NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA (April 2007)

New Facilities:

The Space Life Sciences (SLS) Lab Controlled Environment Lab (CEL) has been operational for 3 ½ years. The 606+ ft^2 (56 m^2) of controlled environment chamber space currently consists of eight EGC M-48 walk-in chambers, four GC-36 reach-in chambers with ante-rooms, two GC-15 reach-in chambers, four M-12 reach-in chambers, one GC-8 and a number of smaller Percival and Conviron incubators. The SLS lab is currently developing a Low Pressure Atmospheric Control chamber for testing, calibration and validation of sensors, engineering components/systems, and conducting low pressure experiments for the Orion Exploration Vehicle and lunar outpost applications. This hypobaric testbed will be housed in the CEL.

Equipment / Sensors / Control Systems:

- Last year, the control and monitoring system for the CEL, CMDS [Command, Monitoring and Data System], was completed with added capabilities to the system including remote access via internet, alarming, and data collection and analysis. Continued modifications to CMDS to meet user or project specific requirements.
- The ultrasonic humidifiers that were installed in all of the CEL's M-48 and M-12 chambers continue to perform flawlessly.
- An M-48 chamber was modified to have zero-humidity air input (via facility installed desiccant dryer) as an alternate method of controlling relative humidity below the current capability of ~25%.
- Added capability of the CEL to perform Biosafety level 1P GMO plant research studies. Initial testing will involve baseline studies with GM soybean plants donated from Monsanto Company.
- A new high output LED array from ORBITEC with $\geq$300 µmol m^{-2} s^{-1} PPF @ each of six spectral components (400, 440, 520, 640, 660, and 720 nm) was received and testing is underway.
- A Low Pressure Atmospheric Control chamber is close to completion to provide a capability for The LPAC chamber will control, pressure, temperature, atmospheric constituents (N_2, O_2, CO_2, CO, Ar, and H_2O), and can be outfitted with discrete test chamber(s) (inserts) for controlling the concentration of Volatile Organic Compounds (VOCs).
- LADA plant growth units that are currently being used in the Russian module of the International Space Station were tested in an M-12 chamber to assess microbial numbers and types on radish roots for food safety.
- ORBITEC has delivered two VEGGIE units (Phase II SBIR grant) of a Vegetable Production System, a deployable plant growth unit 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 water/nutrient delivery, but utilize the cabin environment for temperature and CO_2 control to minimize complexity and power requirements.

Unique Plant Responses:

- VOC exposure studies have been completed. Ethanol inhibits growth of radish at 10% of the exposure levels established by NASA, OSHA and ACGIH) and is lethal at 50% of the workplace allowable 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 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. We still don't know the mechanism behind this.

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 does 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 show optimal temperatures for growth and generally increasing yield with increasing PPF. Significant tipburn was observed on lettuce plants at higher PPF levels.
- A similar series of environmental factorial studies was completed with dwarf tomato (Red Robin) and dwarf pepper (Hanging Fruit Basket). Mild oedema (intumescence) continues to occur on pepper leaves, likely due to low UV radiation in these controlled environment tests.

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 have established an exceptional dataset on the effects of environment on edible and total biomass yields, water use, nutrient uptake, and anti-oxidant capacity

within the edible biomass of lettuce, radish, green onion, tomato, and bell pepper. Future plans are to incorporate these baseline data into a model for predicting yield and input requirements in spacecraft, and to transfer that information to controlled agriculture 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.

Recent Publications/Presentations:

Edney, S.L., J.T. Richards, M.D. Sisko, N.C. Yorio, G.W. Stutte and R.M Wheeler. 2006. Compatibility of salad crops grown in mixed crop hydroponic systems. *Proc. Plant Growth Reg. Soc.* 32: 133-140.

Edney, S.L., J.T. Richards, M.D. Sisko, N.C. Yorio, G.W. Stutte, and R.M. Wheeler. 2007. Mixed vs. monoculture hydroponic production of salad crops at three CO_2 concentrations. *Proc. 33rd PGRSA Annual Meeting*: 193-200.

Eraso, I., G.W. Stutte, O. Monje, S. Anderson, and R.D. Hickey. 2006. Sensitivity screening of radish seedlings to spacecraft VOCs. *Proc. Plant Growth Reg. Soc.* 32: 141.

Kim, H-H., R.M. Wheeler, J.C. Sager, G.D. Goins, and J.H. Norikane. 2006. Evaluation of lettuce growth using supplemental green light with read and blue light-emitting diodes in a controlled environment--A review of research at Kennedy Space Center. *Acta Hort.* 711:111-119.

Levine, L.H., P.A. Bisbee, J.T. Richards, M.N. Birmele, R.L. Prior, M. Perchonok, M. Dixon, N.C. Yorio, G.W. Stutte, and R. M. Wheeler. 2007. Quality characteristics of the radish grown under reduced atmospheric pressure. *Advances in Space Research* (in press).

Mathieu, J., R. Linker, L. Levine, L. Albright, A.J. Both, R. Spanswick, R. Wheeler, E. Wheeler, D. deVilliers, and R. Langhans. 2006. Evaluation of NICOLET model for simulation of short-term hydroponic lettuce growth and nitrate uptake. *Biosystems Engineering* 95(3):323-337.

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.

Richards, J.T., S.L. Edney, N.C. Yorio, G.W. Stutte, and R.M. Wheeler. 2006. Yields of salad crops grown under potential Lunar and Mars habitat environments: Effect of temperature and lighting. *SAE Tech. Paper* 2006-01-2029.

Richards, J.R., K.A. Corey, A.L. Paul, R.J. Ferl, R.M. Wheeler, and A.C. Schuerger. 2006. Exposure of Arabidopsis thaliana to hypobaric environments: Implications for low-pressure bioregenerative life support systems for human exploration missions and terraforming on Mars. *Astrobiology* 6(6):851-866.

Sager, J.C., G.W. Stutte, R.M. Wheeler, and N.C. Yorio. 2005. Advanced life support project: Crop experiments at Kennedy Space Center. In: Y. Tako (ed.) Proc. Int. Symp. Closed Habitation Experiments and Material Circulation Tech. Inst. Environ. Sci., Rokkasho, Japan. pp. 120-130.

Sager, J.C., J.H. Norikane, A.J. Both, and T.W. Tibbitts. 2005. Quality assurance for environment of plant growth facilities. *ASAE Paper* 054137.

Shevtsov, J., I. Eraso, G.W. Stutte. 2006. *Paecilomycels lilacinus* and *Fusarium verticilliodides* remove t-butanol from contaminated air. *SAE Tech. Paper* 2006-01-2150.

Stutte, G.W. 2006. Process and Product: Recirculating hydroponics and bioactive compounds in a controlled environment. *HortScience* 41: 526-530.

Stutte, G.W., I. Eraso, S. Anderson and R.D. Hickey. 2006. Bioactivity of volatile alcohols on the germination and growth of radish seedlings. *HortScience* 41(1): 108-112.

Stutte, G.W., O. Monje, R.D. Hatfield, A-L Paul, R.J. Ferl, and C.G. Simone. 2006. Microgravity effects on leaf morphology, cell structure, carbon metabolism and mRNA expression of dwarf wheat. *Planta* 224: 1038-1049

Stutte, G.W., I. Eraso and S. Matthews. 2007. Volatile ethanol affects germination and growth of lettuce, radish, soybean and wheat seeds. Proc. 33rd PGRSA Annual Meeting: 192

Wheeler, R.M. 2006. Potatoes for human exploration of space: Observations from NASA-sponsored controlled environment studies. *Potato Research* 49:67-90.

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:

Deirdre Hayes, Limerick University, Limerick, Ireland
Sarah Matthews, Limerick University, Limerick, Ireland
Joey Norikane, summer faculty, University of Kentucky
Hyeon-Hye Kim, consultant, University of Kentucky
Catherina O'Keefe, Limerick University, Ireland
Karen Downing, Limerick University, Ireland