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The Use of the Plant Characterization Unit for Investigating Crop Sub-Optimal Mineral Nutrition

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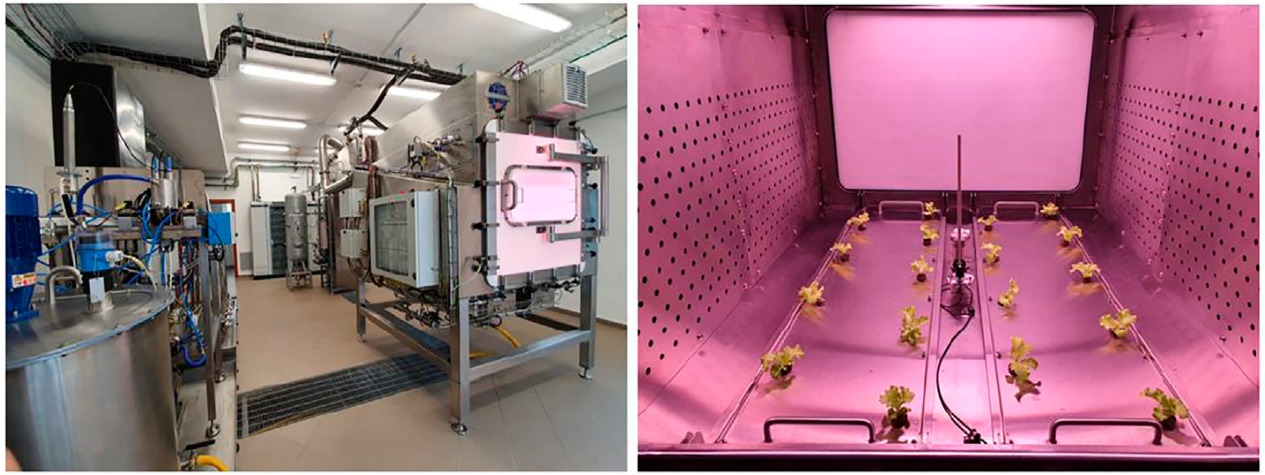
Introduction

- Higher plants are vital for Bioregenerative Life Support Systems (BLSS) such as the MELiSSA loop for producing food, H_2O, and O_2 and capturing CO_2.
- Mineral nutrition of crop in Space is currently ensured using slow-release mineral fertilizers, but on the long term it will need to be ensured by recycling nutrients from waste produced within BLSS.
- However, producing optimal nutrient solutions for hydroponic crop production from waste fluxes will be challenging (Frossard et al., 2024).
- It is therefore probable that crops will be growing under suboptimal conditions in BLSS.
- The impact of these suboptimal conditions on plant growth should be known so that their performance in terms of food, H_2O, and O_2 production and CO_2 uptake can be modeled in a realistic manner and on the long term.

Introduction

- The Plant Characterization Unit (PCU) of ESA @ the University of Naples is an appropriate equipment for collecting such data because it allows measuring the release of O_2, CO_2 and H_2O as well as growth, canopy temperature and element concentrations in the nutrient solution (Pannico et al., 2022).



The PCU
Pannico et al. (2022)

- But the PCU is highly demanded and allow to grow only one crop with one treatment at a time.
- Schiefloe et al. (2023) studied the effect of the NO_3 to NH_4 ratio on lettuce growth in the PCU.

- The aim of this study was to assess whether we could measure the impact of nutrient solutions enriched in NaCl or depleted in K on plant growth compared to a plant growing under in an ideal nutrient solution using the PCU

Materials and Methods

https://www.myseeds.co/

- Lettuce (*Lactuca sativa*) cv Grand Rapids

- Treatments
  - Optimum nutrient solution (ACSA) control (2 runs, control_1 and control_2)
  - ACSA plus 27 mM NaCl (1 run, +NaCl)
  - ACSA with 0.5 mM K (instead of 4.8 mM) (1 run, -K)

- Four test sequences of four weeks; dates of PCU use
  - Control_1: 24/11-22/12/2022
  - +NaCl: 26/01-23/02/2023
  - -K: 02/03 -30/03/2023
  - Control_2: 06/04-04/05/2023

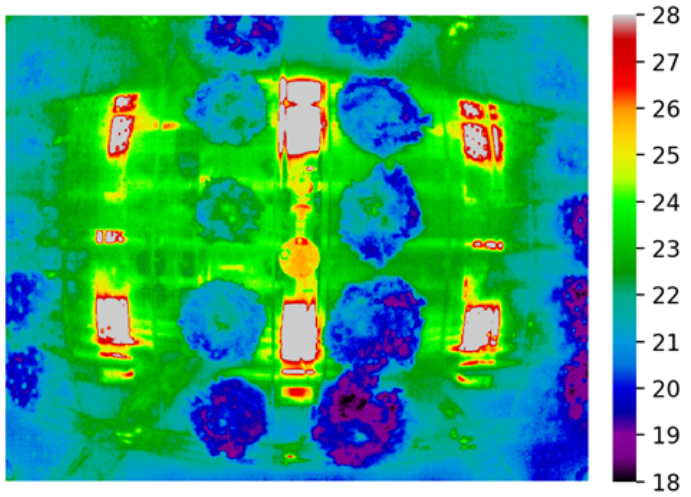
- 10 plants/test (density 5.6/m^2)

Analyses

- Monitoring of plant growth during the experiment
  - Net O_2 and H_2O production
  - Projected leaf area, canopy temperature

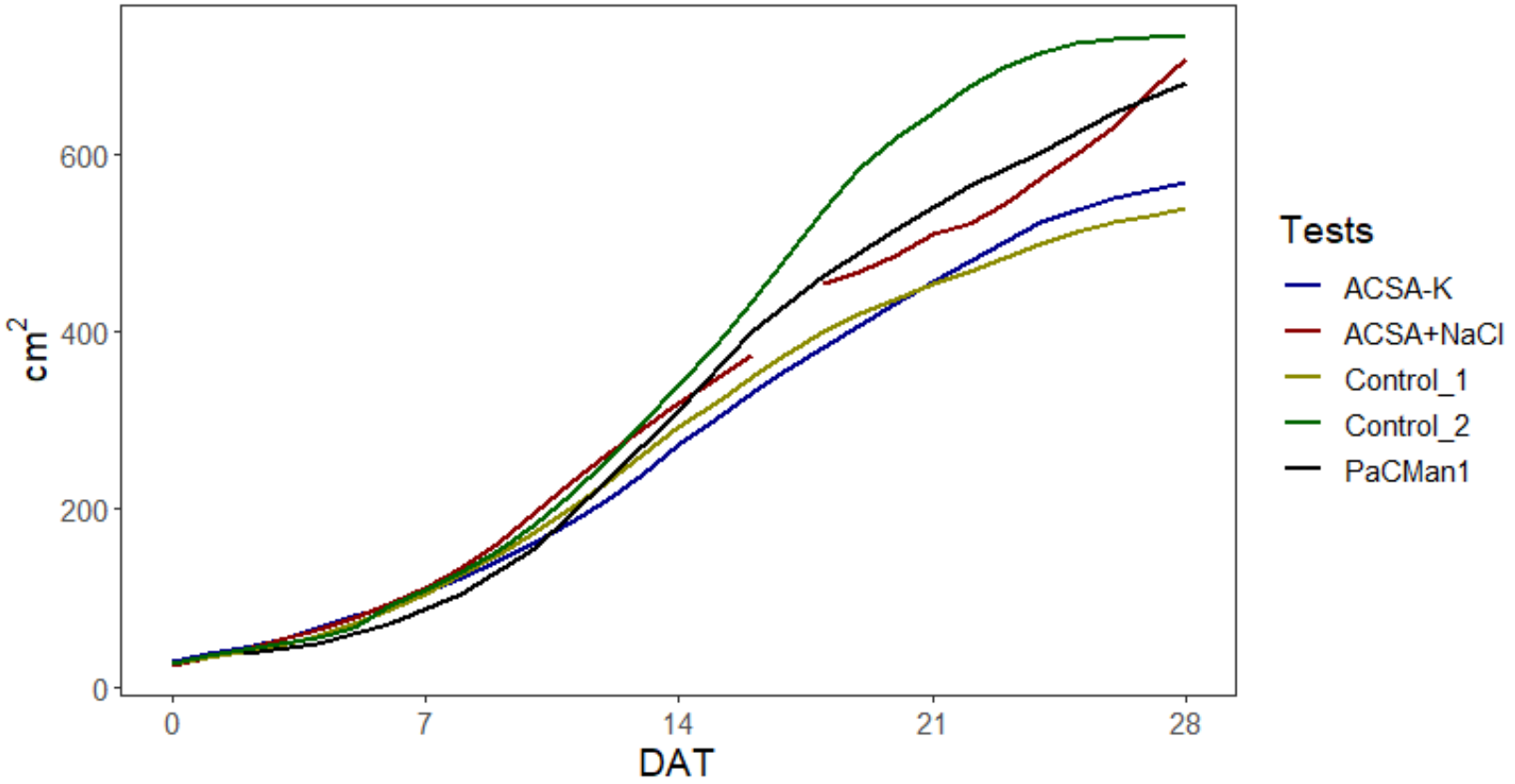
- Postharvest measurements
  - Plant biomass, leaf production
  - Nutrient concentration in biomass
  - Maximum quantum efficiency of photosystem (Fv/Fm)
  - Stomatal conductance, transpiration and C concentration in biomass
  - SPAD

- Ion concentration in the nutrient solution at the end of plant growth



Leaf temperature of the plants at 28 DAT of the Control_1.

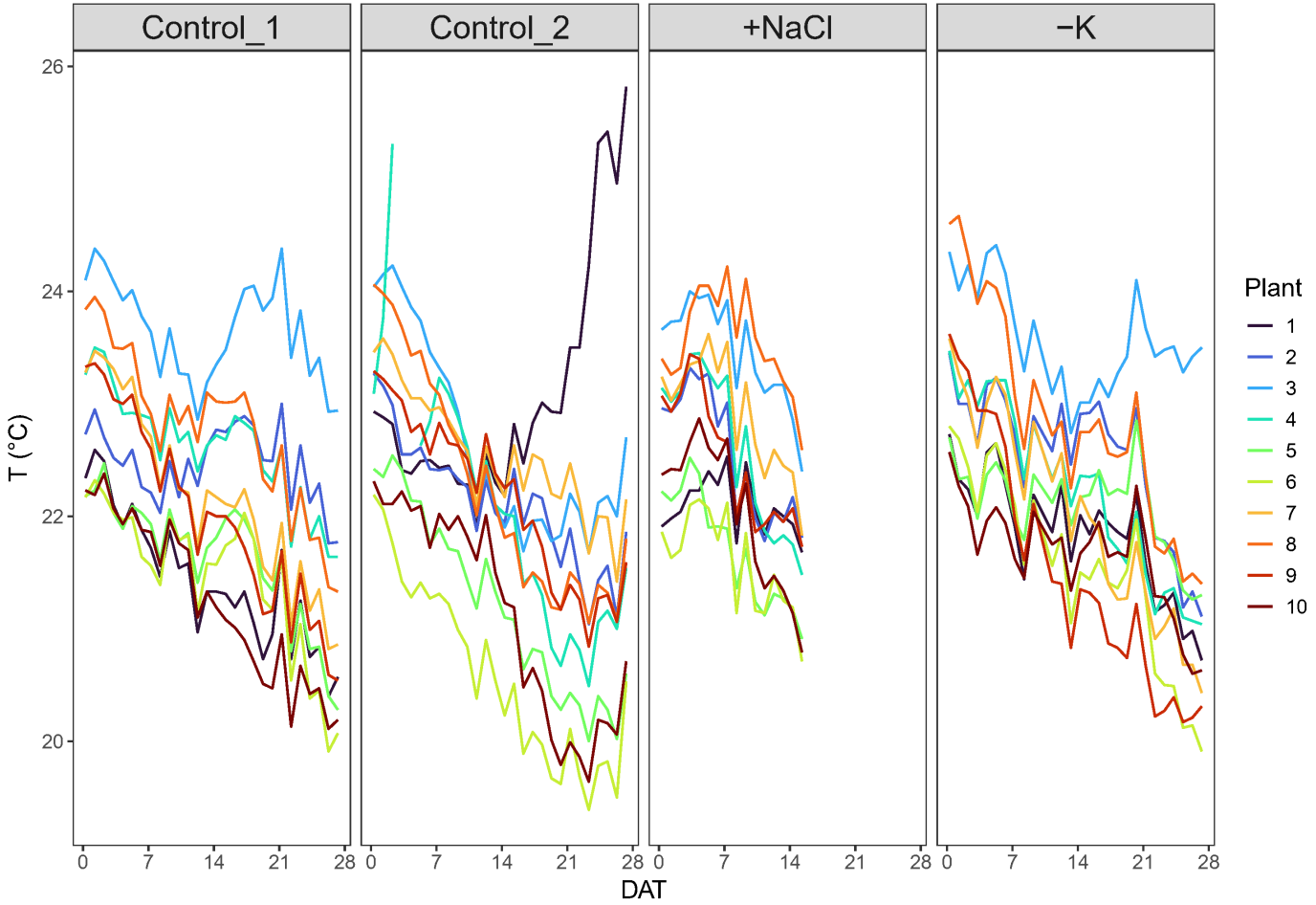
Results: Projected Leaf Area (average values)



Top view photo inside the PCU at 20 DAT of -K.

- Differences between the two control treatments;
- Inter plant variability
- Control_2 >+NaCl>-K

Results: Canopy Temperature (data per plant)



- Canopy temperature decreases as leaf surface increases: OK
- Huge variability between plants

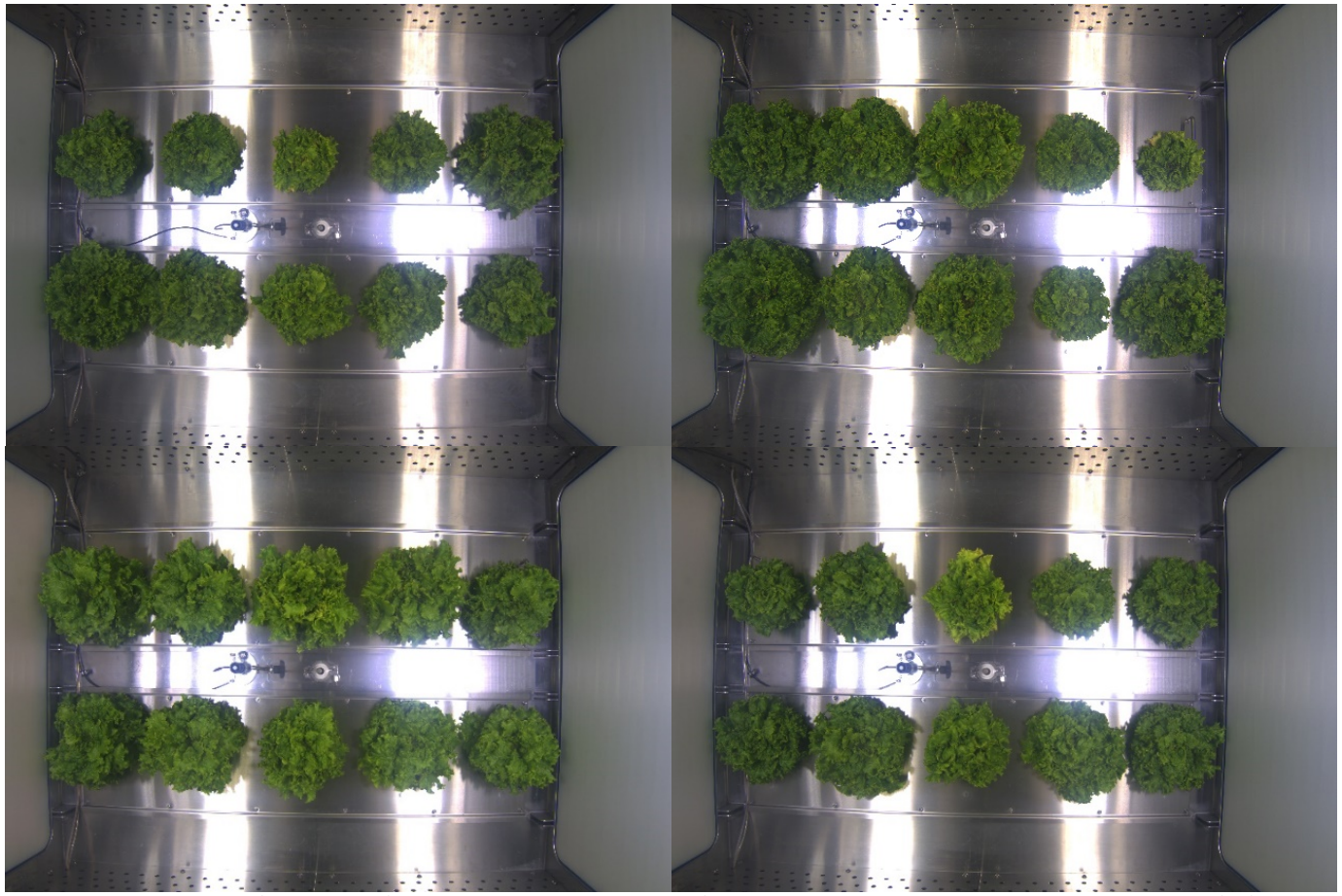
Results: Biomass Production (1)

Test	Leaf DW	Stem DW	Root DW	Leaf number	Leaf area
	g plant^{-1}			leaves plant^{-1}	cm^2 plant^{-1}
Control_1	17.8 ± 3.3^{ab}	4.2 ± 1.0^{a}	3.6 ± 0.5^{c}	77.6 ± 21.6^{b}	2691 ± 925^{c}
Control_2	21.1 ± 3.9^{a}	4.4 ± 0.7^{a}	6.3 ± 0.6^{a}	84.1 ± 16.0^{ab}	3289 ± 827^{abc}
+NaCl	18.7 ± 2.3^{ab}	4.3 ± 1.0^{a}	4.8 ± 0.5^{b}	102.6 ± 14.8^{a}	4053 ± 573^{a}
-K	17.0 ± 2.3^{b}	3.5 ± 0.7^{a}	5.0 ± 0.9^{b}	71.5 ± 16.0^{b}	2936 ± 828^{bc}

- Differences between the two control treatments;
- Large standard deviations

Results: Biomass Production (2)

A B C D



Top view photos of the PCU taken right before the harvest at 28 DAT of Control_1 (A), Control_2 (B), +NaCl (C), -K (D).

Problems of leaf necrosis/thickening (Ca deficiency?): max in control_1, min in Control_2

Results: O_2 and H_2O Production

Tests	O_2 produced	H_2O produced	O_2 produced	H_2O produced
	mol plant^{-1}	L plant^{-1}	mmol (g DW shoot)$^{-1}$	L (g DW shoot)$^{-1}$
Control_1	0.86	3.21	0.039	0.15
Control_2	0.94	3.34	0.037	0.13
+NaCl	0.92	3.11	0.040	0.14
-K	0.77	2.71	0.038	0.13

Results: Nutrient Concentrations in Leaves

Crop Test	Ca	K	Mg	N	Na	P
	mg (g DM)$^{-1}$					
Control_1	4.0 ± 0.9^{b}	33.3 ± 6.1^{b}	1.4 ± 0.2^{b}	38.9 ± 6.6^{a}	1.5 ± 0.2^{c}	4.2 ± 1.1^{b}
Control_2	7.1 ± 1.3^{a}	44.2 ± 5.9^{a}	1.8 ± 0.2^{ab}	43.3 ± 5.4^{a}	1.4 ± 0.2^{c}	6.3 ± 0.8^{a}
+NaCl	5.9 ± 0.5^{a}	48.9 ± 3.0^{a}	0.5 ± 0.1^{c}	47.1 ± 2.5^{a}	12.6 ± 1.7^{a}	6.0 ± 2.0^{a}
-K	6.5 ± 1.4^{a}	16.0 ± 3.0^{c}	1.8 ± 0.3^{a}	41.9 ± 9.3^{a}	6.2 ± 1.4^{b}	6.2 ± 1.1^{a}
optimum range*	4.5 – 7.5	33 - 64	2.5 – 4.0	33 -48	-	3.5 -7.5

To be noted

- Ca, Mg, N, P are in the optimum range (considering all leaves)
- Na is high in +NaCl
- K is low in -K

Results: Micronutrient Concentrations in Nutrient Solution

Crop test	DAT	Cu	Zn
		mg L^{-1}	
Theoretical concentration at start		0.05	0.22
Control_1	0	0.33 ± 0.00	0.90 ± 0.00
	28	1.23 ± 0.01	1.91 ± 0.01
+NaCl	0	0.25 ± 0.01	0.47 ± 0.00
	28	0.85 ± 0.06	1.06 ± 0.01
-K	0	0.08 ± 0.00	0.55 ± 0.00
	28	0.52 ± 0.02	1.26 ± 0.01
Contol_2	0	*	0.39 ± 0.03
	28	0.50 ± 0.08	1.03 ± 0.01

To be noted

- Cu and Zn concentrations were too high at beginning of control_1 and increased with time

Conclusions

- High inter plants variability and high variability between control treatments make results analysis very complicated.
- Inter plants variability can be due to variability in light, ventilation, temperature within the PCU or/and to variability between plantlets.
- Why are results from control_1 and control_2 different? We do not know. May be substances are released from the hardware. In any case this shows that treatments need to be repeated in several runs.
- Results were compared to those previously obtained by ESA/NASA; this comparison suggests that results from control_2 are closer to what could be expected from a lettuce growing under optimal conditions.
  - Although leaf surface development was slower in +NaCl compared to control_2, no large effect was observed on plant performance with Grand rapids; this cultivar tolerates well the presence of NaCl.
  - The –K treatment resulted in lower biomass, leaf surface, and H_2O and O_2 production.
- The PCU is currently updated in the PACMAN3 project to remedy to the current shortcomings.

Many thanks for you attention!

Acknowledgements

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