Space Crop Production: Goals and Challenges

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Space Crop Production Systems

- Designed to mitigate the **risks of inadequate food and nutrition** during long duration NASA exploration missions (>3 years). Processed and pre-packaged food loses nutrients during processing and during storage, and may not provide the expected nutritional content or have the same taste when consumed.
- Provide **fresh 'Pick-and-Eat' crops (lettuce, radish, peppers)** grown *in situ* for crew consumption during Mars transit and surface habitat missions.
- **Supplement the astronaut food system** with bioavailable vitamins and amino acids that degrade during long term storage.

Veggie - Select Crops for growth at elevated CO_2 (3000 ppm) and 40% RH

National Aeronautics and Space Administration

From the first taste of Red Romaine Lettuce in fall 2015, astronauts have **GROWN** and **EATEN** a range of salad crops in orbit as NASA researches ways to keep crews healthy on future missions exploring the Moon and Mars. These plants are good sources of Vitamin C and Vitamin K, and they have traits that make them good candidates for feeding future space explorers.

www.nasa.gov

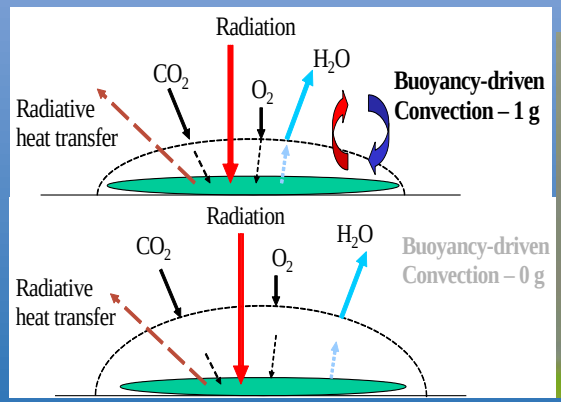
SP-2021-04-313-KSC

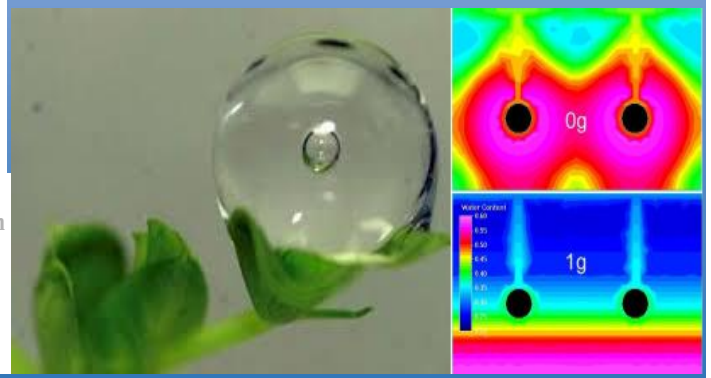
Crop Productivity is determined by:

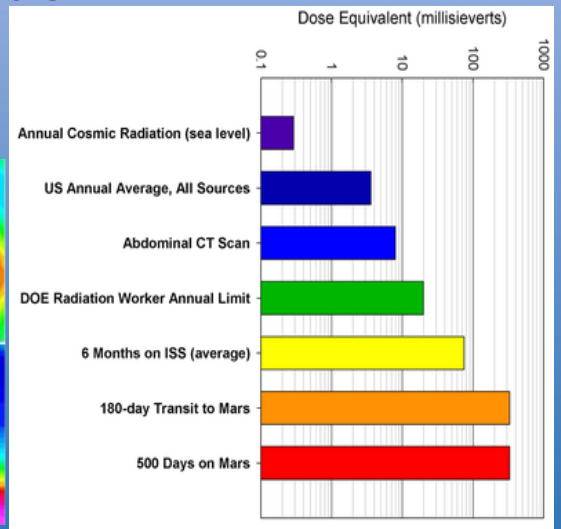
- On Earth:
  - Crop yield = f (G x E x M)
    - where G = Genetics, E = Environment, M = Management (cultivation - tillage, irrigation, crop rotation)

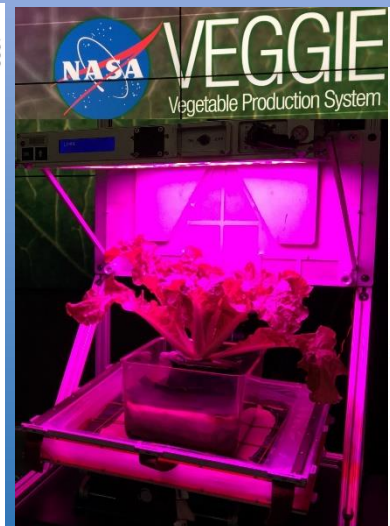
Source: Aerofarms

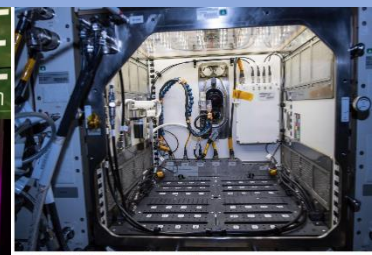
- In Space:
  - Crop Yield = f (G x SE x SM x **R** x **D**)
    - where **SE** **x** **SM** = Spaceflight Environment & **Management**, **R = Radiation**, **D = Distance**
    - **SE – reduced gravity affects plant growth indirectly** (lack of buoyancy driven convection, phase separation, and capillary forces)
    - **SM – soilless, gravity independent watering and nutrient delivery systems**
    - **R – Deep space radiation beyond LEO, the Moon, and Mars**
    - **D – Logistics of resupply and hardware robustness**

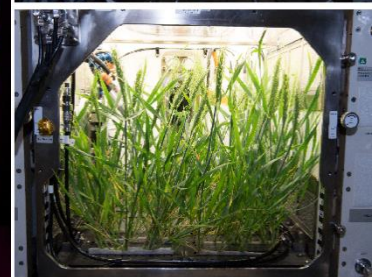






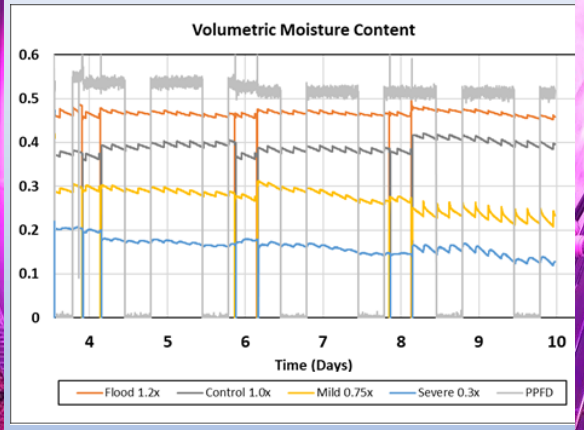


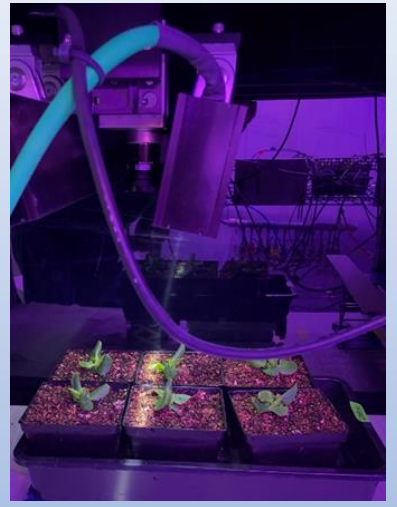


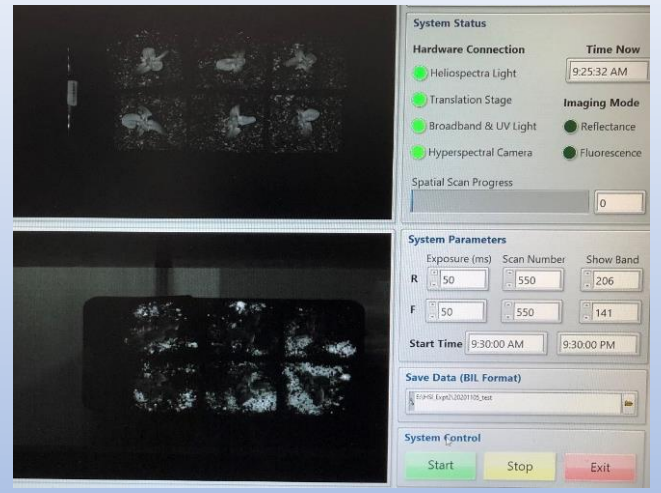


Plant Health and Food Safety

KSC

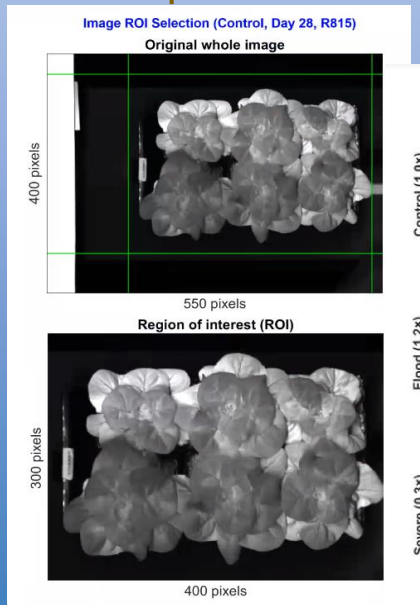


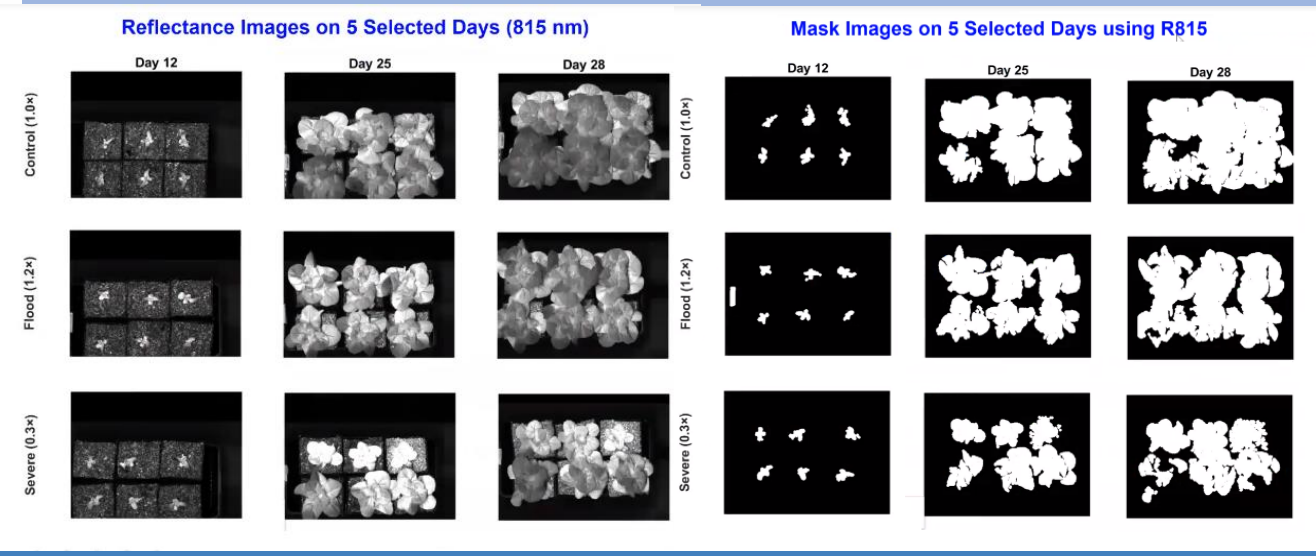




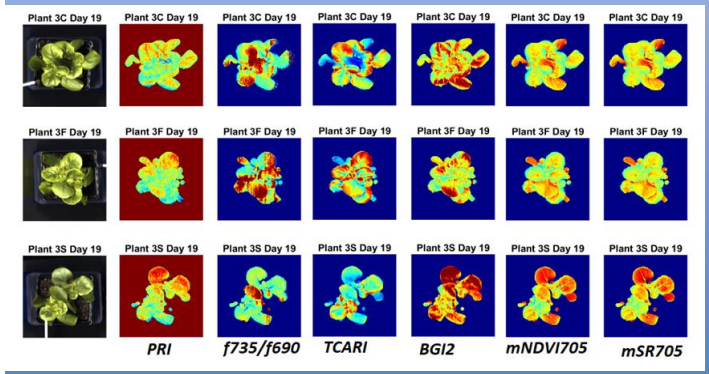
Grow plants | Impose stress treatments | 28-day cycles | Image plants | Collect Images -> USDA

USDA EMFS Lab





Monje et al, ICES-2019-289



Crop images | Use reflectance to remove background – Masking | Develop Vegetation indices using AI

Plant Growth Systems in Space

Plant Growth Systems in Space

Salyut Space Stations	Mir	Space Shuttle	International Space Station (ISS)
Oasis Series	SVET	Plant Growth Unit (PGU)	Advanced Astroculture (ADVASC)
Vazon	SVET-GEMS	Plant Growth Facility (PGF)	Biomass Production System (BPS)
Malachite	Vazon	Astroculture (ASC)	Lada
Biogravistat/Magnetobiostat	Svetoblok	Plant Generic Bioprocessing Apparatus (PGBA)	European Modular Cultivation System (EMCS)
Svetoblok	Astroculture (ASC)		Plant Experiment Unit (PEU)
Phyton Series			Advanced Biological Research System (ABRS)
			VEGGIE

APH

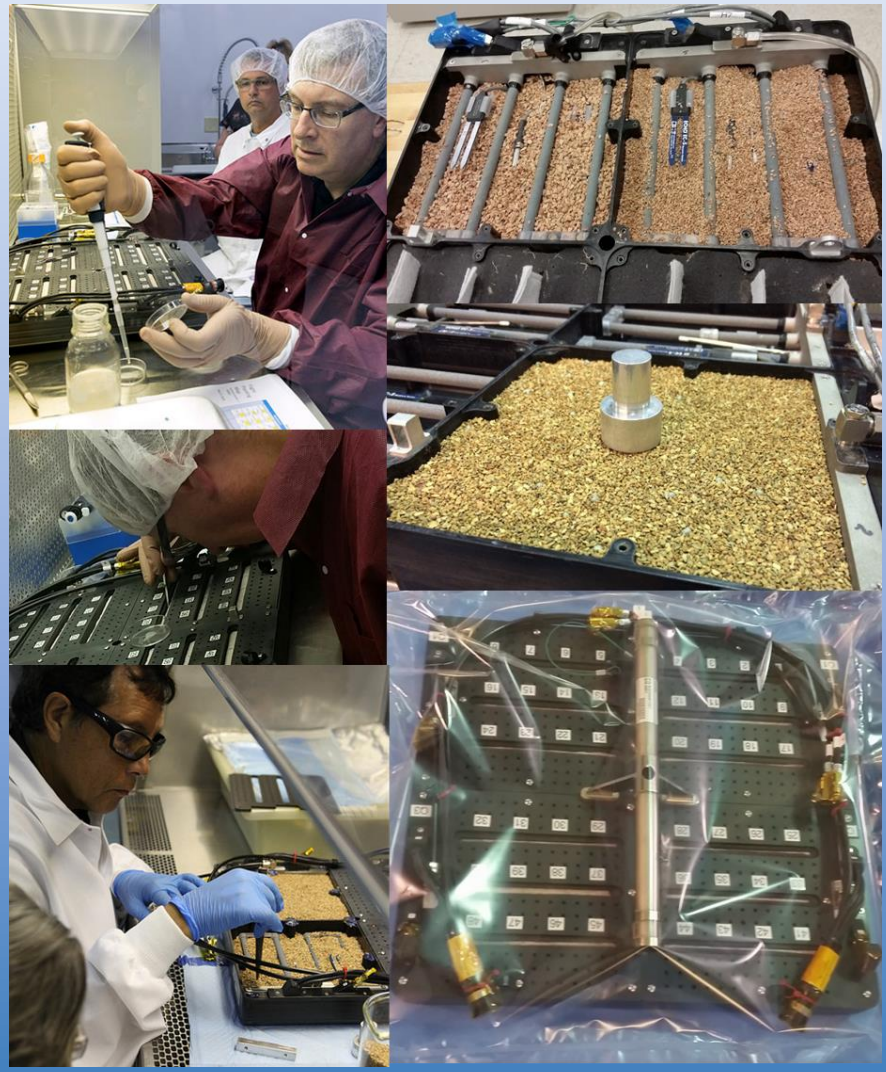
Zabel et al. Life Sci. Space Res. (2016)

Space Biology -> Crop Production

The solid-substrate based water delivery system used in APH evolved in SVET, Astroculture, ADVASC, LADA and BPS chambers. Since plants are grown for science, the APH root module is launched pre-planted, contains 4 kg of substrate, and is discarded after the plants are harvested.

- These practices are unsustainable for space crop production systems. For example, scaling the ~0.2 m^2 APH rooting system to a salad machine producing 13 Outredgeous lettuce crops/year (365 d/28 d growth cycle) produces 5.3 kg of lettuce, but requires ~53 kg of fertilized media. Thus, APH has a low productivity ratio of 0.10 kg edible mass/kg of resupply mass.
- Therefore, new soilless water and nutrient delivery systems are needed to avoid constant resupply of bulky single-use porous media – sustainability.

Monje et al, ICES-2019-260

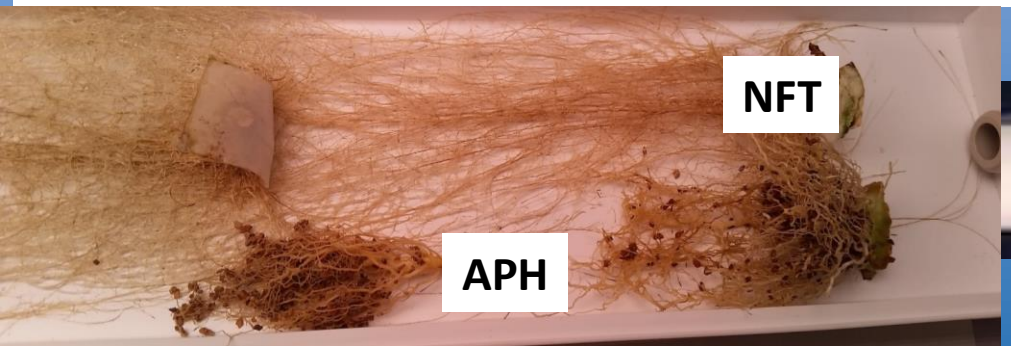


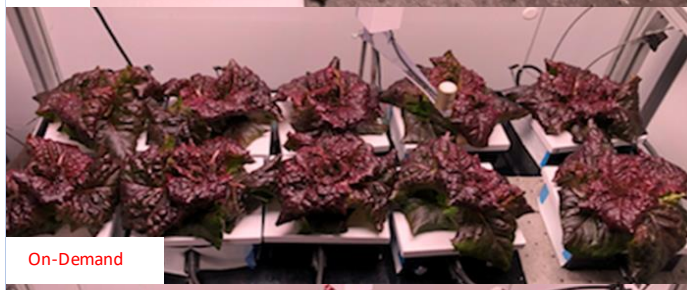
Growing Plants Without Soil

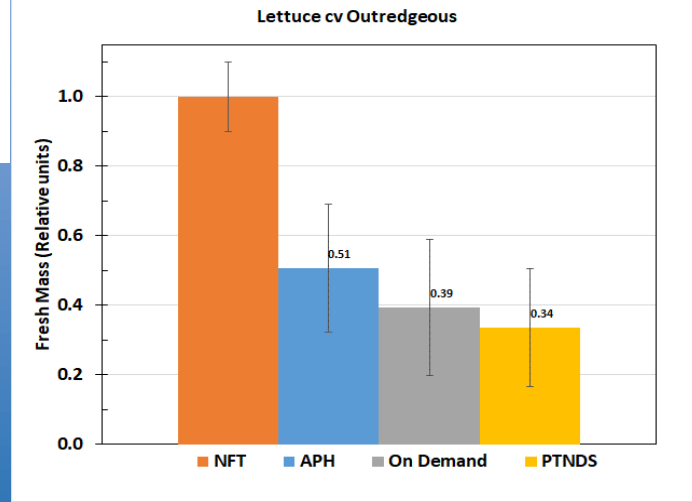
Hydroponics (e.g., nutrient film technique, NFT) is the leading technology for optimal food production on Earth. The APH substrate-based system, aeroponics (ICES-2019-195) and the Omni-Gavity hydroponic system (ICES-2019-242) are alternates developed to address challenges for containment, providing sufficient aeration to the roots, and liquid/gas separation observed in microgravity.

- Productivity Comparison: soilless water and nutrient delivery systems (Porous Tube Nutrient Delivery System (PTNDS) and On-Demand) vs NFT and APH. The PTNDS uses ceramic porous membranes held under suction for watering plants germinated directly on the tubes. The On-Demand system uses feedback from a moisture sensor to maintain a constant root zone moisture in foam block.
- The NFT system produced on average 78 g plants. The productivities of the APH, On-Demand, and PTNDS systems were 51%, 39%, and 34% of the NFT, respectively. These results suggest that water delivery technologies that close these gaps in productivity are needed.

Monje et al, ICES-2019-260







Conclusions

- Space crop production systems for use on ISS, the Moon and Mars must be sustainable and ensure food safety. These systems have evolved from supporting space biology experiments to becoming sustainable food crop production systems.
- Salad crops must be selected to be small and to grow in typical spacecraft cabin conditions (i.e. elevated CO_2 and low humidity).
- Plant health monitoring systems must be developed to ensure high yields and to ensure the food is safe to eat.
- Watering systems must be sustainable and easily sanitized to support multiple crops. The crop production systems must be simple to operate, minimize crew intervention as well as provide nutritious and palatable salad crops.

Questions?

Acknowledgments

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