NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA (April 2016)

Gioia Massa, Matt Romeyn, LaShelle Spencer, Matthew Mickens, Ray Wheeler

Impact Nugget:

The Veggie vegetable production system has been operating on the International Space Station (ISS) for more than 3 years. The passive, capillary based watering systems is still causing some issues (insufficient or excess water) and the astronauts have been watering manually. Three crops of red romaine lettuce, two crops of Chinese cabbage plants, and three combined plantings of lettuce (cv. Outredgeous and cv. Waldmann's Green) and mizuna have been grown and the astronauts are allowed to eat the leaves.

Facility Description:

- We have now moved from completely from Space Life Science Lab (SLSL) to the Space Station Processing Facility (SSPF). We have purchased and installed six Percival walk-in chambers (6 ft X 8 ft) and two reach-in chambers for the SSPF facility, and continue to organize a nearby lab for storing plant and chamber supplies, and planting and harvesting activities. All chambers have T5 fluorescent lamp banks with supplemental incandescent sockets. Larry Koss of our team is installing aspirated sensor boxes for redundant temperature, RH, and CO_2 monitoring, and will connect them all to Opto-22 modules along with a custom developed software systems for real-time, graphic output with a computer in the growth chamber area. The Opto-22 system can also accommodate additional sensor and control functions, such as irrigation timing or pH and EC for hydroponic systems.

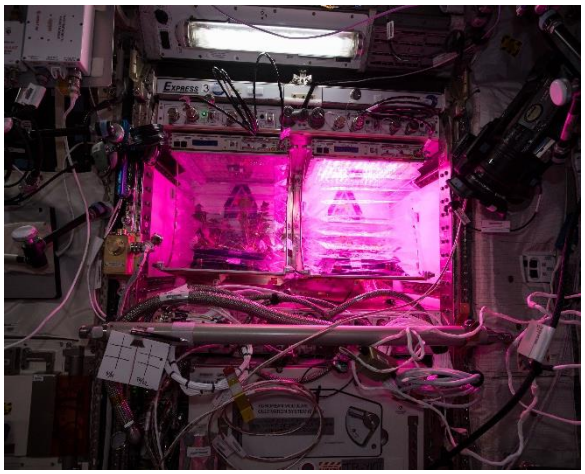

Fig. 1. Two Veggie plant chambers side by side on the International Space Station.

New Equipment / Sensors / Control Systems:

- We purchased seven Heliospectra RX30 LED lighting systems that provide nine , selectively dimmable LED wavelengths -- 380, 400, 420, 450, 520, 630, 660, 735 nm, and white (~5700 K), and continue to use four dimmable, 6500 K white LED arrays from BIOS Lighting (Melbourne, FL) and five custom 1:1 red/blue LEDs arrays from AIBC International (Ithaca, NY). Matt Romeyn has begun testing the prototype Phytofy RL LED fixture by OSRAM on microgreens that provides similar wavelength capability to the APH, and Matt Mickens has completed experiments with the Artificial Sunlight Research Module (ASRM) from Specialty Lighting of Holland that employs all LEDs to closely simulate the solar spectrum from near UV, through PAR, to the far-red region. We also purchased a LI-6800 portable leaf photosynthesis system this past year.

Unique Plant Responses:

- This isn't unique, but we have initiated a series of tests to grow different leafy crops in controlled environments. These include chard, wasabi green, amara mustard, shungiku (an edible crysanthemum), several radicchio spp., several escaroles, sorrel, bok choi, red mustard, kale, red Russian kale, as well as

lettuce. The intent of these tests to assess their potential for supplemental foods crops for space. We are tyring to follow some of the protocols used for the "baseline" testing with lettuce and marigold by NCR-101 members in the late 1970s.

Accomplishments:

- Gioia Massa continued to oversee some of the "validation" testing with Veggie plant growth systems on the International Space Station (ISS), which included a third trial with red romaine lettuce, and the first two tests with Chinese cabbage. Gioia has a 3-yr NASA grant to conduct the first official plant testing using Veggie (with leafy greens and dwarf tomato in 2018). Ray Wheeler, Mary Hummerick, Matt Romeyn and LaShelle Spencer at KSC, Bob Morrow at ORBITEC, and Cary Mitchell at Purdue are Co-Is on the grant along with other Co-Is from Johnson Space Center focusing on food and behavioral health. Matt Romeyn leads this research at KSC and continues to run ground studies as we prepare for flight. The focus of this research is to assess fertilizer and light quality impacts on crop growth, nutrient content, and organoleptic appeal. We have worked closed with Florikan Inc. to assess different controlled release (CR) fertilizer combinations. In addition to lighting and fertilizer, we are testing a new Veggie water delivery systems called PONDS (Passive Orbital Nutrient Delivery System), which holds a container of solid growth media (e.g., arcillite and CR fertilizer) that is surrounded by a small reservoir of water. The concept was designed by Howard Levine, Jeff Richards, and Larry Koss and KSC, and a flight system has been developed by Techshot Inc. and Tupperware Brands. Proof-of-concept flight testing of PONDS should start soon with the first set launched to the ISS April 2, 2018.

- LaShelle Spencer, Matt Romeyn, and Ray Wheeler, along with super undergraduate and graduate interns, initiated several of growth chamber tests with lettuce, mizuna, radish, dwarf tomato and dwarf peppers to assess their microbial counts, and are comparing these to similar vegetables purchases in local grocery stores. The intent of these studies is to establish some baseline or "norm" for acceptable microbial counts and food safety considerations for edible space crops.

- Matt Romeyn, Oscar Monje, and Larry Koss have set a several test bed to compare different watering techniques that might be considered for space applications (primarily looking at systems for µ-gravity operations). These challenges are not new but we want to establish some baseline data for a possible new NASA mission to develop a "deep-space gateway", which would be positioned somewhere near the moon and provide a staging point for lunar surface or Mars transit missions. The Gateway would only be "manned" for perhaps 1 month out of a year, so the ability to have autonomous operations, start-up, and shut-down would be an important consideration.

- Matt Mickens completed his comparison of lettuce growth under white LEDs supplemented with various narrow-band LEDs of red (635 nm), blue (460 nm), green (525 nm), and far red (745 nm). The white LED control treatment had a ~2800 K color temp. A sixth treatment utilized a Heliospectra light fixture with LEDs at 425, 525, 660, and 735 nm. Using a PPF of about ~200 µmol m^{-2} s^{-1} with an 18-h photoperiod, we saw the best overall growth for lettuce with the Heliospectra LEDs, and lowest biomass under red and blue LEDs only. When applying similar treatments to Red Pak Choi, conversely the optimal light recipe for edible biomass and leaf area were red (660 nm) and blue (460 nm) LEDs only, and any addition of green, far red, or broad spectrum light reduced leaf area, while increasing stem elongation.

Impact Statements:

- Thanks to many hard working colleagues at KSC, Orbitec, and numerous universities, and the controlled environment plant research community, we have successfully extended their reach to the International Space Station with a second Veggie plant growth unit and now the Advanced Plant Habitat (APH). The APH is the largest plant growth chamber ever flown (~0.2 m^2 growing area) and will be used for fundamental plant

research in space. APH uses porous steel watering tubes embedded in trays of arcillite, and provides a well-controlled, closed environment that will allow tracking of whole canopy photosynthesis, respiration, and transpiration. As with the prior Astroculture and BPS chambers flown in space, the humidity is condensed and recycled back to the plants. Lighting is provided by a range of narrow-band along with white LEDs, and can provide up to ~800 µmol m^{-2} s^{-1} at the plant level. Initial validation tests in APH using dwarf wheat and *Arabidopsis thaliana* were recently completed and follow on testing is planned.

Fig. 2. (Left) Growth chamber testing of "new" salad crops for possible use on the Intl. Space Station. (Right) Ground tests with the Advanced Plant Habitat (APH) recently sent to the Intl. Space Station. The APH has a broad range of environmental control capabilities, with multi-spectral LED lighting, a closed air loop for canopy gas exchange, gravity independent watering system, humidity/condensate recycling, and temp, RH, and CO_2 control.

Recent Publications:

Anderson, M.S., D. Barta, G. Douglas, R. Fritsche, G. Massa, R. Wheeler, C. Quincy, M. Romeyn, B. Motil, and A. Hanford. 2017. Key gaps for enabling plant growth in future missions. AIAA Proceedings, Oct. 2017.

Ehrlich, J.W., G.D. Massa, R.M. Wheeler, T.R. Gill, C.D. Quincy, L.B. Roberson, K. Binsted, and R.C. Morrow. 2017. Plant growth optimization by vegetable production system in HI-SEAS analog habitat. AIAA Proceedings, Oct. 2017.

Graham, T. and R. Wheeler. 2017. Mechanical Stimulation controls canopy architecture and improves volume utilization efficiency in bioregenerative life support candidate crops. Open Agriculture 2017 (2):42-51.

Lunn, G.M., G.W. Stutte, L.E. Spencer, M.E. Hummerick, L. Wong, R.M. Wheeler. 2017. Recovery on nutrients from inedible biomass of tomato and pepper to recycle fertilizer. Intl. Conf. on Environmental Systems ICES-2017-060.Graham, T. and R. Wheeler. 2016. Root restriction: A tool for improving volume utilization efficiency in bioregenerative life –support systems. Life Sciences in Space Research 2017 (9):62-68.

Massa GD, Newsham G, Hummerick ME, Morrow RC, Wheeler RM (2017) Plant Pillow Preparation for the Veggie Plant Growth System on the International Space Station. Gravitational and Space Research, **5**(1): 24-34.

Massa, G.D., N.F. Dufour, J.A. Carver, M.E. Hummerick, R.M. Wheeler, R.C. Morrow, T.M. Smith. 2017. VEG-01: Veggie hardware validation testing on the International Space Station. Open Agriculture 2017 (2):33-41

Matula, E., O. Monje, and J. Nabity 2016. Influence of transient heat transfer on metabolic functions of *Chlorella vulgaris* used for environmental control and life support systems of long duration spaceflight. AIAA SPACE 2016, SPACE Conferences and Exposition, AIAA 2016-5463 http://dx.doi.org/10.2514/6.2016-5463.

Morrow, R.C. R.C. Richter, G. Tellez, O. Monje, R. Wheeler, G. Massa, N. Dufour, and B. Onate. 2016. A new plant habitat facility for the ISS. Intl. Conf. on Environmental Systems, ICES-2016-320. 541. Morrow, R.C.

R.C. Richter, G. Tellez, O. Monje, R. Wheeler, G. Massa, N. Dufour, and B. Onate. 2016. A new plant habitat facility for the ISS. ICES-2016-320.
Wheeler, R.M. 2017. Agriculture for space: People and places paving the way. Open Agriculture 2017 (2):14-32.

Scientific Outreach:

- In collaboration with Fairchild Tropical Botanic Gardens in Miami, a school challenge called "Growing Beyond Earth" was developed, which in 2016-2017 enabled 124 schools and more than 3000 middle and high school students in south Florida to have botany racks installed in their classrooms with LED lights. In this citizen science initiative, students researched and grew multiple crop varieties to help select new crops that could eventually be grown in the Veggie hardware on ISS and they posted their progress and results on twitter @growbeyondearth and provide their data to NASA. Since inception this program has been expanded, with Fairchild Gardens awarded a NASA grant to informal learning institutes. This year approximately 150 middle and high schools are participating with several having multiple racks. Also students are working on enhanced projects: after studying photoperiod responses to Asian leafy green crops students developed research proposals for novel experiments, conducted those experiments, and prepared posters of their research for presentation at a spring student research symposium.
- In collaboration with Fairchild Gardens also, Joshua Ehrlich, one of the participants of the 2017 NASA-funded Hawaii Hi-SEAS Mars analog eight month test, completed testing of crop growth using a Veggie system and also using the Fairchild Growing Beyond Earth system. He tested crop growth and light levels and worked to produce food for the Hi-SEAS crew. In addition Josh conducted outreach events from "Mars" with students engaged in the Growing Beyond Earth challenge. Josh posted his progress on twitter and on his blog https://small-steps-giant-leaps.travel.blog/ and prepared presentations and publications of his work for the International Astronautical Congress.
- KSC interns are developing a display space of Kenney food production research in the past, present work, and future aspirations. This display will be co-located with our plant growth chambers and will be a featured stop to student tours and media who visit KSC to see our food production research.

Committees / Panels:

ASHS CE Working Group (Wheeler, Massa)
Com. on Space Research (COSPAR) Life Science Commission F Vice Chair (Wheeler)
EDEN-ISS Project (EU Funded) Science Advisory Board (Wheeler)
Amer. Soc. Grav. and Space Res. (ASGSR) Education / Outreach Committee (Massa)