NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA (March 2008)

New Facilities:

The Space Life Sciences Lab (SLSL) Controlled Environment Lab (CEL) has been operational for 4 ½ years and provides 606+ ft^2 (56 m^2) of controlled environment chamber space. The SLSL has developed a Low Pressure Testbed for testing, calibration and validation of sensors, engineering components/systems, and conducting experiments for the Orion Exploration Vehicle and lunar outpost applications. Additionally, a vacuum chamber for lunar and Mars dust/regolith testing has been installed with 10^{-7} Torr capability.

Equipment / Sensors / Control Systems:

- The primary control and monitoring system for the CEL, CMDS [Command, Monitoring and Data System], continues to improve with added capabilities including remote access via internet, alarming, and data collection and analysis. The flexibility of CMDS allows for development to meet user or project specific requirements.
- An M-48 chamber was modified to have zero-humidity air input (via facility installed desiccant dryer) as a method of dropping chamber relative humidites to as low as 10%.
- Added capability of the CEL to perform Biosafety level 1P GMO plant research studies. Initial testing involved baseline studies with GM soybean plants donated from Monsanto Company.
- Continued testing and use of a new high output LED array from ORBITEC with $\geq$300 µmol m^{-2} s^{-1} PPF @ each of six wavelengths (400, 440, 520, 640, 660, and 720 nm).
- A Low Pressure Tesbed (LPT) provides a capability for maintaining atmospheric pressure, temperature, and relative humidity for a variety of testing applications. Future development plans for the LPT include controlling atmospheric constituents (N_2, O_2, CO_2, CO, Ar, and H_2O) and inclusion of discrete test chamber(s) (inserts) for controlling the concentration of volatile organic compounds (VOCs).
- LADA plant growth units similar to those being used in the Russian module of the International Space Station were tested in an M-12 chamber to assess microbial communities and function on radish roots for food safety.
- ORBITEC has delivered two "VEGGIE" units (Phase II SBIR grant from NASA) as a deployable plant growth system for producing salad type crops. The VEGGIE design provides growing areas that can be "daisy chained" together to provide approximately a 1 m^2 growing area (6 VEGGIE units) and can be stowed within a single crew transfer bag on the Space Shuttle. The VEGGIE units provide LED lighting and a water/nutrient delivery matting, but utilize the cabin environment for temperature and CO_2 control to minimize complexity and power requirements.
- Continued development of a "Lighting Testbed" with the addition of a 1 m integrating sphere and an Optronics spectroradiometer with spectral range in the visible and near IR (380 to 1180nm) to obtain Spectral Power Distributions and total lumen outputs as well as a goniometer to obtain lamp distribution characteristics.

Unique Plant Responses:

- VOC exposure studies have been completed. Ethanol inhibited growth of radish at 10% of the human exposure level established by NASA, OSHA and ACGIH) and was lethal at the 50% level. There was significant variation in sensitivity to particular alcohols, with ethanol and t-butanol being the most phytotoxic, and the methanol and 2-propanol being less so.
- Testing of elevated CO_2 (1200 and 10,000 ppm) effects on stomatal conductance and metabolite profiles of soybean and fava bean plants is underway. As with previous studies with soybean, potato, radish, and lettuce, super-elevated CO_2 (10,000 ppm) causes a "reopening" of stomata relative to 1200 ppm, especially in the dark. Our efforts are focused on determining the mechanism for this stomatal behavior.

Accomplishments:

- VOC exposure studies were completed at 100, 50, 25 and 10% of NASA's Spacecraft Maximum Allowable Concentration (SMAC) levels for target VOCs and T10, T50, and T90 levels were published for methanol, ethanol, 2-propanol, and t-butanol. Seedling bioassay results indicate that the threshold levels are reasonable exposure guidelines, although species and cultivar variation in sensitivity to VOCs do exist.
- Environmental baseline studies for typical open cabin atmosphere in space (such as the Intl. Space Station) were completed with radish, lettuce, and onion. Treatments included ambient, elevated, and super-elevated CO_2 (400, 1200, and 4000 ppm), air temperatures of 22, 25, and 28°C, and PPF levels of 150, 300, and 450 µmol m^{-2} s^{-1} with a 16-h photoperiod with fluorescent lamps. Biomass yields showed optimal temperatures for growth and generally increasing yield with increasing PPF. Significant tipburn was observed on lettuce plants at higher PPF levels.
- Spectral distribution and power efficiency measurements were recently completed on six different commercial LED lighting systems on loan from AJ Both at Rutgers.
- Fully characterized Solid State Lighting Module (SSLM) as well as three other commercial of the shelf (COTS) luminaires on the following parameters: photopic luminous flux, scotopic luminous flux, color rendering index, correlated color temperature, total radiant power, radiant efficiency, luminous efficacy, color coordinates in four different color spaces, color gamut area,

power spectral distribution, light distribution profile, photosynthetic active radiation (PAR), photosynthetic photon flux (PPF), and phytochrome photostationary state.

Impact Statements:

- We completed an environmental response study to characterize potential "salad" crops to be used as dietary augmentation for astronauts in a 3 x 3 factorial study with CO_2, light, and temperature. These experiments established an extensive dataset on the effects of environment on edible and total biomass yields, water use, nutrient uptake, and anti-oxidant capacity of lettuce, radish, green onion, tomato, and bell pepper. Future plans are to incorporate these baseline data into a model for predicting yield and requirements in spacecraft, and to transfer that information to CEA production systems.
- We recently completed studies comparing the effects of various volatile organic compounds (VOCs) on radish growth and development. These compounds can build up both from physical and biogenic sources and may be a concern for growing plants in tightly closed environments like space habitats. We have published threshold responses that can be used to establish exposure guidelines in spacecraft and commercial production facilities. Our intent is to develop a Spacecraft Maximum Allowable Concentration (SMAC) list for plants that will be adapted by NASA on future exploration missions.
- We completed testing of light intensity (100, 150, 300 and 450 µmol m^{-2} s^{-1} PAR) and light quality (440, 530, 640, 730 nm LED's) on lettuce growth and bioprotectant compound production to determine environmental thresholds and cultivar sensitivity. Bioprotectants such as anthocyanins provide a potential radiation countermeasure to both reduce the effective radiation dose and induce *in situ* repair of radiation damage during long-duration missions. The objective of this work is to increase concentration of bioprotectants in foods as a radiation countermeasure.

Recent Publications/Presentations:

Edney, S.L., J.T. Richards, N.C. Yorio, M.D. Sisko, G.W. Stutte and R.M. Wheeler. 2007. Mixed vs. monoculture hydroponic production of salad crops at three CO2 concentrations. *Proc. Plant Growth Reg. Soc.* 33:193-200.

Kim, H.H., J. Norikane, R.M. Wheeler, J.C. Sager, and N.C. Yorio. 2007. Electric lighting considerations for crop production in space. *Acta Hort.* 761:193-202.

Levine, L.H., P.A. Bisbee, T.A. Richards, M.N. Birmele, R.L. Prior, M. Perchonok, M. Dixon, N.C. Yorio, G.W. Stutte, and R.M. Wheeler. 2008. Quality characteristics of radish grown under reduced atmospheric pressure. *Adv. Space Res.* 41:754-762.

Monje, O. S. Anderson and G.W. Stutte. 2007. The effects of elevated root zone temperature on the development and carbon partitioning of spring wheat. *J. Amer. Soc. Hort. Sci.* 132:178-184.

Monje, O., J. Catechis, and J.C. Sager. 2007. Effects of relative humidity on the adsorption of dichloromethane by Carbosieve SIII. *SAE Technical Paper* 2007-01-3249.

Monje, O., I. Eraso., C. O'Keefe, and R. M. Wheeler. 2007. Testbed for determining the filtering capacities of COTS adsorbents. *SAE Technical Paper* 2007-01-3137.

Stutte, G.W., I. Eraso and S. Matthews. 2007. Volatile ethanol affects germination and growth of lettuce, radish, soybean and wheat seeds. *Proc. Plant Growth Reg. Soc.* 33:192.

Stutte, G.W., I. Eraso, and K.B. Downing. 2007. Feasibility of controlled environment production of Scutellaria species. *Acta Hort.* 756:213-219.

Wheeler, R.M., C.L. Mackowiak, G.W. Stutte, N.C. Yorio, L.M. Ruffe, J.C. Sager, R.P. Prince, and W.M. Knott. 2008. Crop productivities and radiation use efficiencies for bioregenerative life support. *Adv. Space Res.* 41:706-713.

Wheeler, R.M., G.W. Stutte, C.L. Mackowiak, N.C. Yorio, J.C. Sager, and W.M. Knott. 2008. Gas exchange rates of potato stands for bioregenerative life support. *Adv. Space Res. 41*:798-806.

Wilkerson, E.G., R.A. Bucklin, P.A. Fowler, and V.Y. Rygalov. 2007. Convective heat transfer over a flat plat in hypobaric conditions. *Transactions of the ASABE* 50(3):981-991.

Scientific Outreach:

Committees / Panels:

ASHS Publications Committee (Stutte)
ASHS CE Working Group (Stutte, Yorio, Wheeler)
Plant Growth Reg. Soc. of America Steering Com. (Stutte)
Intl. Advanced Life Support Working Group (Wheeler)
ASABE Board of Trustees (Sager)
Com. on Space Research (COSPAR) F4 (Wheeler)

Visiting Scientists:

Catherina O'Keefe, Limerick University, Limerick, Ireland
Karen Downing, Limerick University, Limerick, Ireland
Peter Downey, Limerick University, Ireland
Tony Skerritt, Limerick University, Ireland
Aisling Flanagan, Limerick University, Ireland