NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA (April 2019)

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Impact Nugget:

The Veggie vegetable production system has been operating on the International Space Station (ISS) for more than 4 years. Several crops of lettuce (cvs. Outredgeous, Waldmann's Green and Dragoon), Chinese cabbage (cv. Tokyo bekana), mizuna, 'Red Russian' kale, and pak choi (cv. Extra Dwarf) have been grown and the astronauts are allowed to eat the leaves for many of these experiments. The passive, capillary-based watering system has not worked reliably and the astronauts have been watering manually. A new watering systems called PONDS had challenges in initial testing, but a modified PONDS will be tested soon. The PONDS system involves a plastic water reservoir with a cylinder of wetting and non-wetting solid media placed in the center of the reservoir. Water is delivered to the solid media with a series of wicks sticking into the water.

Facility Description:

- Kennedy Space Center (KSC) currently has six Percival walk-in chambers (6 ft X 8 ft) and four reach-in chambers for the Space Station Processing Facility (SSPF), and we 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 installed 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 for all the walk-in chambers and will continue this with the reach-in chambers. Alarming for power failures and lighting have implemented and irrigation alarms will be implemented soon. The Opto-22 system can also accommodate additional sensor and control functions, such as irrigation timing or pH and EC for hydroponic systems. In addition, we installed two CO_2 scrubbing systems that support trays of NaOH pellets. We have found that these scrubbers can hold ambient ~400 ppm CO_2 while a person is inside the chamber.

Fig. 1. *Serena M. Auñón-Chancellor harvesting Red Russian kale from Veggie plant chambers on the International Space Station.*

New Equipment / Sensors / Control Systems:

- We continue to use Heliospectra RX30 LED lighting systems for many of our studies. The fixtures provide nine, selectively dimmable LED wavelengths -- 380, 400, 420, 450, 520, 630, 660, 735 nm, and white (~5700 K). We also 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 Mickens 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 have tested OSRAM PHYOFY preproduction lights and have ordered several of PHYTOFY RL lights for testing. These are currently being installed. We also purchased a LI-6800 portable leaf photosynthesis system this past year, and both LaShelle Spencer and Lucie Poulet have been trained in operating this instrument.

Unique Plant Responses:

- We completed a series of tests to grow different leafy crops in controlled environments with or without supplemental far-red lighting. These included chard, wasabi mustard amara mustard, shungiku (an edible crysanthemum), several radicchio spp., several escaroles, sorrel, pak choi, red mustard, kale, red Russian kale, as well as lettuce. We are in the process of analyzing the data, but in general, species with distinct stems and internodes showed more elongation with supplemental FR (as expected), while heading plants (lettuce, escarole, radicchios) showed greater leaf expansion with FR. The Pak Choi cv. Extra Dwarf showed no difference.

Accomplishments:

- Ye Zhang and Matt Romeyn continued to oversee some of the "validation" testing with Veggie plant growth systems on the International Space Station (ISS), which mixed crop tests with two types of lettuce and mizuna, continuous production in two veggie units, and the addition of new crops, Red Russian Kale, Dragoon lettuce, Wasabi mustard and Extra Dwarf pak choi.
- Gioia Massa has a 3-yr NASA grant to conduct the first official plant testing using Veggie (with leafy greens in 2019 and dwarf tomato in 2020). Ray Wheeler, Mary Hummerick, Matt Romeyn and LaShelle Spencer at KSC, Bob Morrow at Sierra Nevada, and Cary Mitchell at Purdue are Co-Is on the grant along with several Co-Is from Johnson Space Center focusing on food and behavioral health. 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. Two sets of mizuna will be grown in Veggie plant pillows, one grown for 28 days and the second for 56 days with repetitive harvesting. Tomatoes will be grown in the Passive Orbital Nutrient Delivery (PONDS) growing system. A modified version of this hardware will be tested on ISS soon.

- Mary Hummerick and LaShelle Spencer along with super undergraduate and graduate interns, grew several growth chamber tests with lettuce, mizuna, radish, dwarf tomato and dwarf peppers to assess their microbial counts, and compared these to similar vegetables purchases in local grocery stores. The intent of these studies was to establish some baseline or "norm" for acceptable microbial counts and food safety considerations for edible space crops. In general, plants grown in the controlled environment chambers were lower in microbial counts than similar crops purchased at grocery stores, and in all cases, the levels of microbes could be dropped by treating the leaves or fruits with ProSan, a citrate based sanitizing agent. Colleagues at Johnson Space Center will use the data to develop a risk assessment for fresh produce grown in space.

- Matt Romeyn, Oscar Monje, LaShelle Spencer and Larry Koss, along with new team member and former intern Jacob Torres continue 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 1-2 months out of a year, so the ability to have autonomous operations, start-up, and shut-down would be an important consideration.

- LaShelle Spencer, Matt Romeyn, Ray Wheeler and some super interns completed a set of studies where leaf vegetables were grown at 400, 1500, 3000, and 6000 ppm CO_2 to study growth and development, and stomatal conductance across a range of CO_2. For the first tests at 400, it became very difficult to hold the set point due to CO_2 pollution in the surrounding room and humans coming and going in the chamber. We later added CO_2 scrubbing systems from Percival, which contain multiple trays with color-indicating NaOH coated pellets. This worked quite well for holding 400, even with one person in the chamber. But you need to be sure the pellets are changed when they are exhausted. Larry Koss of the KSC group put an acrylic “window” on the scrubbing box to allow easy viewing of the pellets.

- Matthew Mickens completed his Postdoctoral Fellowship in August, 2018, and accepted a position as Operations Manager, Indoor Vertical Farming with Intravision Greens, Inc. in Newark, NJ.

- Lucie Poulet was selected as a NASA Postdoctoral Fellow and began working at KSC in January, 2019, on a project entitled “Modeling plant growth and gas exchanges in various ventilation and gravity levels.”

Impact Statements:

- Thanks to many hard working colleagues at KSC, Sierra Nevada Corp., 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 completed its first peer-reviewed science test with Arabidopsis, with a second test with radish coming up soon. APH uses porous metal-ceramic 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 $\mu mol\ m^{-2}\ s^{-1}$ at the plant level. Initial validation tests in APH using Apogee dwarf wheat and *Arabidopsis thaliana* were recently completed and follow on testing is planned.

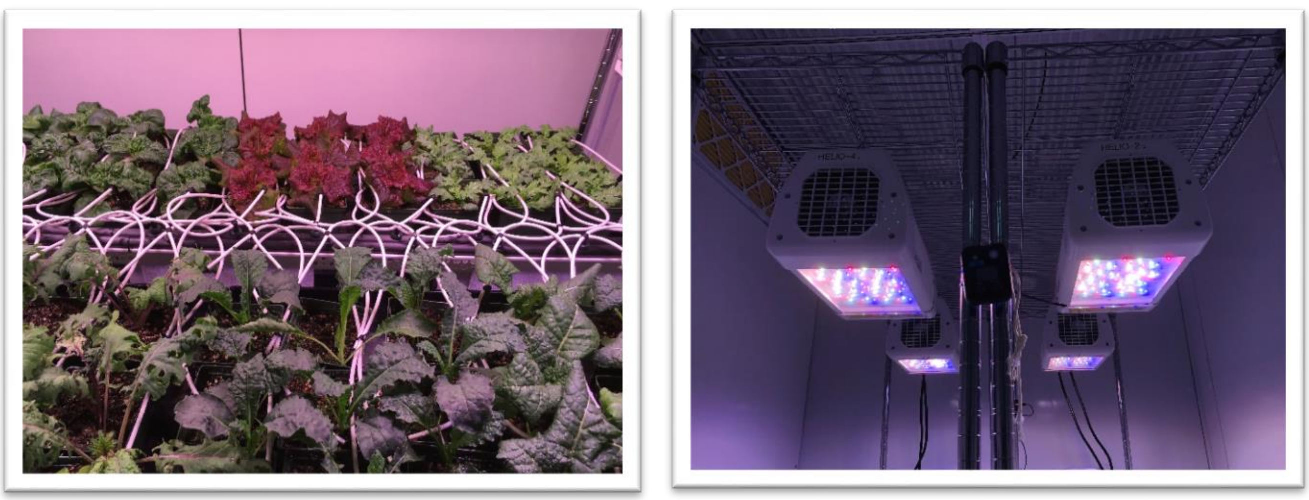

Fig. 2. *Left: Test of leafy greens as candidate spaceflight crops. Tests were carried out at 400, 1500, 3000, and 6000 ppm CO_2 to straddle a range of CO_2 levels that might be encountered in space craft like the Intl. Space Station. Right: Heliospectra lamps used for lighting in the studies.*

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.

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 Res, 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.

Mickens, M.A., E.J. Skoog, L.E. Reese, P.L. Barnwell, L.E. Spencer, G.D. Massa, and R.M. Wheeler 2018. A strategic approach for investigating light recipes for 'Outredgeous' red romaine lettuce using white and monochromatic LEDs. Life Sci. Space Res. 19:53-62.

Mickens, M.A., M. Torralba, S.A. Robinson, L.E. Spencer, M.W. Romeyn, G.D. Massa, and R.M. Wheeler. 2019. Growth of red pak choi under red and blue, supplemented white, and artificial sunlight provided by LEDs. Scientia Horticulturae 245:200-209.

Urbaniak C, Massa G, Hummerick M, Khodadad C, Schuerger A, Venkateswaran K. (2018) Draft Genome Sequences of Two *Fusarium oxysporum* Isolates Cultured from Infected *Zinnia hybrida* Plants Grown on the International Space Station. Genome Announc. 6 (20). pii: e00326-18. doi: 10.1128/genomeA.00326-18.

Wheeler, R.M. 2017. Agriculture for space: People and places paving the way. Open Agriculture 2017 (2):14-32.

Scientific Outreach:

- The "Growing Beyond Earth" educational collaboration with Fairchild Tropical Botanic Gardens in Miami continues to generate data for NASA, while inspiring middle and high school students. Students, first in south Florida and now around the country have botany racks in their classrooms with LED lights and are helping to select crops and define growing techniques for space. They post their progress and results on twitter @growbeyondearth and provide their data to NASA. Building on the success of this citizen-science initiative, Fairchild has also been awarded additional grants to develop the first ever maker space in a botanical garden, the Growing Beyond Earth Innovation studio, which will be opening in spring of 2019.
- KSC continues to average 3-5 undergraduate and graduate students as food production interns in summer, fall, and spring terms. Interns work on plant growth experiments, hardware development and testing, and space food production strategic planning.
- KSC food production team members continue to advise universities in engineering design courses focused on aspects of space plant growth. University teams are helping to design or modify crop water delivery systems, robotic plant care systems, resource recovery systems, and many other types of space plant production hardware.

Committees / Panels:

ASHS CE Working Group (Wheeler, Massa)
Com. on Space Research (COSPAR) Sub-Commission F4.2 Chair (Wheeler)
EDEN-ISS Project (EU Funded) Science Advisory Board (Wheeler)
Amer. Soc. Grav. and Space Res. (ASGSR) Governing Board and Education / Outreach Committee (Massa)