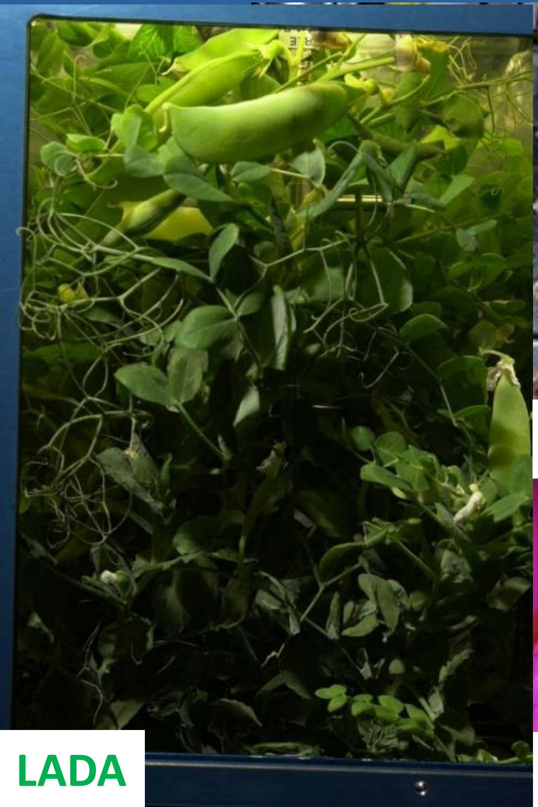
Smart Crop Farming Systems for Artemis Exploration Missions

O. Monje, M.E. Hummerick, M.W. Nugent, L.E. Spencer, A.B. Curry
Amentum, Space Crop Production Team, Kennedy Space Center, FL
and
J.R. Finn
Bionetics Corp., Air Revitalization Lab, Kennedy Space Center, FL
and
A.E. Orourke and R.F. Fritsche
Utilization and Life Sciences Office, NASA UB-A, Kennedy Space Center, FL

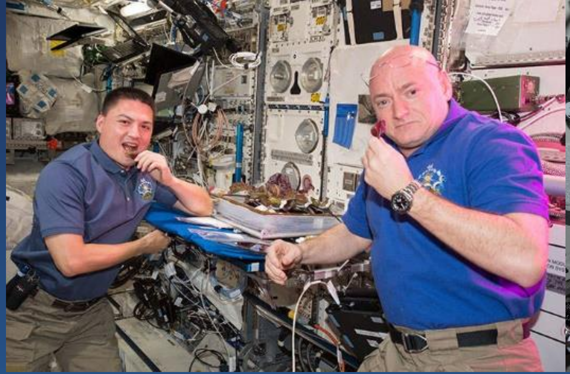
37th Annual ASGSR Meeting
2021 Baltimore, MD

In space, explorers need *in situ* crop production

- Space Farming - enables exploration of space:
  - **Sustainable:** minimize logistics of resupply – distance from Earth
  - **Resources:** Light, CO_2, O_2, Nutrients, Water, Seeds. **Plant chambers – watering system**
  - **Crew Psychological Well-Being:** green Earth (smell and taste)
  - **Food Systems:** palatable, nutritious and safe source of fresh crops – **Long duration missions**



Science Goals



- Plant growth systems developed on Earth have been adapted for growing crops in microgravity on ISS [Veggie, Advanced Plant Habitat, Ohalo III].

Veggie and APH – used for space biology and crop production experiments

- Seeds were germinated on the Moon during China's recent 2019 Chang'e 4 lunar lander mission (cotton seed). However, plant growth and development under the combined influence of the ionizing radiation and the partial gravity (1/6 g) environment of the Moon has not been demonstrated.

- The impact of ionizing radiation on crop plants remains a critical gap in spaceflight radiation research as short-term acute exposures do not mimic chronic low dosage exposures. Ionizing radiation effects include reduced germination and seed viability, as well as the potential for abnormal growth due to DNA damage. Partial g affects moisture distribution phenomena.

- Future exploration missions in surface habitats require sustainable crop production systems that ensure food system security.

Lunar Missions – grow plants in partial gravity

- Water behavior affects plant growth indirectly:
  - On Earth (1 g), a 'well-drained' soil – supplies root zone sufficient moisture and oxygen for active nutrient uptake.
  - On ISS (0 g), moisture redistribution reduces aeration to roots causing poor growth.
  - On Moon/Mars (1/6 and 1/3 g), we lack sufficient data to predict fluid distribution and aeration in partially wet substrates.
- Task: Export 1-g agricultural methods to partial gravity habitats.
  - Demonstrate sustainable watering systems to optimize plant growth

Plant Health and Food Safety

Figure 1 – Autonomous plant health monitoring system in a Martian greenhouse.

Design requirements of Space Crop Production systems

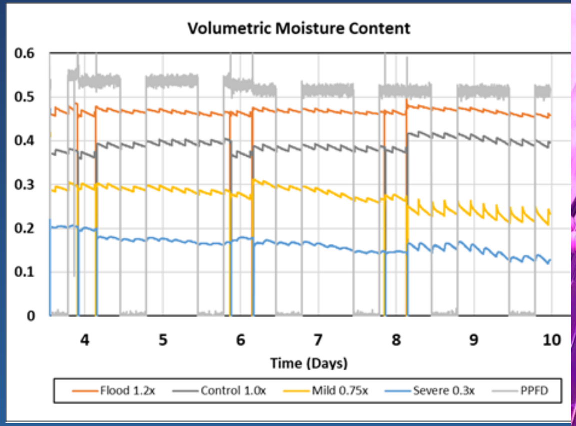
Autonomous plant health and food safety monitoring systems:

- **Ensure produce is safe to eat by the crew**
- Assess plant health without crew intervention
- Enable early stress detection for decision making
- In SOA health detection – changes may have taken place days earlier before visual changes in leaf area or color are detected.
- Detect (abiotic/biotic stress) in near real-time - moisture or nutrient stress, fungal attack, equipment failure.
- Sensing technologies studied:
    - Remote sensing – hyperspectral imaging
    - Plant health – fluorescence imaging

Monje et al., ICES-2021-289

KSC

Grow plants



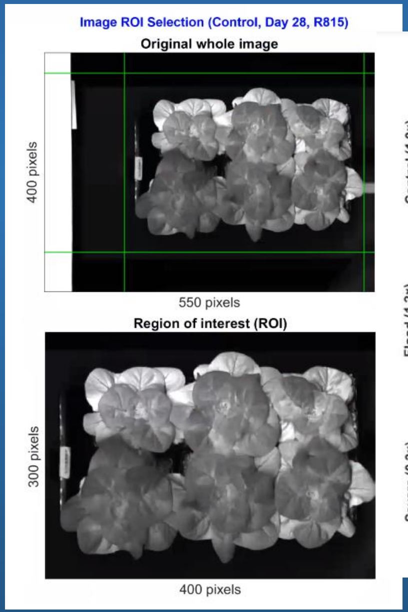
Impose stress treatments

28 day cycles

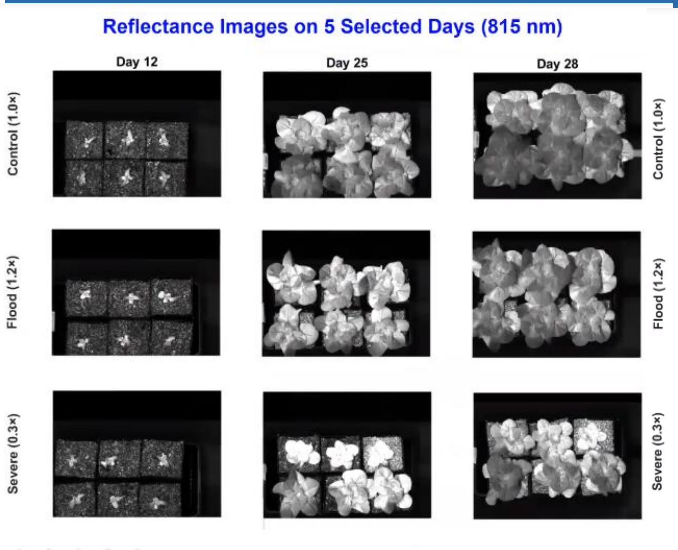
Image plants

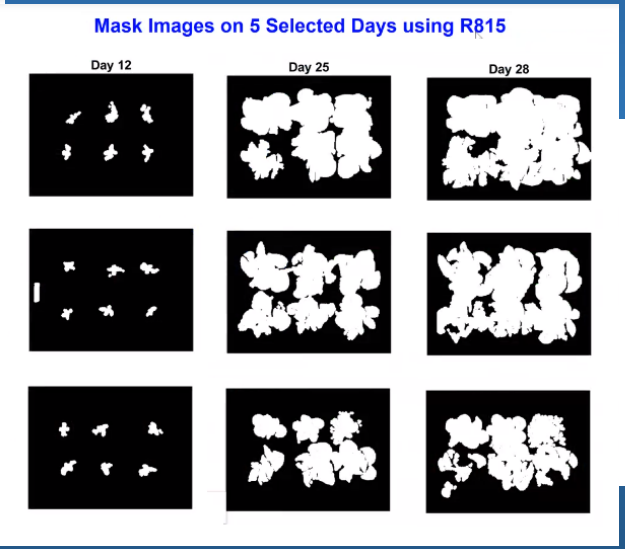
Collect Images -> USDA

USDA



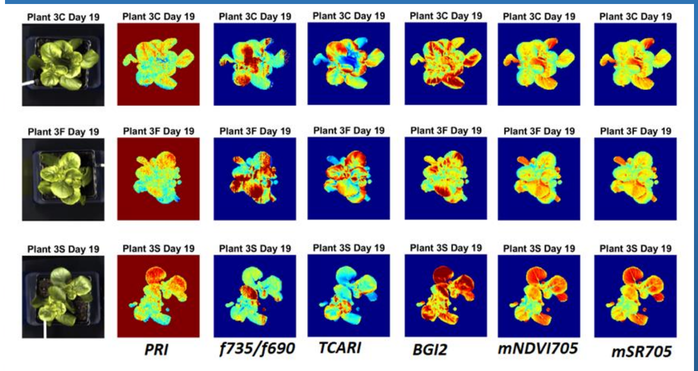
Crop images





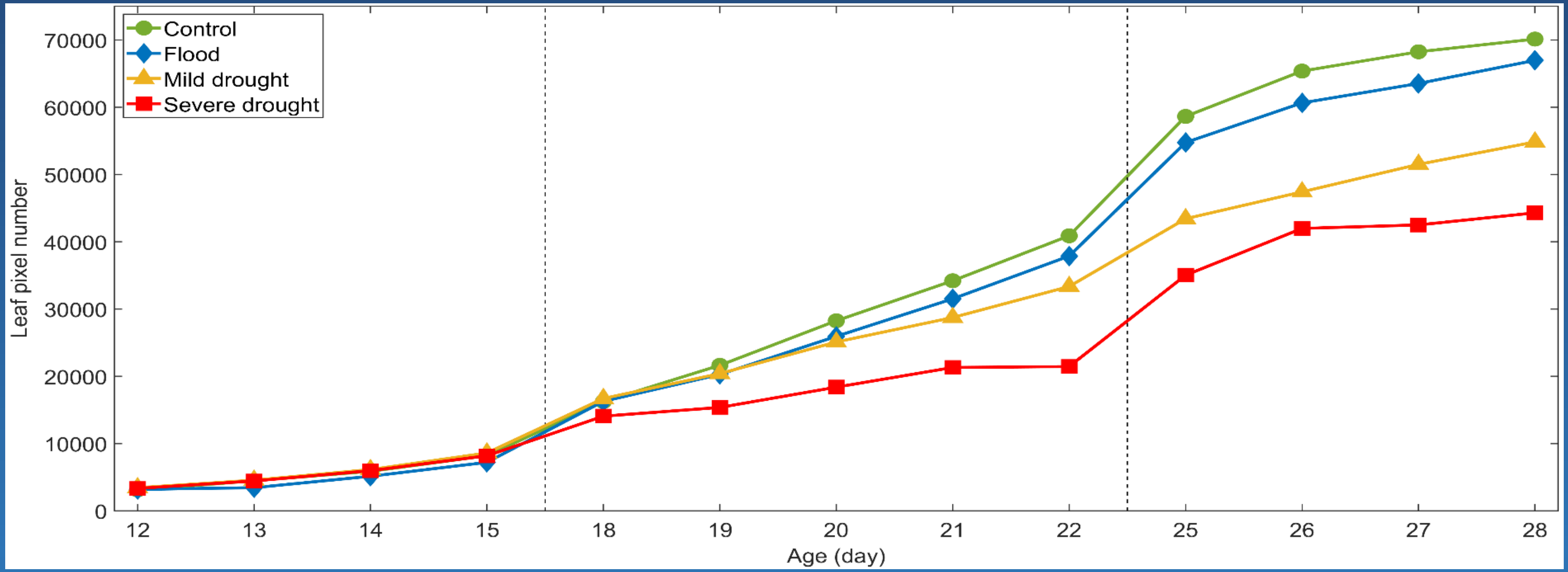
Use reflectance to remove background – Masking

Monje et al., ICES-2021-289



Develop Vegetation indices using AI

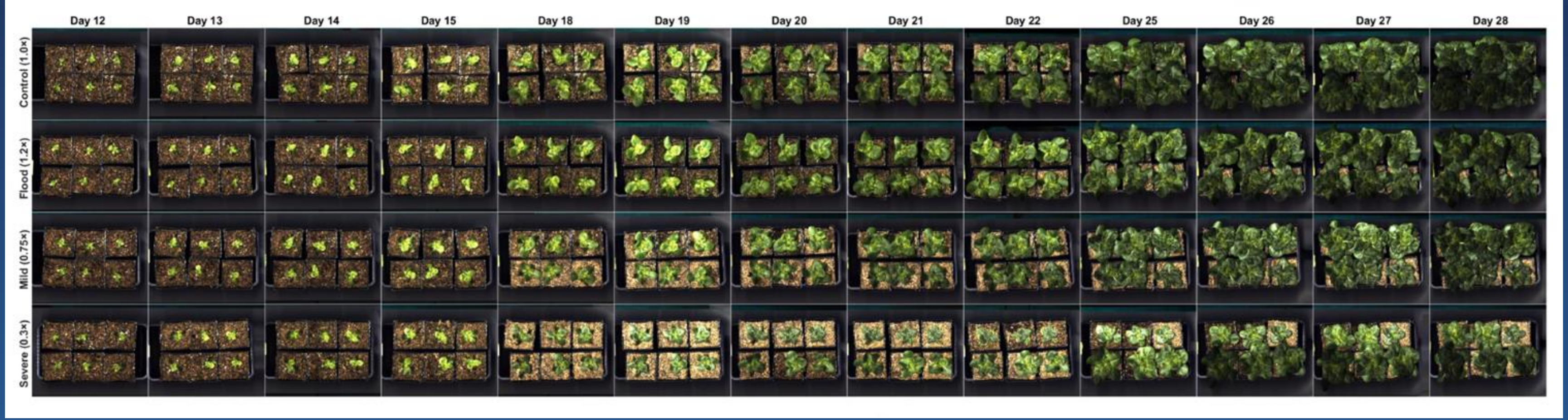
Stress Detection – Pixel Area from Images

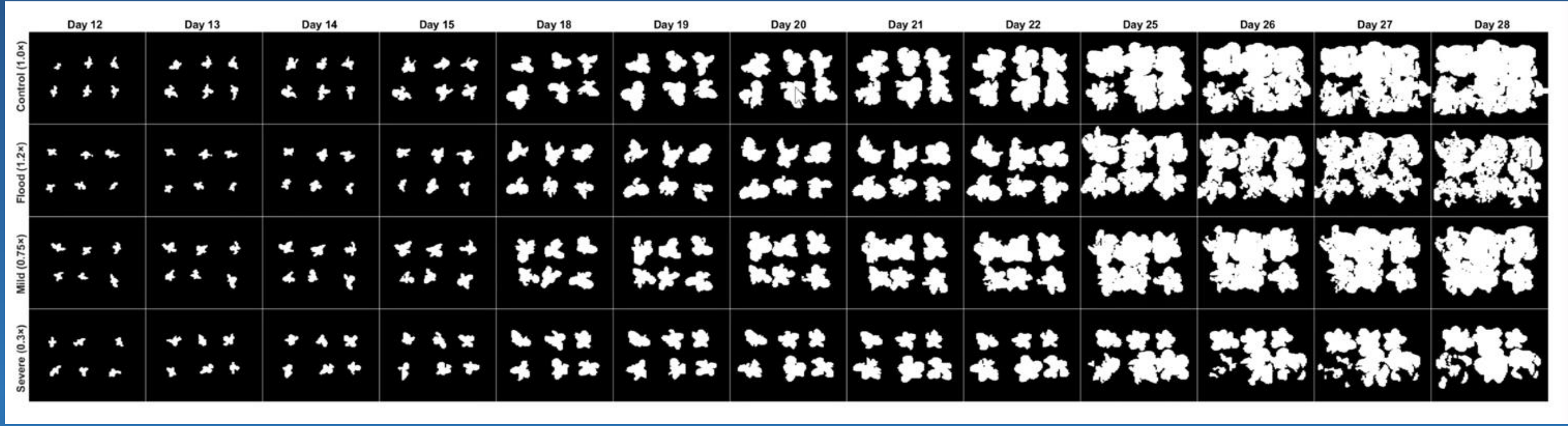


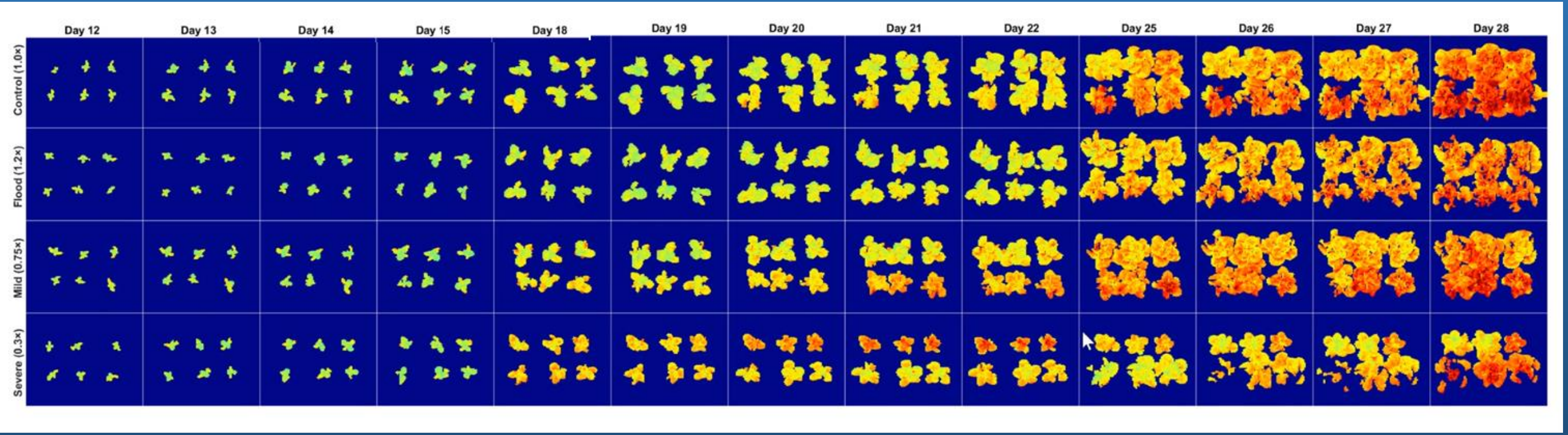
Total leaf areas on each sampling day estimated by pixel numbers in plant mask images of lettuce samples under four treatments.

Data Processing from Daily Image Acquisition

Generate training sets for different crops under biotic stress







The Lunar Surface

Both a Destination and an Analog for Mars

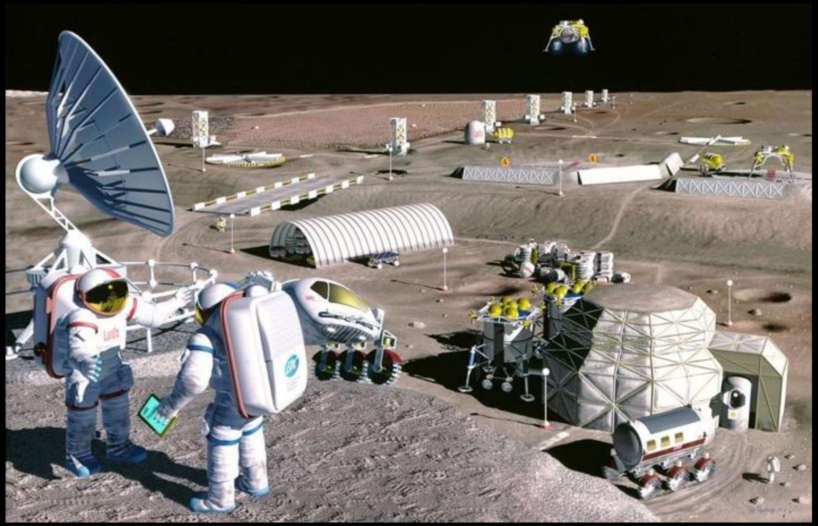
- First opportunity to perform fundamental research in both the unique radiation and partial gravity environment beyond LEO

- Location to evaluate both short and long-term radiation effects on seed viability, plant performance nutrition and palatability

- Enable development and demonstration of dependable, advanced crop production systems needed for future Mars habitat

- Evaluate Hydroponic vs soil-less vs regolith-based watering systems

- Demonstrate automated crop production technologies in relevant environments



Conclusions

- Food production must be optimal and safe for human consumption. To ensure this and to develop essential future technologies, plant growth facilities (i.e. Veggie and APH) can be enhanced with imaging systems (including hyperspectral, multispectral, lidar, and fluorescence imaging systems) for nondestructive monitoring of plant health, stress and assessing food safety.
- Prototype crop production systems designed for deployment on ISS and will likely be tested on other platforms. Research into crop performance in radiation and partial gravity will be likely be conducted at the Gateway as well as on the lunar surface. The goal is to advance crop production systems for deployment at lunar habitats, and on the Mars transit-habitat in preparation for human missions to Mars.
- Databases of crop responses to stress obtained during ground studies can be used to develop novel artificial intelligence (AI) algorithms for optimizing crop production (i.e. environmental settings during growth) and for detecting crop indices that ensure food safety.
- Future farming systems should be sustainable and smart. Novel adaptive AI algorithms are needed for reducing crew intervention. Eventually, AI driven control systems that include autonomous planting, growing, and harvesting as well as periodic sanitization will need to be evaluated and incorporated into mission infrastructure for supplementing crew diets with fresh produce during future Mars exploration missions.

Questions?

Acknowledgments
The authors thank Jianwei Qin and Moon Kim from the Environmental Microbial and Food Safety Laboratory - USDA-ARS Beltsville, MD.
This work was funded by NASA's Biological and Physical Sciences Division and by USDA -ARS, Food Safety National Program.