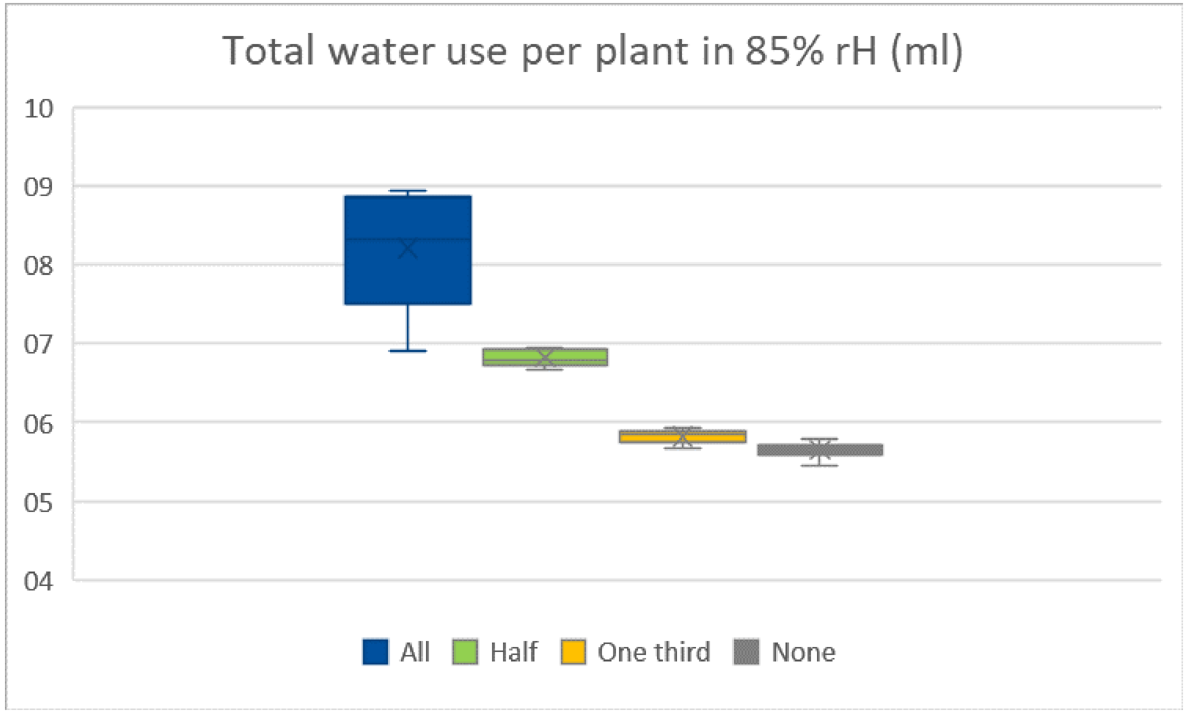
Biomass measurements
Fresh weight and dry weight of
- Leaf
- Shoot
- Root

Temperature measurements
IR thermal Imaging



Results: Total Water Use per plant

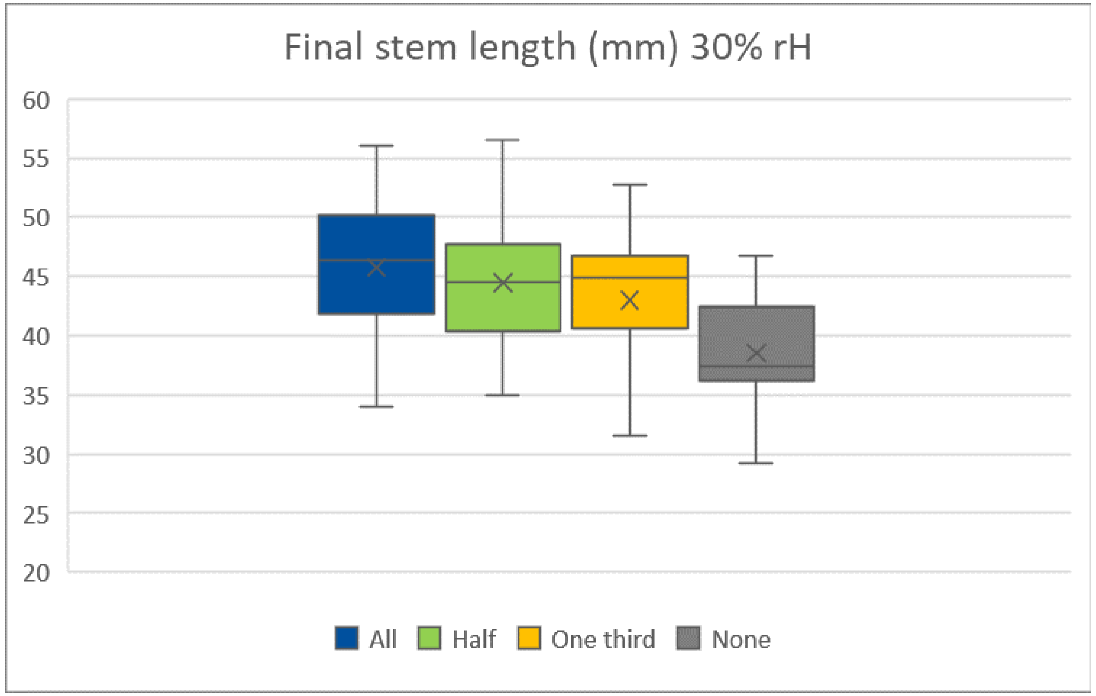


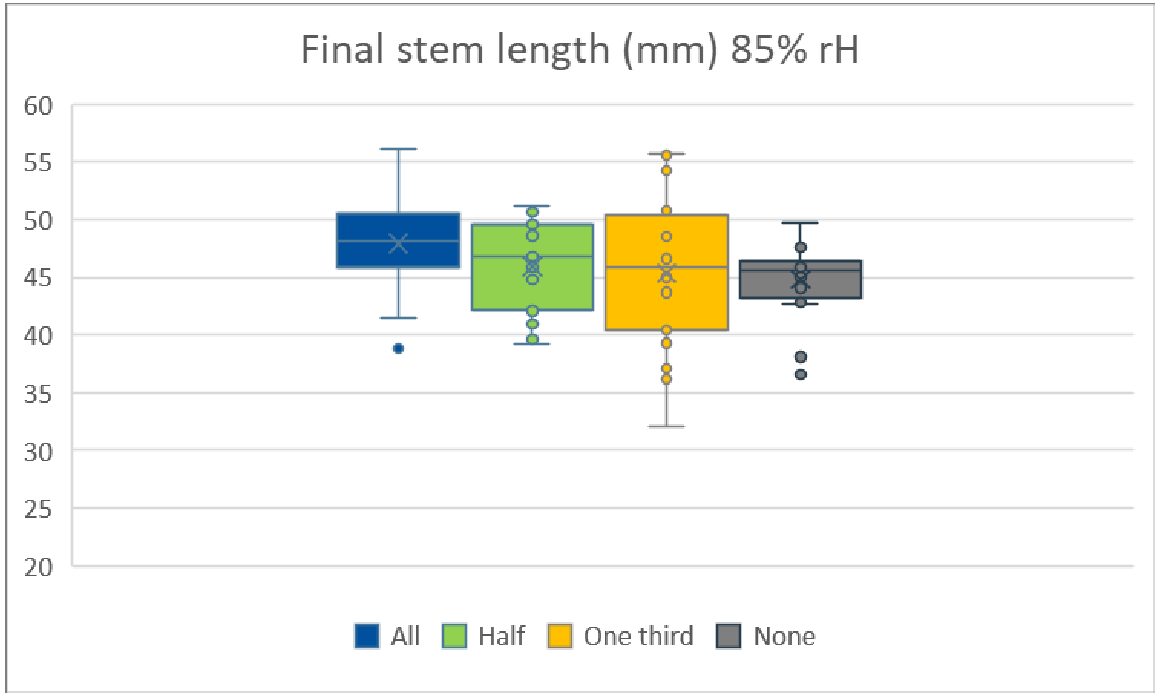


The more water was available to the root the more water was used by the plants

The lower was the rH the higher was the total water use per plant

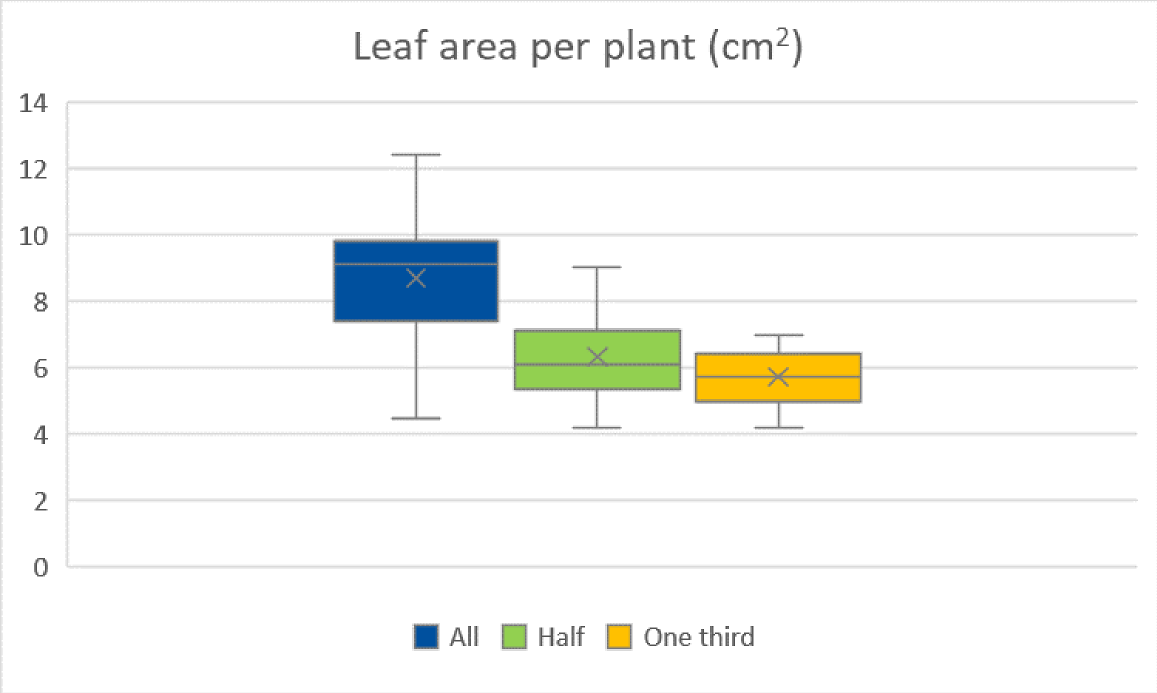
Biometrical results: Stem length

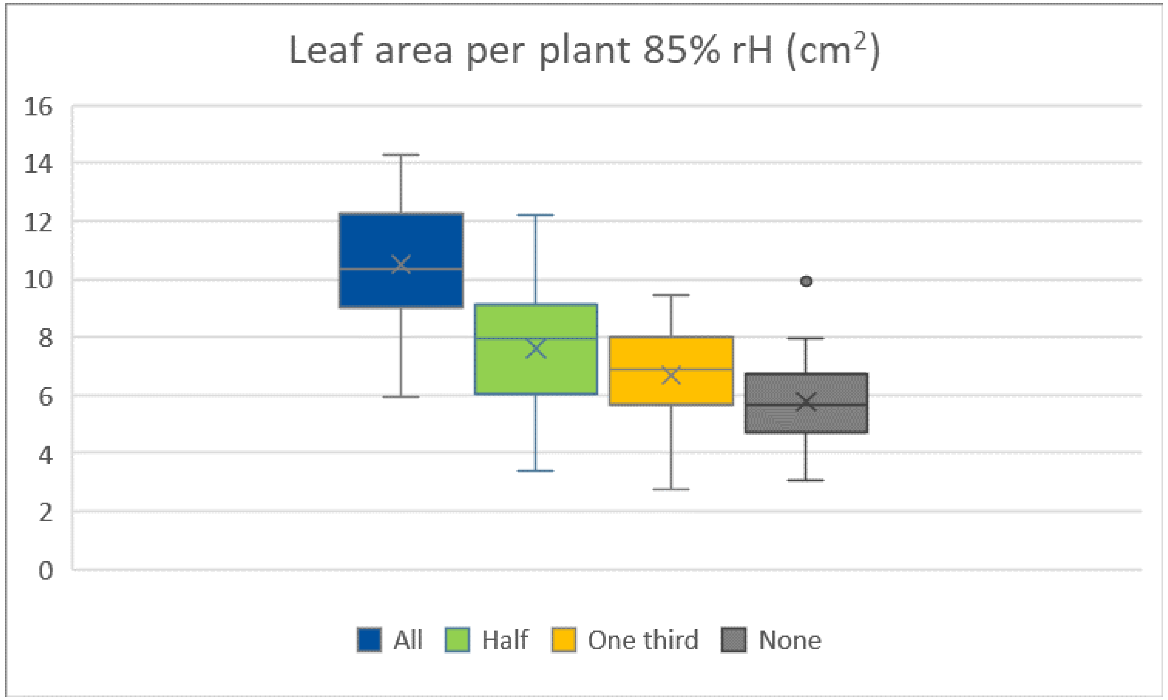




Plant height was not significantly affected by watering regime in both air humidity conditions

Biometrical results: Leaf area

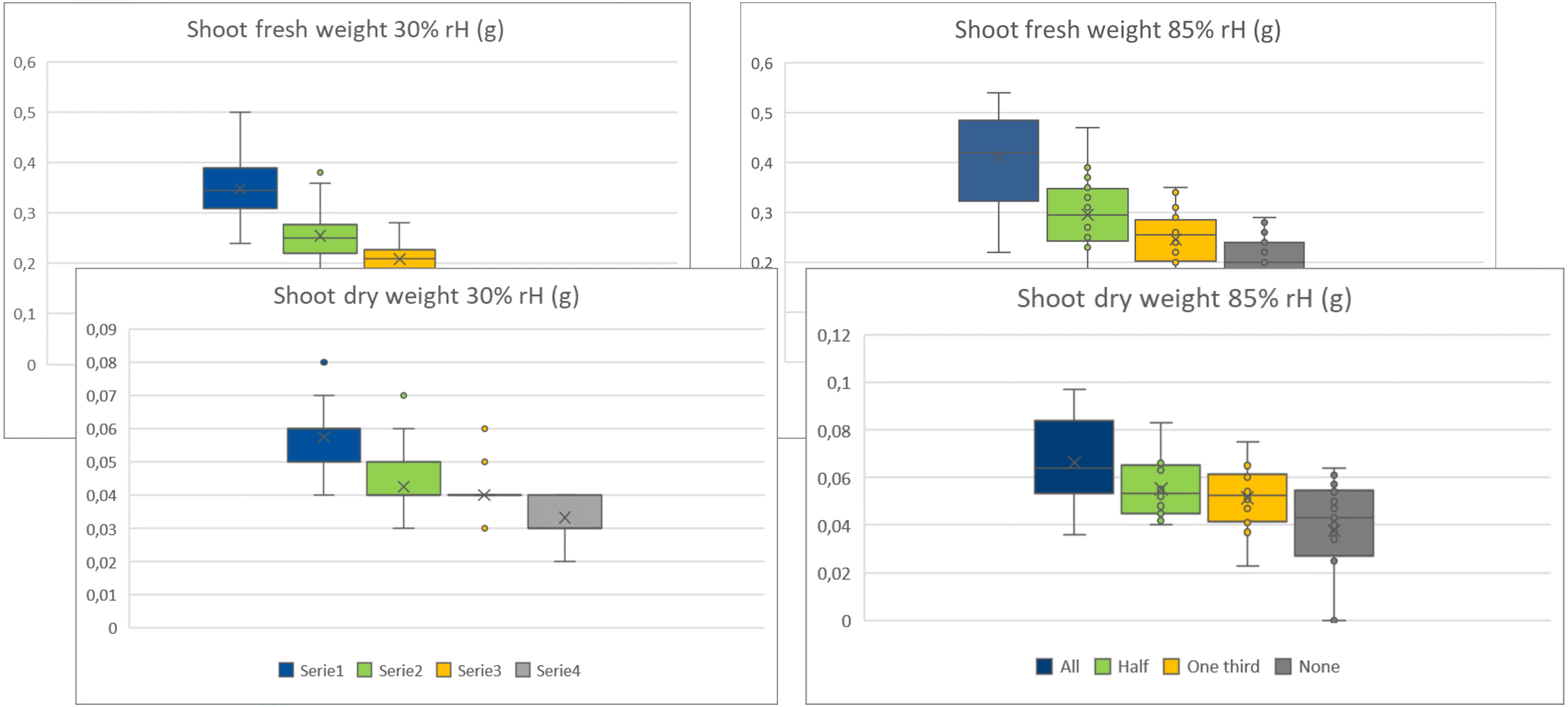




The more water was available the larger was the leaf

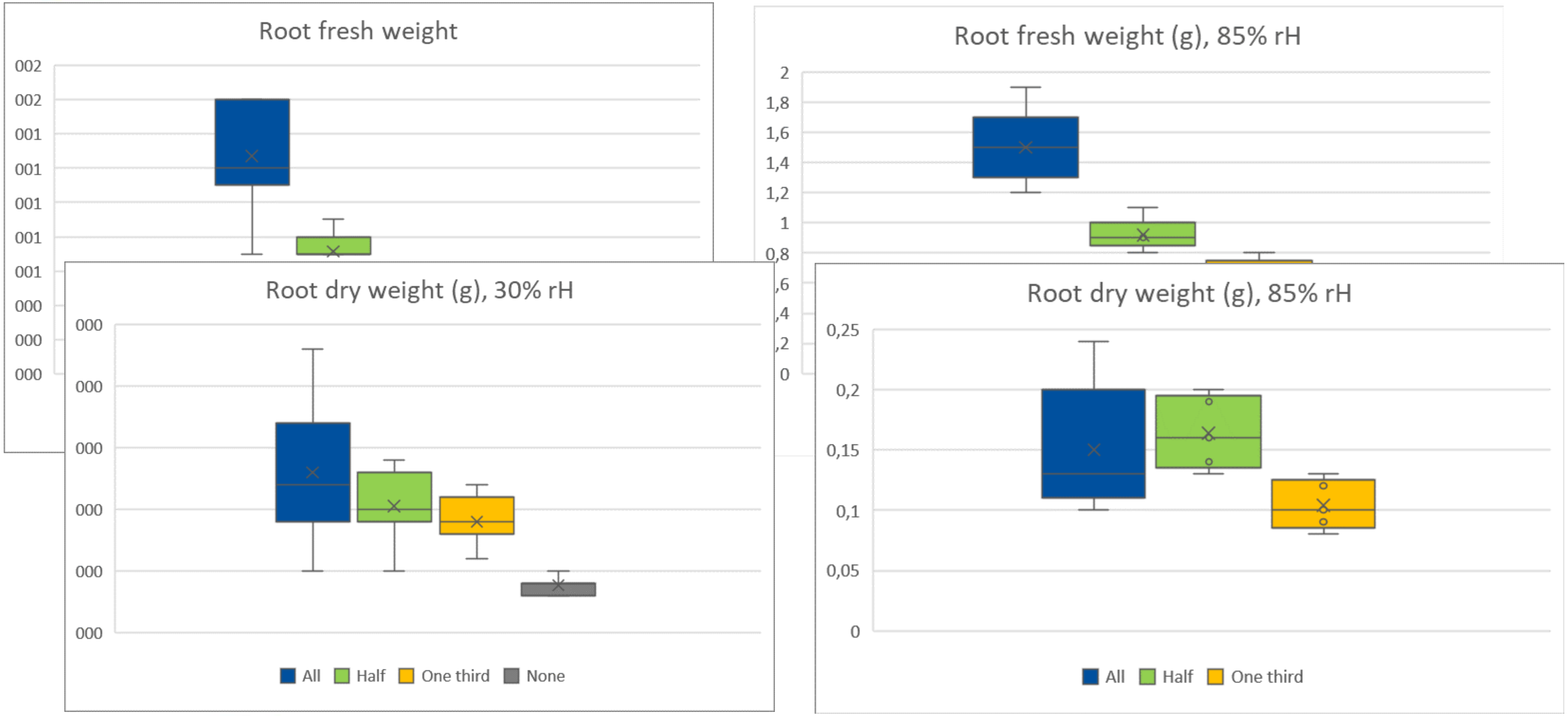
The lower was the rH the smaller was the leaf area

Biomass results: Shoot Fresh and Dry Weight



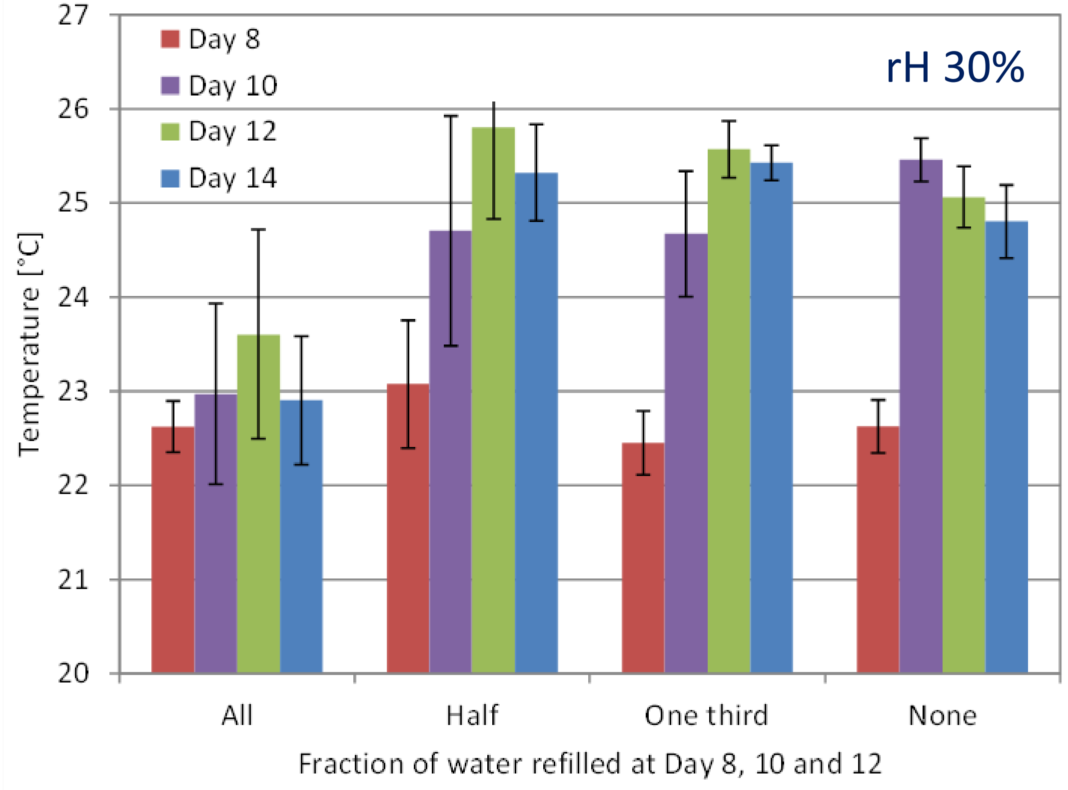
Full water availability increases plant growth and biomass accumulation

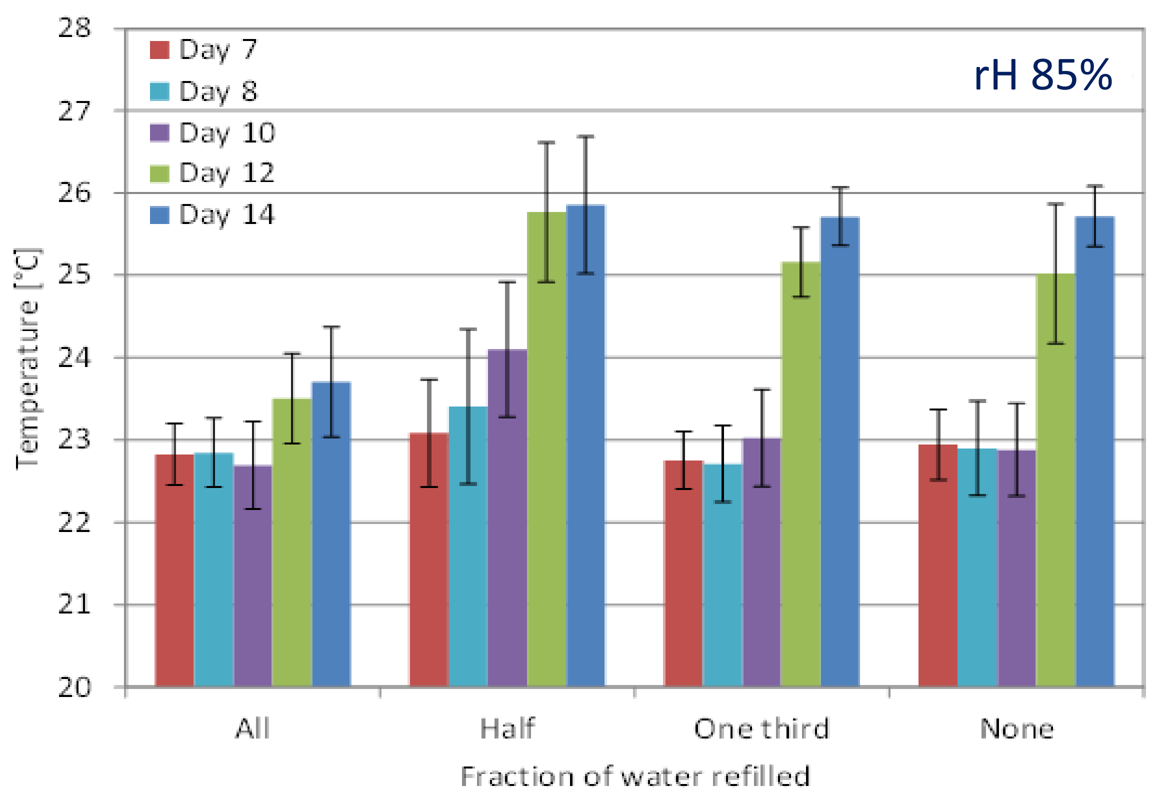
Biomass results: Root Fresh and Dry Weight



Full water availability increases root growth and biomass accumulation

Results on Leaf Temperature (thermal imaging)

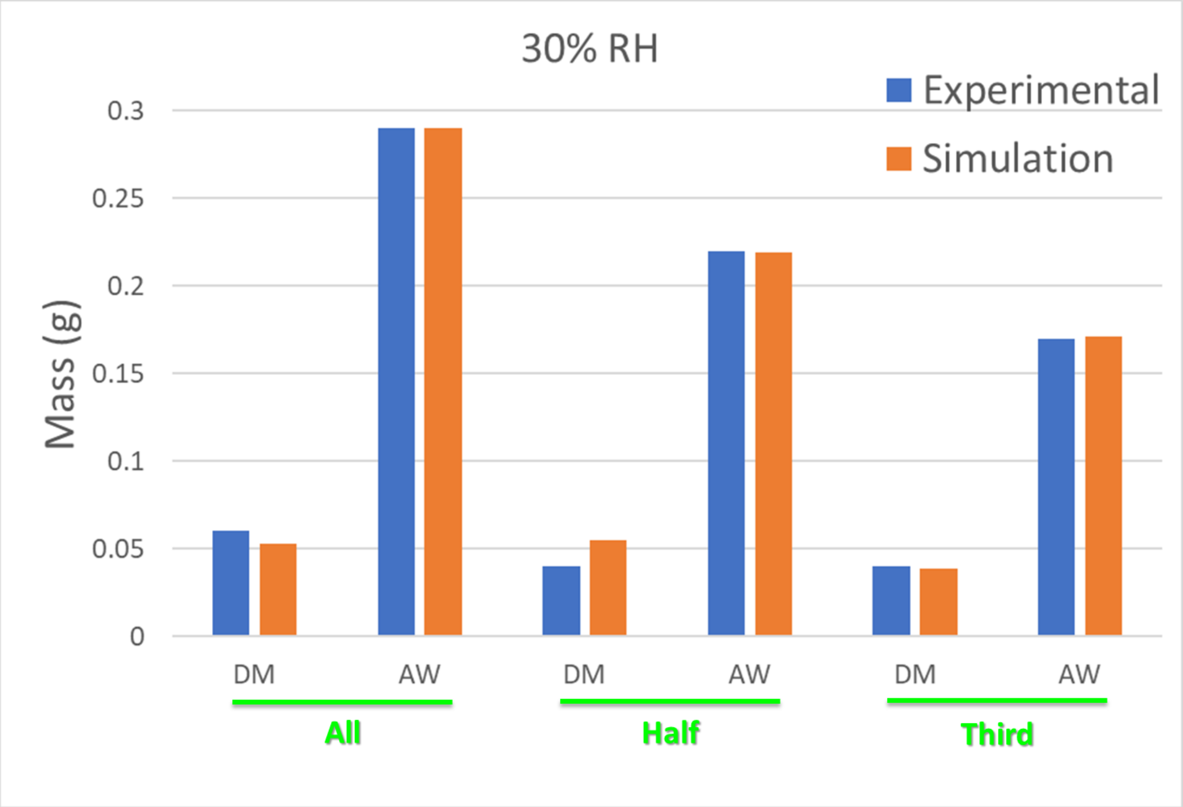


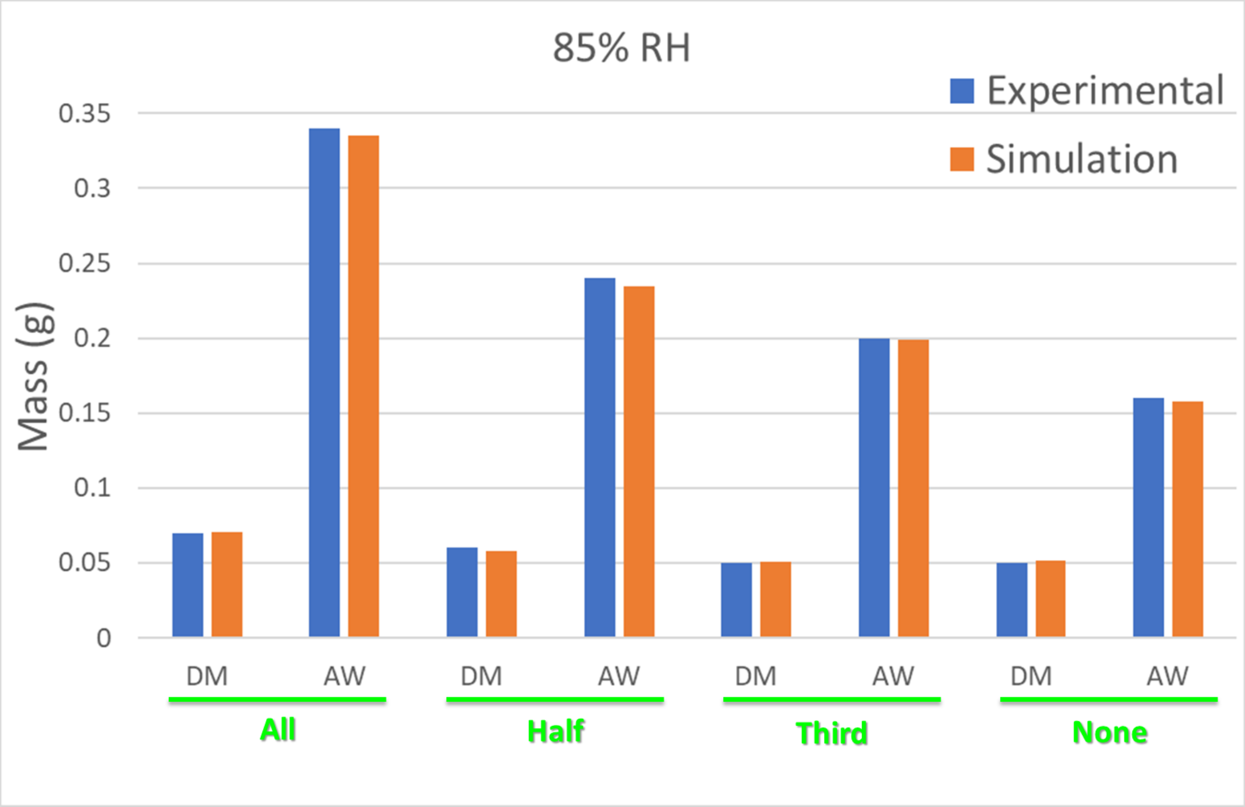


Leaf temperature remained stable only when water was fully available

Shortage of water might have increased leaf temperature because of stomata closure

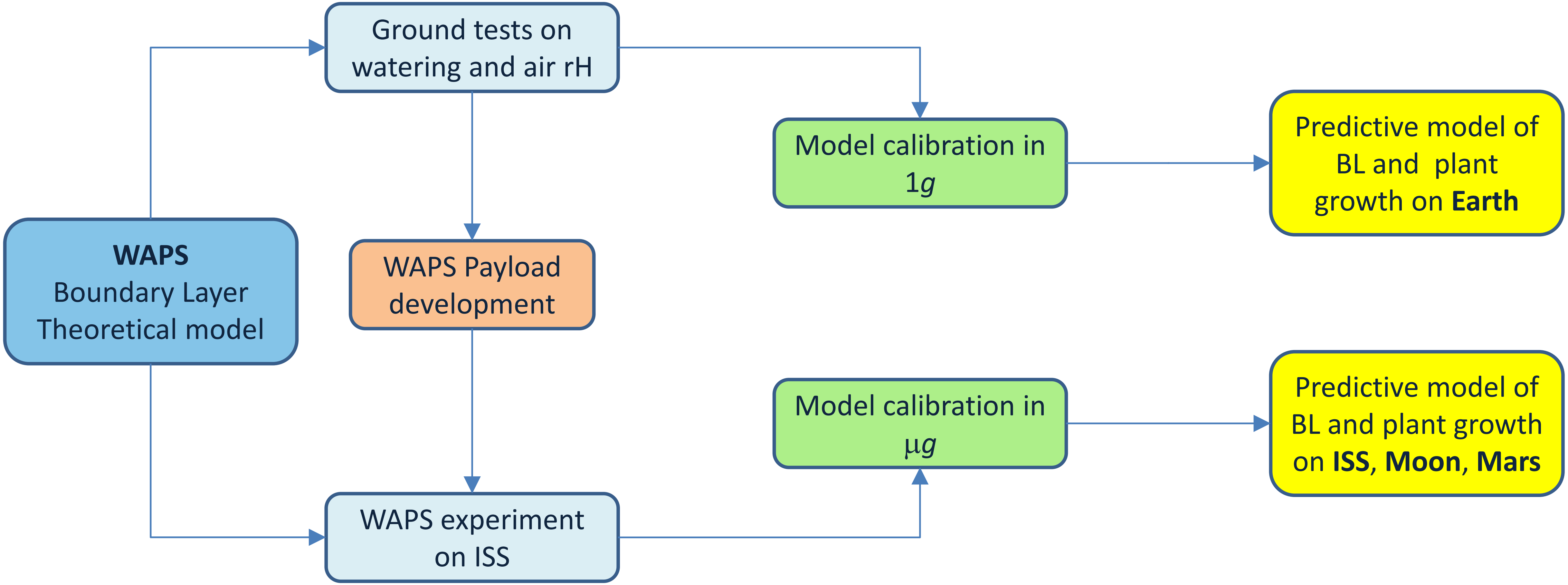
Model validation and calibration





Experimental and simulation results are consistent both in terms of Dry Mass and Accumulate Water

WRAPPING UP



Ground tests on watering and air rH
Model calibration in $1g$
Predictive model of BL and plant growth on **Earth**
WAPS Boundary Layer Theoretical model
WAPS Payload development
Model calibration in μg
Predictive model of BL and plant growth on **ISS**, **Moon**, **Mars**
WAPS experiment on ISS

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THANK YOU.

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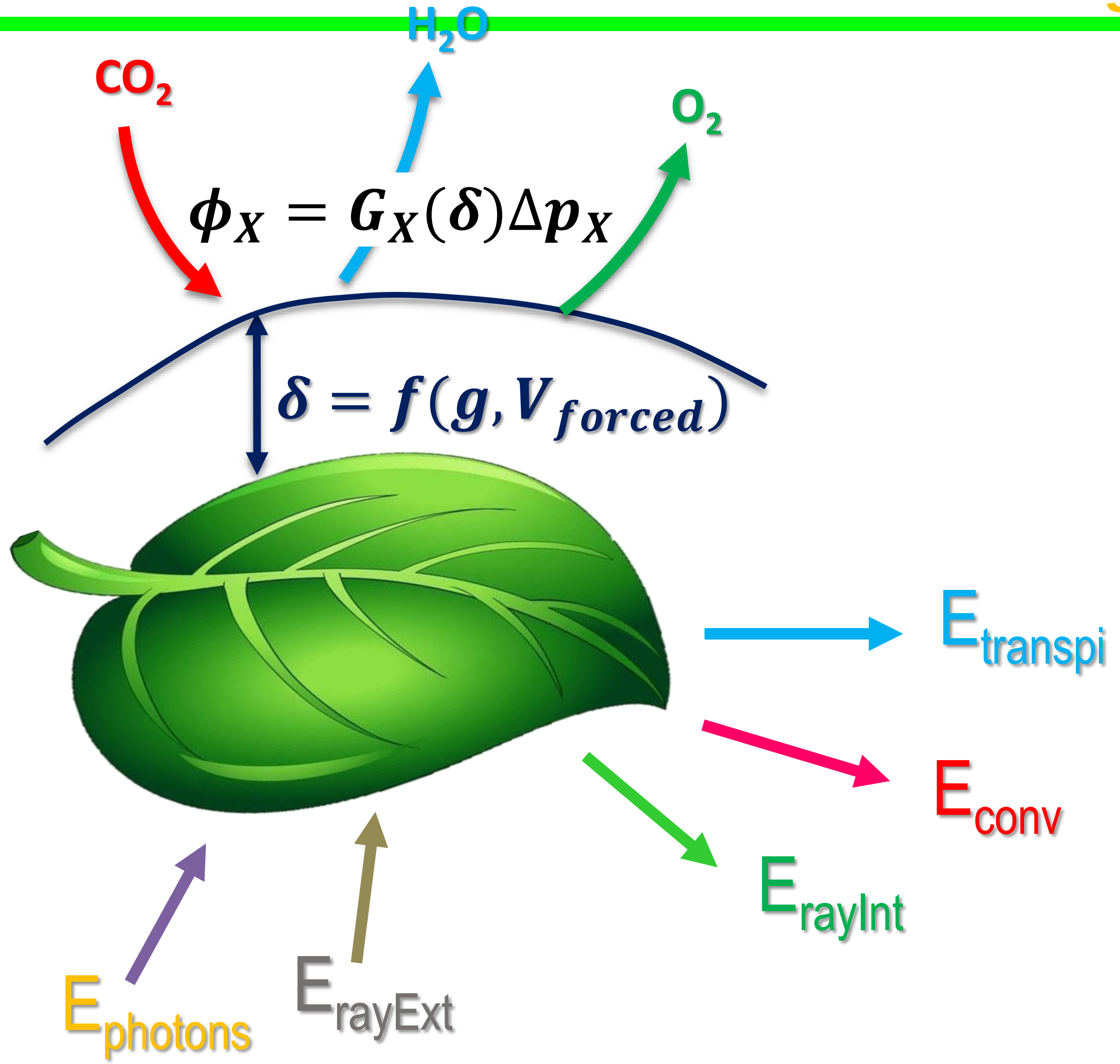
Back-Ups

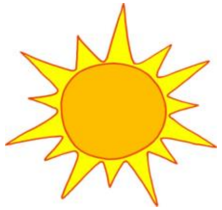
MELiSSA Plant growth theoretical model: mass and energy balance

Mass Balance

Energy Balance



MELiSSA Plant growth theoretical model: Principles of Leaf Energy Balance



$$E_{photons} = I_0 N_A h\, c \sum_{i=1}^{n} \frac{\alpha_i}{\lambda_i}\, LA$$

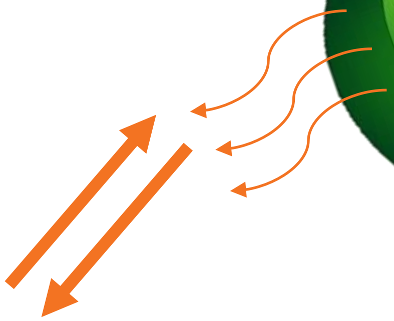
Coupled with the environment

$$E_{conv} = \frac{k_t}{\delta_X}\left(T_{leaf} - T_{bulk}\right) LA$$

Coupled with hydrodynamics and environment

$$E_{transpi} = \lambda_{mol}\, \varphi_{H_2O} LA$$

Coupled with mass balance



$$E_{ray} = \varepsilon\sigma\left(T_{leaf}^4 - T_{bulk}^4\right) LA$$

$$\frac{dT_{leaf}}{dt} = \frac{E_{photons} - E_{ray} - E_{conv} - E_{transpi}}{Cp_{leaf}}$$

Main results of the model simulations

This slide is not to stay, i
summary of the results

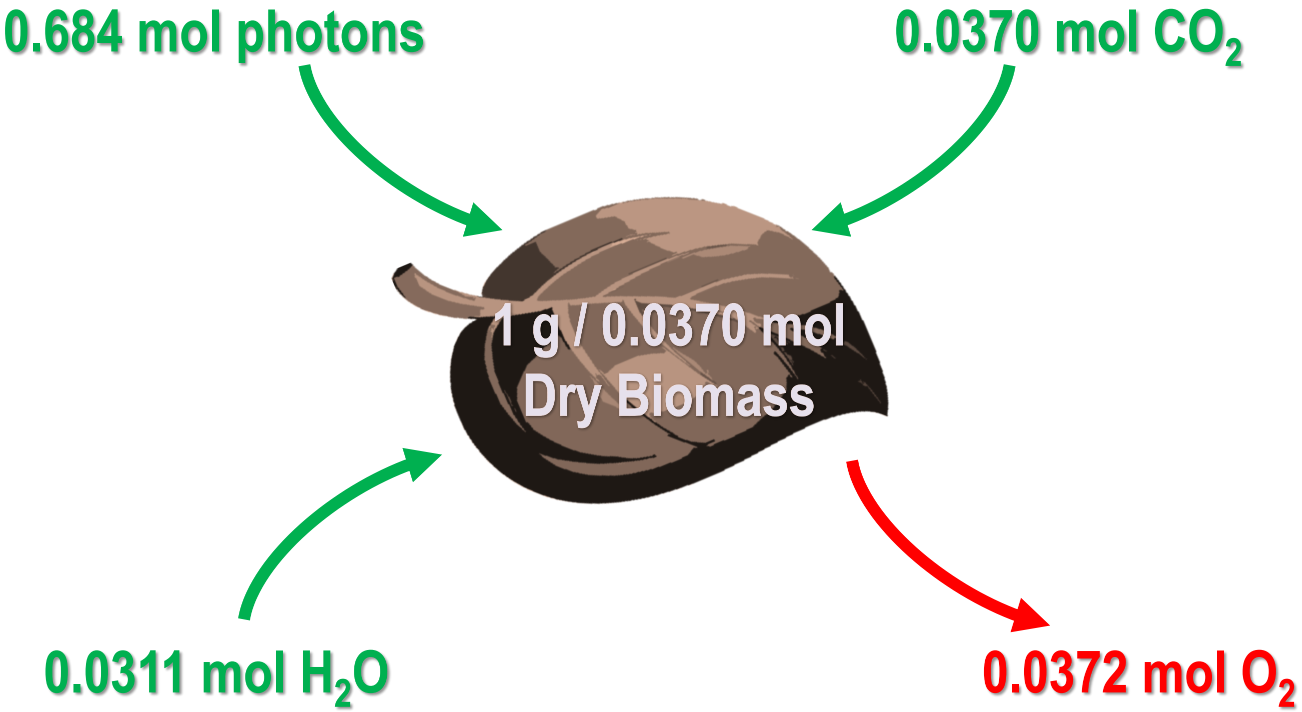
- The boundary layer model was fine tuned
- CO_2 absorption (dry mass) is underestimated for the case at 85% RH
- At 85% RH
  - Average stomatal conductance: 0.5 – 0.9 depending on hydration
  - Leaf absorbance: 0.95
- At 30% RH
  - Average stomatal conductance: 0.06 – 0.11 depending on hydration
  - Leaf absorbance: 0.95 for 2 highest hydration and 0.7 for the 2 lowest

Comparison experimental and simulation results

Relative Humidity	Hydration	Experimental		Simulation			
		Dry Mass (g)	Free Water (g)	Dry Mass (g)	Free Water (g)	Stomatal conductance	Leaf absorbance
85 %*	All	0.07	0.34	0.071	0.335	0.9	0.95
	Half	0.06	0.24	0.058	0.235	0.9	0.95
	Third	0.05	0.2	0.051	0.199	0.5	0.95
	None	0.05	0.16	0.052	0.158	0.57	0.95
30 %	All	0.06	0.29	0.053	0.290	0.11	0.95
	Half	0.04	0.22	0.055	0.219	0.056	0.95
	Third	0.04	0.17	0.039	0.171	0.06	0.7
	None	0.03	0.04				

* CO_2 absorption multiplied by 1.15 – meaning without this coefficient, dry mass is undeerestimated by 15%.

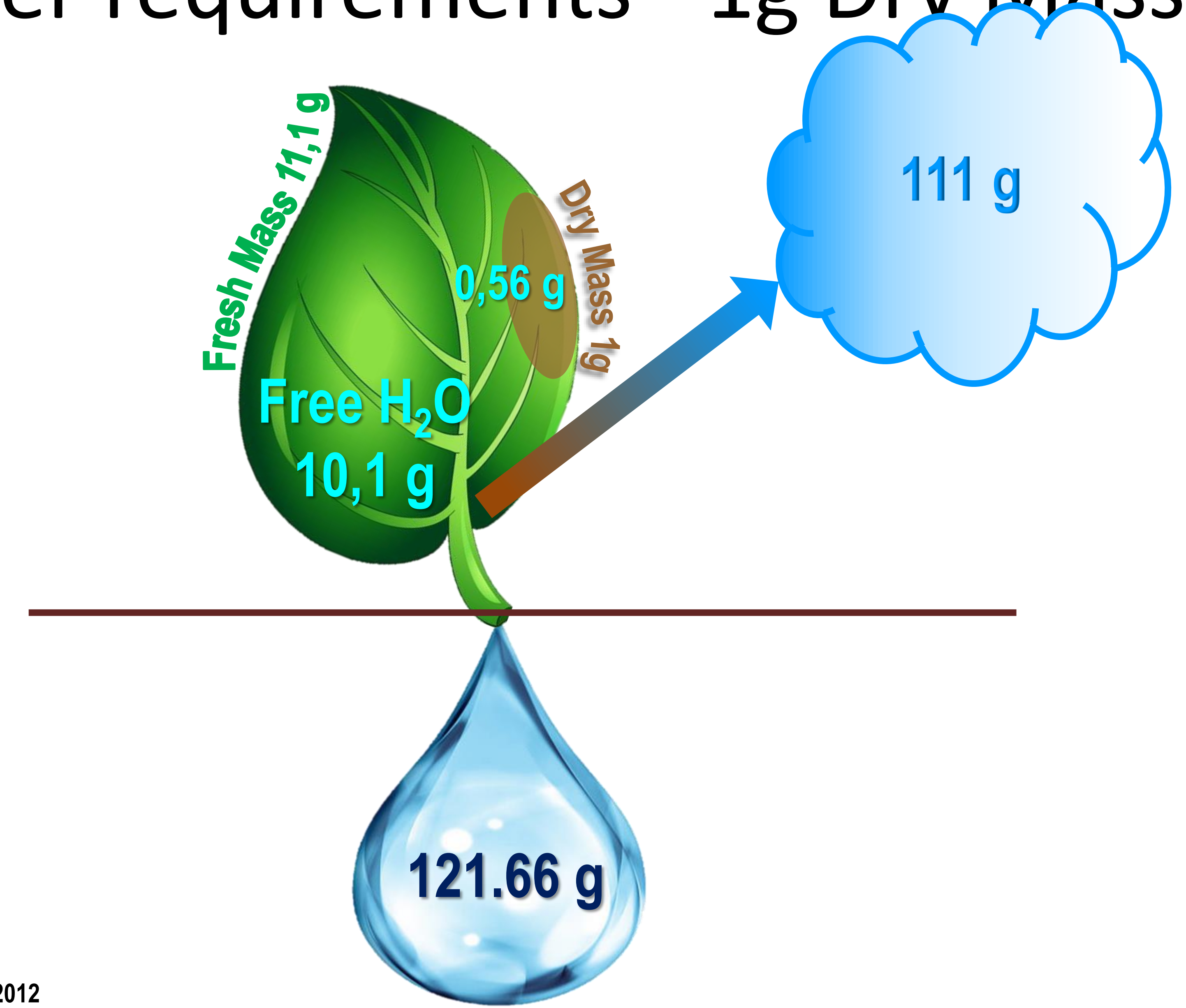
Stoechiometry



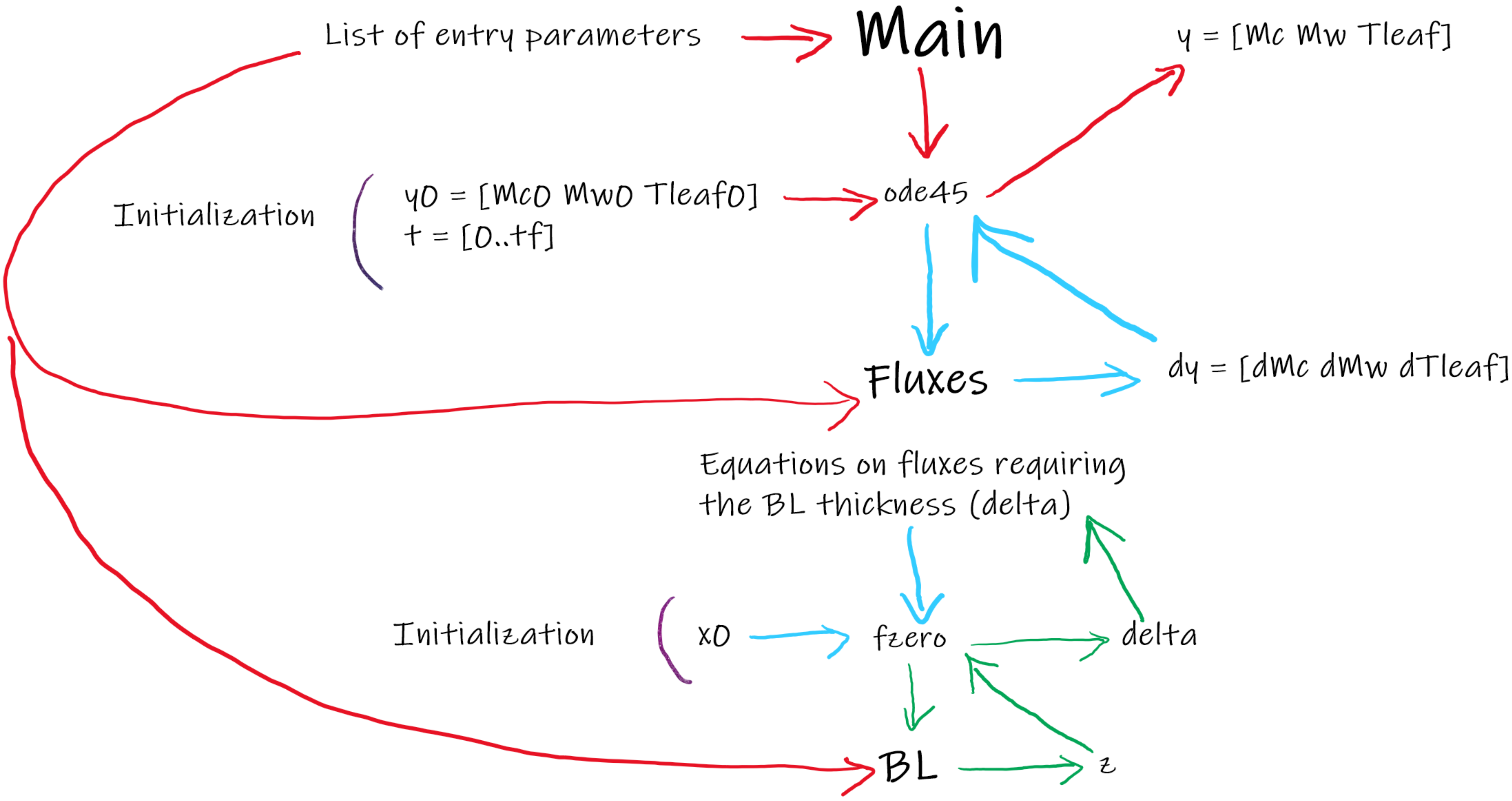
$$CO_2 + 0.833\ H_2O \rightarrow CH_{1,667}O_{0,833} + O_2$$

Hézard, PhD thesis, 2012
Sasidahran, PhD thesis, 2012

Water requirements - 1g Dry Mass



Hézard, PhD thesis, 2012
Sasidahran, PhD thesis, 2012


List of entry parameters
Main
y = [Mc Mw Tleaf]
Initialization
y0 = [Mc0 Mw0 Tleaf0]
t = [0..tf]
ode45
Fluxes
dy = [dMc dMw dTleaf]
Equations on fluxes requiring the BL thickness (delta)
Initialization
x0
fzero
delta
BL
z