AECOM

Embracing the Digital Environment

On-Demand Watering System for Food Production in Microgravity

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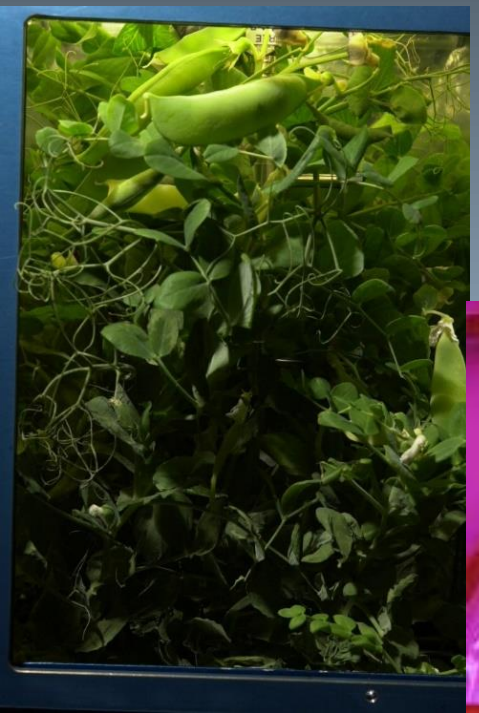
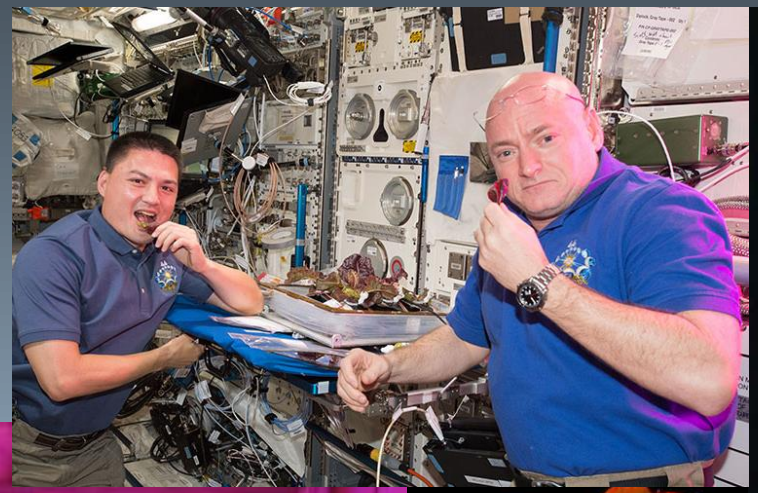
In space, explorers need *in situ* food production

- Space Farming enables colonization of space
  - Sustainable: minimize logistics of resupply
  - Supplies: Light, CO_2, O_2, Nutrients, Water, Seeds, Plant chamber – Soil ?
  - Crew Psychological well-being: green Earth
  - Food Systems: palatable, nutritious and safe source of fresh food (limited shelf-life <3yr)

LADA



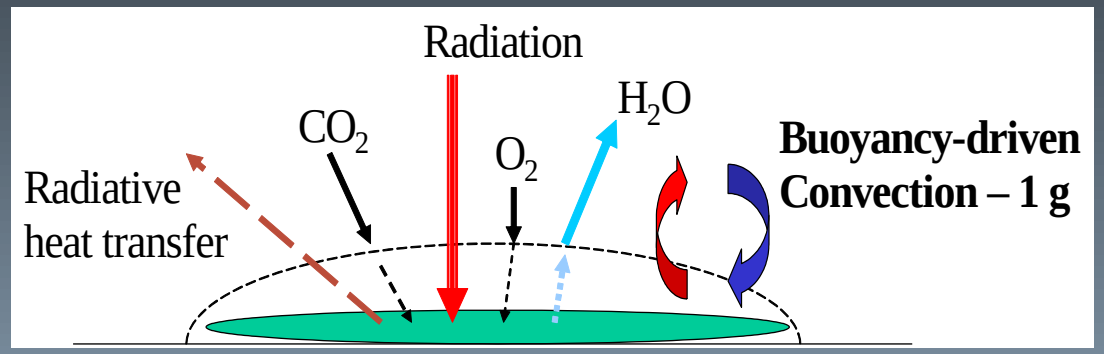
VEGGIE

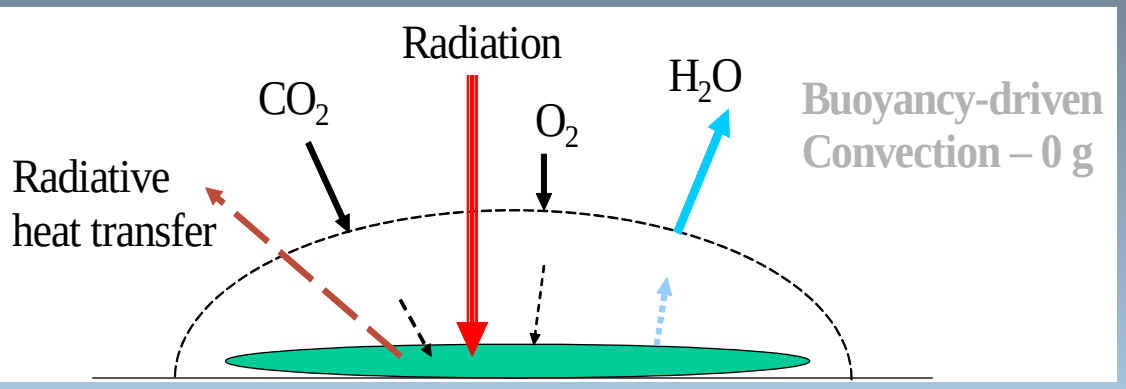


Space-Flight Environment

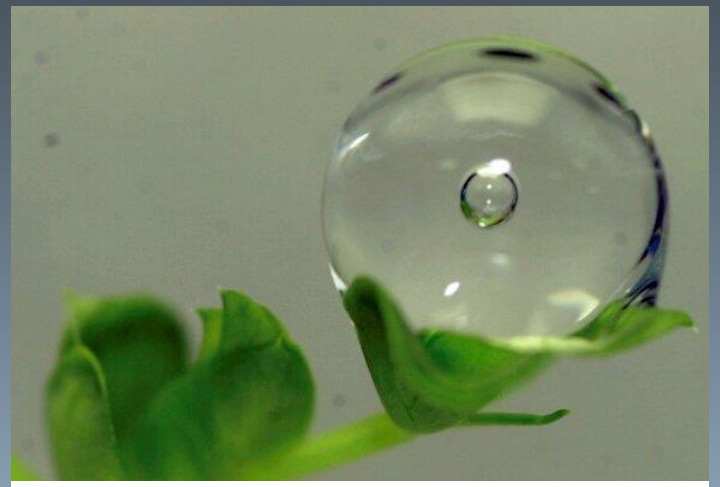
The absence of gravity induces physical effects that alter the microenvironment surrounding plants and their organs.

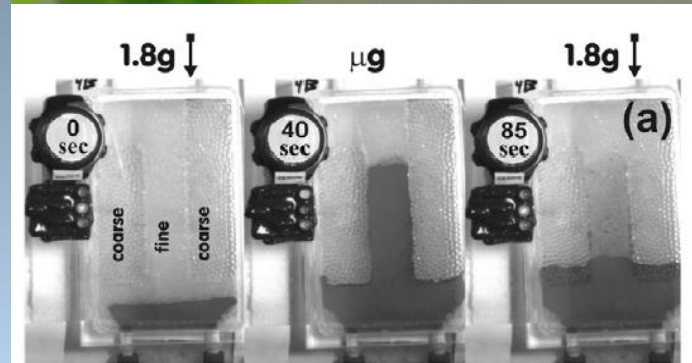
These effects include: increased boundary layers surrounding plant organs and the absence of convective mixing of atmospheric gases. In addition, altered behavior of liquids and gases is responsible for phase separation and for dominance of capillary forces in the absence of gravitational forces (moisture redistribution)

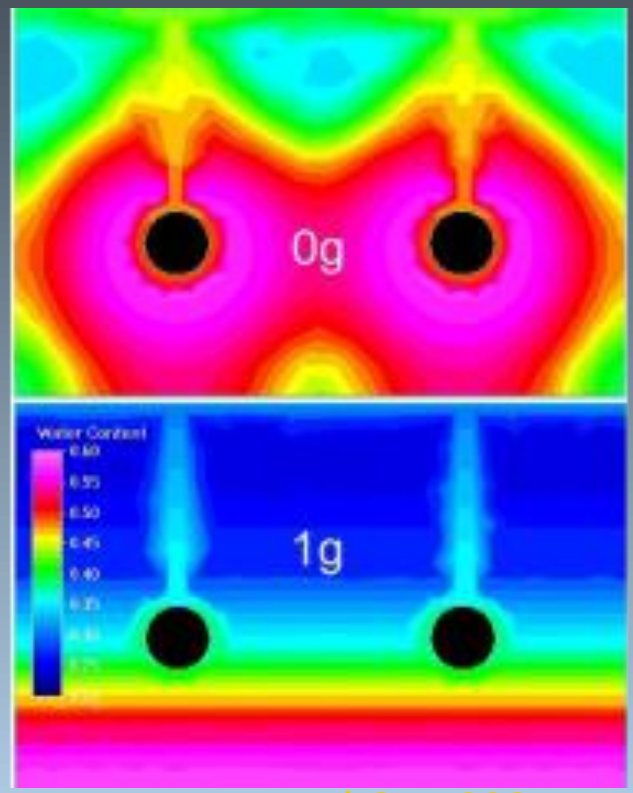




Monje et al. 2003





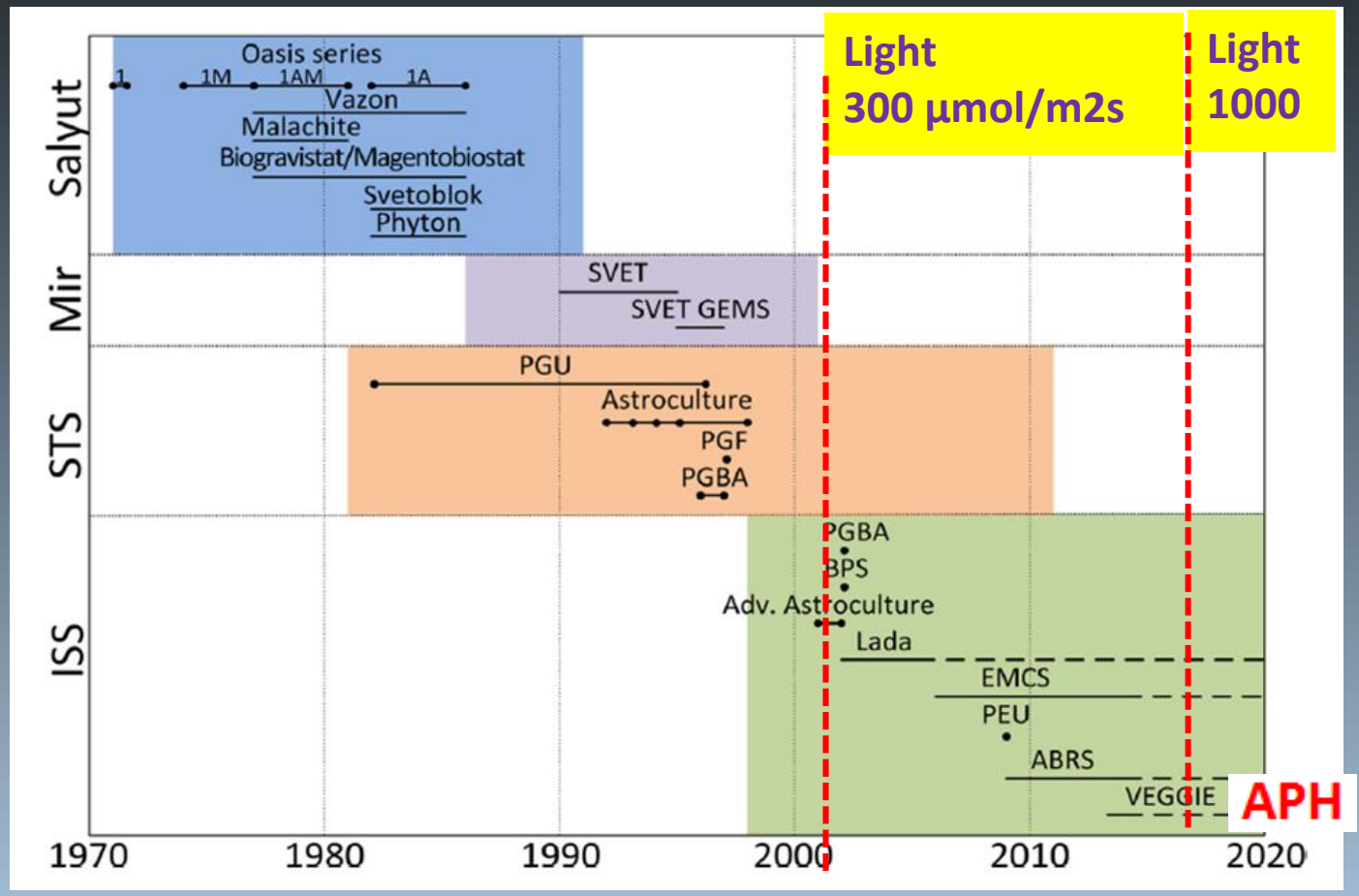


Jones and Or, 1998

Plant Growth Systems in Space

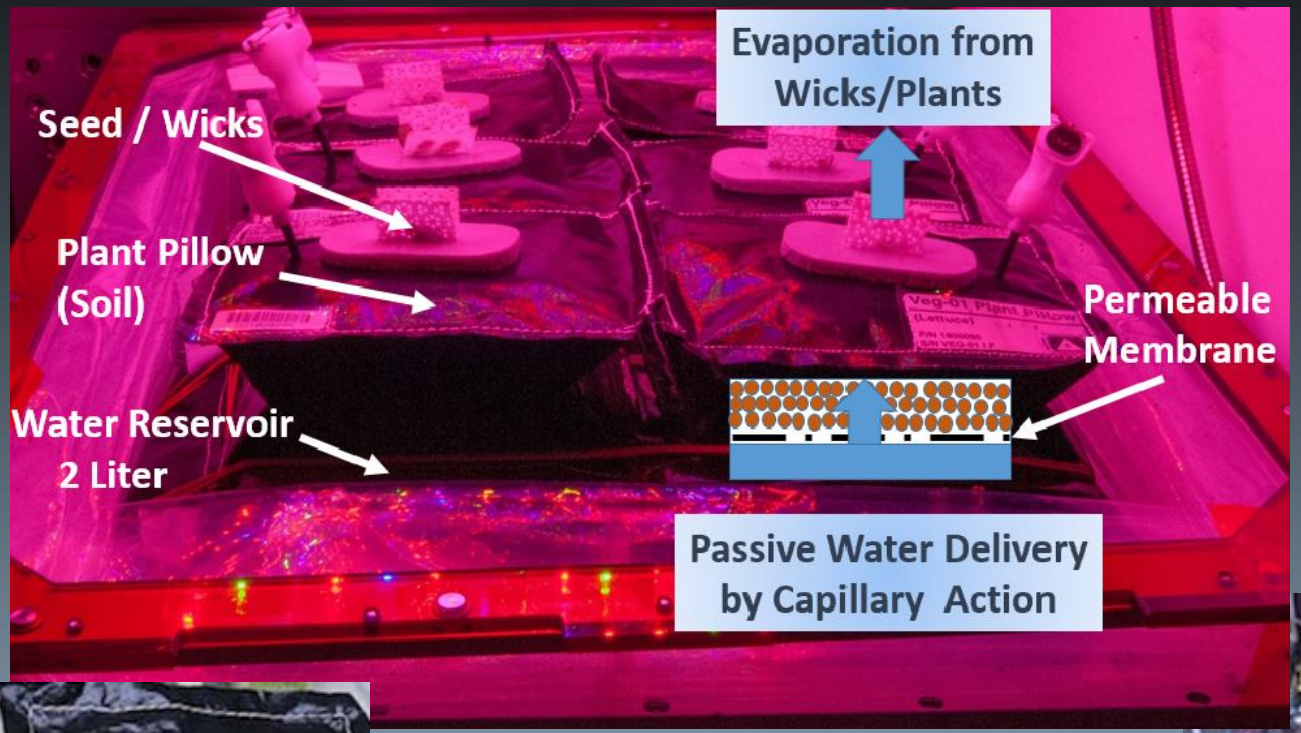
Table 2
Detailed information on the nutrient delivery systems used in flown plant growth chambers.

	Nutrient delivery subsystem
Oasis 1	Two compartment system (water and ion exchange resin)
Oasis 1M	Fibrous ion exchange medium
Oasis 1AM	Cloth ion exchange medium
Oasis 1A	Included root zone aeration system
Vazon	Cloth sack filled with ion exchange resin
Malachite	Ion exchange resin, water supply
Biogravistat/ Magnetobiostat	n.a.
Svetoblok	Agar based, later also used other media
Phyton	1.5% agar nutrient medium
SVET	Polyvinyl formal foam surrounded perforated tubing wrapped in a wick within zeolite based substrate enriched with nutrients
SVET-GEMS	Similar to SVET but with additional sensors
PGU	Passive system capable of containing varied substrates/materials
PGF	Passive system capable of containing varied substrates/materials
ASC	Porous tubes in matrix
PGBA	Agar, soil or growth substrate in gas permeable polypropylene bags with option to connect bags to water supply
ADVASC	Porous tubes in matrix
BPS	Porous tubes in matrix
Lada	Perforated tubing wrapped in a wick within a matrix
EMCS	Water reservoir providing water to experiment unique nutrient delivery equipment
PEU	Rock wool fed by integrated water line
ABRS	Experiment specific
VEGGIE	Passive NDS, rooting pillows, manual water and nutrient supply



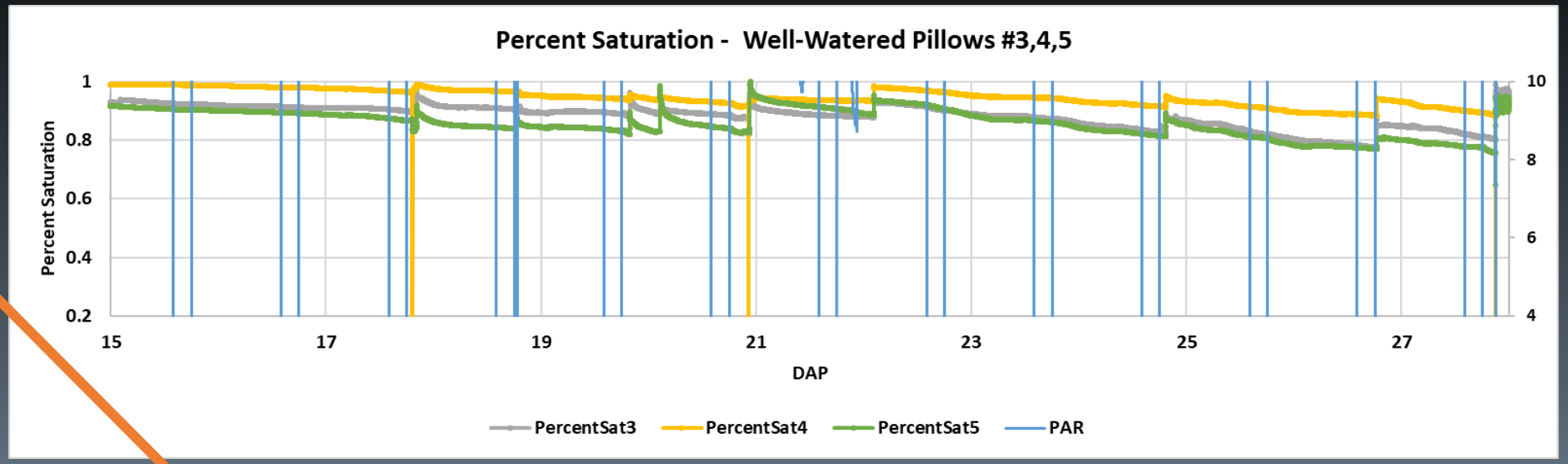
Zabel et al. Life Sci. Space Res. (2016)

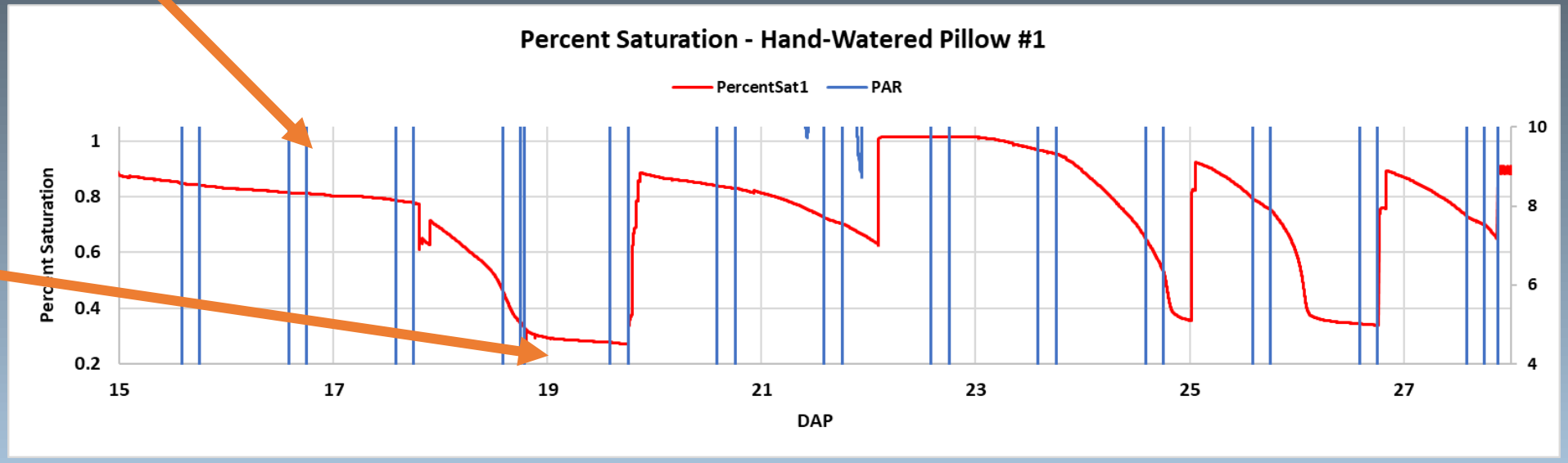
1 - Veggie Pillows: Passive Watering



In Veggie, Passive Watering is often replaced by Hand Watering

Veggie Pillow Watering: Passive vs ‘Hand’ Watering



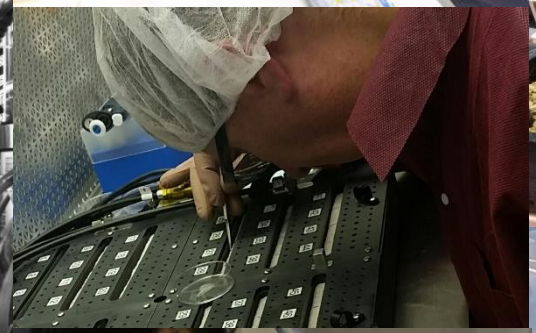


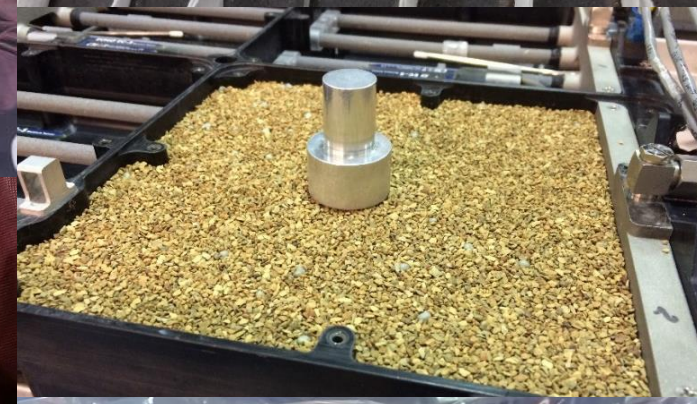
Veggie Pillow Watering: Wilting Affects Plant Growth

Parameter	Well-Watered	Wilted	Ratio
Height (cm)	17.3 ± 0.7	16.0 ± 1.4	1.1
Fresh mass (g)	71.0 ± 6.8	33.3 ± 2.9	2.1
Leaf Area (cm^2)	1753 ± 269	1122 ± 103	1.6
Leaf Number (#)	35.0 ± 1.6	28.7 ± 1.7	1.2
Root Volume (ml)	12.3 ± 2.2	5.0 ± 0.1	2.5
Dry mass (g)	4.0 ± 0.4	2.4 ± 0.2	1.7

2 - APH Science Carrier

- Four quadrants – independent moisture control
- Baseline – 4 kg porous substrate / slow release fertilizer
- Pre-planted / Contains water and substrate





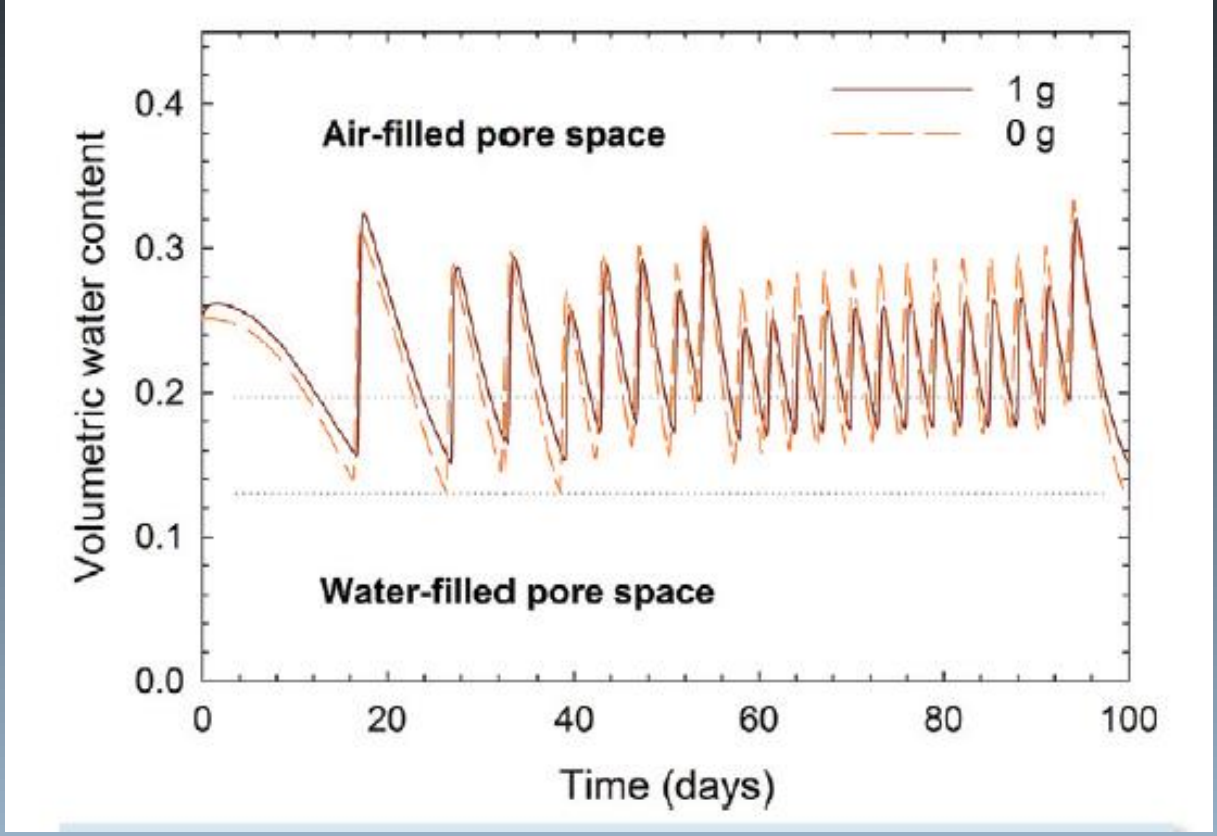
APH – Not A Food Production Facility

Scaling the 0.2 m^2 APH system - salad machine producing 13 crops of Outredgeous lettuce per year (365 days/28 day growth cycle) produces 104 lettuce plants (two 50.9 g plants/quadrant).

Production: 5.3 kg of lettuce per year **Inputs:** ~52 kg of media and 0.6 kg of fertilizer

This system has a productivity ratio of **0.10 kg of edible mass per kg of resupply mass**.

On-Demand Watering – Gravity Independent

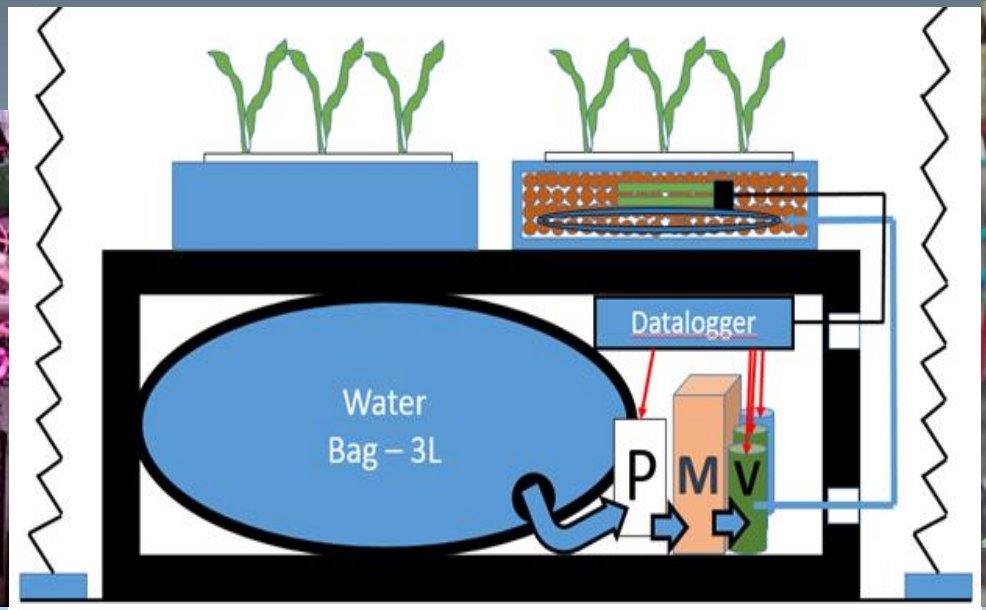


- On Demand Watering
  - HYDRUS-1 Model – Wheat crop – 15 cm root module.
  - On-demand watering was equally as effective at controlling volumetric moisture of porous media at 1g or in microgravity

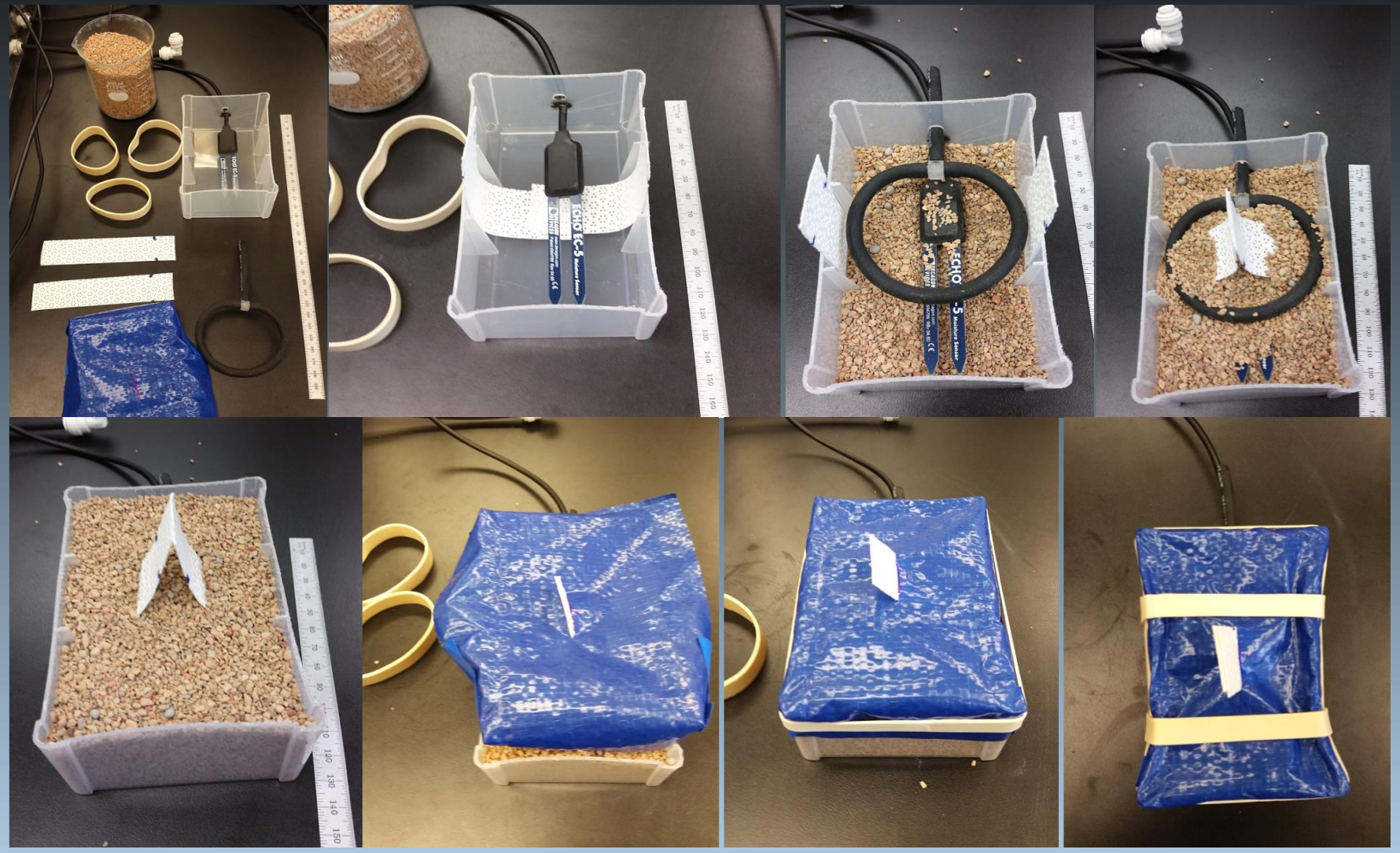
Jones et al., 2012 VDZJ

Active Watering System for Veggie

- KSC KickStart Project 2014 - $5K
- Uses power – 10 W
- Automated operation - Water on-demand, less media
- Additional resources – CR-6 Datalogger , EC-5 sensors, pumps



Assembly of Analog Veggie Pillows



Crops

24 day Chinese cabbage

49 day Chinese cabbage

55 day Zinnias

80 day Zinnias

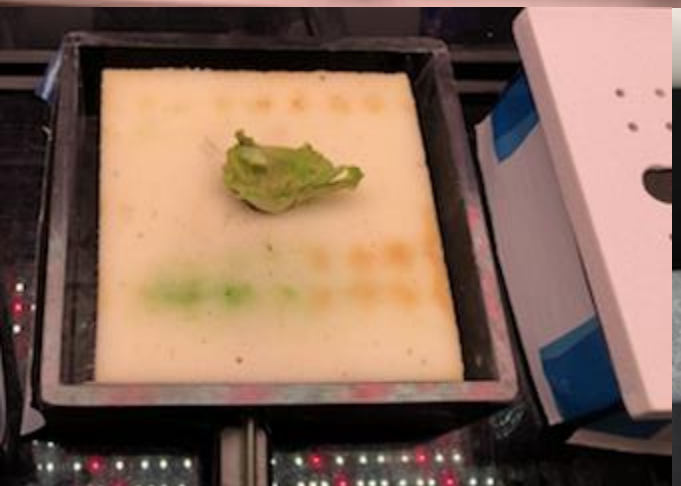
3 -On Demand Veggie System

- Productivity
  - 38+/-7.4 g 24 days (227 gFW)
  - 49+/-9.6 g 35 days (290 gFW)* n=6
  - 3.42 kg lettuce/32.1 kg resupply
  - **1.06 kg edible per kg of resupply mass**
  - **10 x APH**
- Consistency
  - 100% germination
  - Water stress – wilting observed
  - Power – 10 W
- Crew Time
  - Water refill every 3 days
  - Use 10 L bag

On Demand - Foam System

Replace Porous Substrate

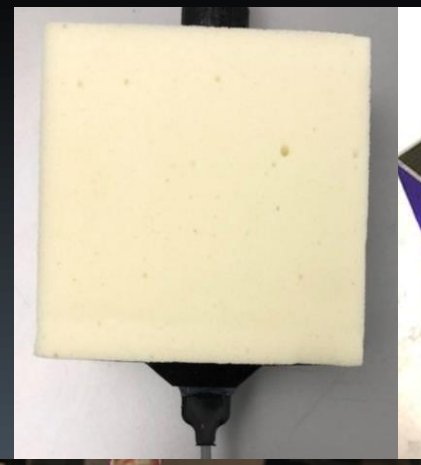
- Sublime Foam
- 13 g Not Reusable
- Adequate porosity
- No dust mitigation

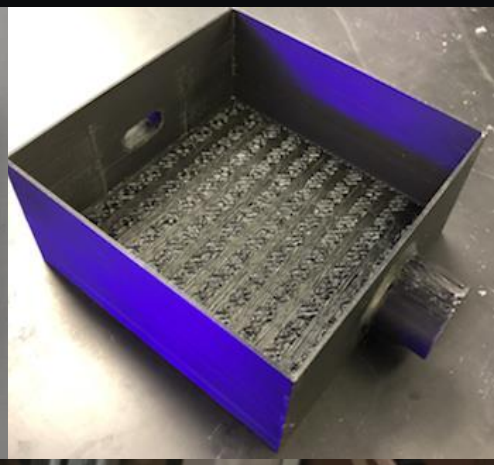


4 -On Demand Foam System

Parameter	3 Plants	4 Plants
Height (cm)	18.0 ± 3	16.8 ± 0.3
Fresh Mass (g)	48.2 ± 8.5	50.0 ± 4.9
Leaf Area (cm^2)	1176.7 ± 300	1169.3 ± 144
Leaf Number (#)	31.3 ± 7.3	31.5 ± 4.1
Productivity Ratio	**11.1**	**15.3**

- System
  - 13 g foam per block
  - Increased planting density
  - Increased productivity vs APH





Watering System Comparison

System	plants/unit	g/Plant	g FW/unit	g Media/unit	Plant FW kg/yr	Media kg/yr	Productivity Ratio	APH
APH	2	50.9	101.8	1000.0	1.3	13.0	0.10	1.0
Veggie	1	33	33	210.0	0.4	2.7	0.16	1.5
On Demand Veggie	1	38	38	210.0	0.6	3.2	0.18	1.8
On Demand Foam 3	3	48	144	13.0	1.9	0.2	11.08	109
On Demand Foam 4	4	50	200	13.0	2.6	0.2	15.38	151

Questions?