NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA (April 2017)

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Impact Nugget:

The Veggie vegetable production system has been operating on the International Space Station (ISS) for more than 2 years. The passive, capillary based watering systems is still causing some issues (insufficient or excess water). A third crop of red romaine lettuce and a first crop of Chinese cabbage plants were grown and the astronauts were allowed to eat the leaves.

Facility Description:

- We continued to rent several walk-in and reach-in chambers at Space Life Sciences Lab (SLSL), and in addition have been using two reach-in chambers with red-blue LED lamp fixtures at the SSPF building at Kennedy Space Center. Larry Koss, our electro-mechanical lead has completed a retrofit of a large Thermotron walk-in chamber for growing plants in O&C Building on the main campus of Kennedy Space Center. Larry added banks of T8 fluorescent lamps and has set up his Opto-22 based monitoring and control system. We will also be purchasing five Percival walk-in chambers (6 ft X 8 ft) and two reach-in chambers that will be located at the SSPF facility of Kennedy Space Center, adjacent to several new plant-focused lab areas under development. Anticipated completion of this new facility is Summer 2017. A plant processing area has been established in the SSPF building and testing in this space has commenced with LED arrays, a grow tent, and two small reach-in chambers operating.

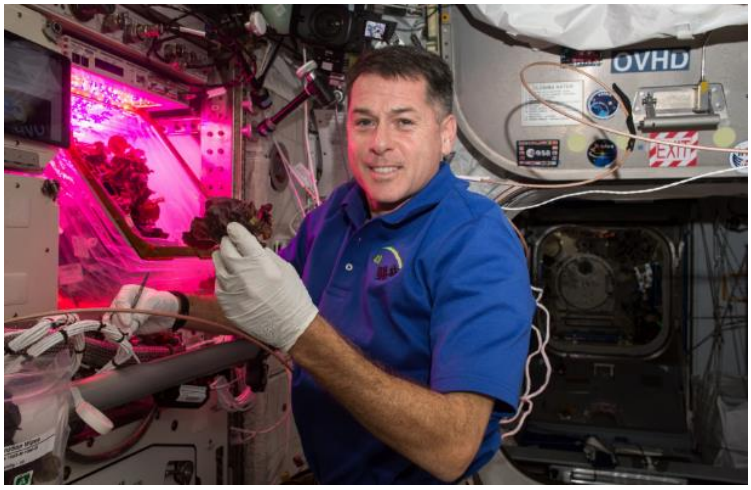

Figure 1. Astronaut Shane Kimbrough harvesting red romaine lettuce (cv. Outredgeous) grown in Veggie plant chamber on the International Space Station.

New Equipment / Sensors / Control Systems:

- We purchased a Decagon SC-1 porometer for stomatal conductance measurements. It is much smaller than our Li-Cor steady state porometer, and has a built in data logger. Additional equipment purchased in the establishment of the plant processing area includes a large capacity Thermo Scientific forced air oven, a Gilson sieve shaker with sieves for sorting substrate particle sizes, a Wiley tissue mill, a Li-Cor LI-3100C leaf area meter, and Li-Cor quantum meters, an Apogee spectroradiometer, an Atago portable refractometer, a Minolta SPAD meter, a FLIR C2- pocket sized thermal Imaging system, a Heliospectra RX30 lamp, and other standard analytical equipment. ORBITEC retrofitted 6 Biomass Production Systems for Education (BPSe) with LED light-caps to mimic the Veggie system. Several new LED lighting systems have been purchased, including 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).

Unique Plant Responses:

- We continue to grow, propagate, and pollinate genetically engineered plum (*Prunus domestica)* trees with overexpressed FT1 flowering gene (developed by the ARS at Kearneysville, WV). The plants do not have any cold-period dormancy requirements for flowering, which is an advantage as a potential space crop. We have been able to grow fruit from the several of the lines, but have been fighting thrips in these studies, which is new challenge for our growth chamber testing. Larry Koss has built several load cell platforms to track weight changes associated with watering event and transpiration.

Accomplishments:

- Gioia Massa continued to oversee 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 test with Chinese cabbage. Gioia has a 3-yr NASA grant to conduct the first official plant testing with Veggie (with leafy greens and dwarf tomato in 2018). Ray Wheeler and Mary Hummerick 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 in our group leads this research at KSC and continues to run ground studies as we prepare for flight. In particular, we are testing a different water delivery systems called PONDS, which holds a container of solid growth media (e.g., arcillite) that is surrounded by a small reservoir of water. Air permeable patches on the sides of the reservoir allow O_2 to diffuse into the water. But we need to test the system on parabolic air flights to observe behavior of the water in freefall.

- We completed a series of tests using mini-bioreactors to recover soluble nutrients from dried, inedible plant biomass. These tests did not show much improvement on recovery of soluble nutrients compared to previous tests with continuously stirred-tank bioreactors (CSTRs), but dropping the pH of the solution (adding acid) improved recovery of elements like Ca, P, and Mg. As part of this study, we did some calculations that estimate about 90 kg / yr of fertilizer would be required to grow enough food for one person, and would be interested in anyone else's data or publications on fertilizer needs to sustain certain levels of productivity in CEA systems.

- Matt Mickens completed his first growth comparison of lettuce 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 733 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 the White plus far red. After a chamber relocation, we encountered some problems of very aggressive algal (maybe cyanobacteria) growth on the soil surface of pots and in standing water in trays during a follow-up study. Seedlings in that study were severely stunted?! Has anyone else every seen this when a lot of algae growth occurs? We cleaned the humidifiers and heat exchange coils in the chamber to reduce possible sources of the algae.

Impact Statements:

- Thanks to many hard working colleagues at KSC, ORBITEC, and numerous universities, the plant controlled environment and CEA community have successfully extended their reach to the International Space Station with the Veggie plant growth unit. A second Veggie unit is also being sent to ISS to double the capability and allow for greater experimental flexibility. NASA and ORBITEC have built an even larger (0.2 m^2), more highly controlled plant research chamber with over 180 sensors called the Advanced Plant Habitat, or APH, which will be launched in the next few months. The APH is going to be the largest plant growth chamber

ever flown and will be utilized to understand plant growth in space that will help us here on Earth and as we move forward to Mars and beyond.

Figure 2: Dwarf FT overexpressed plum tree can go from rooting to flowers and fruit in about 12 months.

Figure 3.White plus discrete LEDs used to study growth of lettuce and Chinese cabbage.

Recent Publications:

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.

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.

Massa, G.D., Wheeler, R.M., Morrow, R.C., Levine, H.G. 2016. Growth chambers on the International Space Station for large plants. Acta Hort. 1134: 215-222. DOI: 10.17660 / ActaHortic.2016.1134.29

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. In 2016-2017 this program was expanded, with Fairchild Gardens awarded a NASA grant to informal learning institutes. This year 131 schools participated but several had multiple racks. Also students worked on enhanced projects, and a collaboration with Florikan fertilizer corporation further enhanced the project as students tested different fertilizer formulations and concentrations in addition to different plant types.

- In collaboration with Fairchild Gardens also, Joshua Ehrlich, one of the participants of the NASA-funded Hawaii Hi-Seas Mars analog eight month test, is growing crops using a Veggie system and also using the Fairchild Growing Beyond Earth system. He is testing crop growth and light levels and working to produce food for the Hi-Seas crew. In addition Josh is conducting outreach events from "Mars" with students engaged in the Growing Beyond Earth challenge. Josh is posting his progress on twitter and on his blog https://small-steps-giant-leaps.travel.blog/.

Committees / Panels:

ASHS CE Working Group (Stutte, Wheeler, Massa)
Com. on Space Research (COSPAR) Life Science Commission F Vice Chair (Wheeler)
ACMAP Board of Directors (Stutte)
NCERA-101 Executive (Massa)
EDEN-ISS Project (EU Funded) Science Advisory Board (Wheeler)
Amer. Soc. Grav. and Space Res. (ASGSR) Education / Outreach Committee (Massa)