

Project No and Title: NCERA-101 Controlled Environment Technology and Use

Period Covered: 04-2013 to 04-2014

Date Reporting: 06-June-2014

Annual Meeting: 12-April-2014 to 15-April-2014, University of Alaska, Fairbanks, Alaska

Participants:

Lars Aikala (Valoya Oy), Mark Blonquist (Apogee Inst.), A.J. Both (Rutgers Univ.), Keri Bouchard (Convicon), Bruce Bugbee (Utah State Univ.), Bobby Clegg (Syngenta), Eric Cook (Chena Hot Springs), Tricia Costello (Syngenta), Chris Currey (Iowa State Univ.), Matthieu de Carbonnel (Syngenta), Jay Dinwiddie (Syngenta), Nate DuRussel (Mich. State Univ.), Cecil Ellsworth (Univ. Alaska-Anchorage), Matthew Ezzo (EGC), Jonathan Frantz (Pioneer), Gary Gardner (Univ. Minn.), Barret Goodale (Chena Hot Springs), Celina Gómez (Purdue Univ.), Daniel Halldorf (Heliospectra), Alec Hay (Utah St. Univ.), Will Healy (Ball Hort), Ricardo Hernandez (Univ. Arizona), Chris Higgins (HortAmericas), Henry Imberti (Percival Scientific), Murat Kacira (Univ. Arizona), Ramesh Kanwar (Iowa State Univ.), Bernie Karl (Chena Hot Springs), Meriam Karlsson (Univ. Alaska-Fairbanks), Nick Klase (BML Horticulture), John Lea-Cox (Univ. Maryland), Mark Lefsrud (McGill Univ.), Joan Leonard (Ohio St. Univ.), Peter Ling (Ohio St. Univ.), Rod Madsen (Li-Cor), Gioia Massa (NASA KSC), Neil Mattson (Cornell Univ.), William Meng (Mich. State Univ.), Ken Meter (Crossroads Resource Center), Alicia Minzel (LiCor), Cary Mitchell (Purdue Univ.), Bob Morrow (Orbitec), Bill Mukanik (Convicon), Jake Nelson (Utah State Univ.), Genhua Niu (Texas AgriLife), Yosuke Okada (Chena Hot Springs), Derrick Oosterhuis (Univ. of Arkansas), Garrett Owen (Purdue Univ.), Dan Puckett (ACS), Sharon Reid (Convicon), Mark Romer (McGill Univ.), Erik Runkle (Mich. State Univ.), Carole Saravitz (NCSU Phytotron), Tim Shelford (Cornell Univ.), Gregg Short (GShort.com), Todd Smith (Duke Phytotron), Chase Snowden (Utah State Univ.), Christopher Steele (Heliospectra), Ryan Stewart (Brigham Young Univ.), Nancy Tarnai (Univ. Alaska-Fairbanks), Marc Theroux (Biochambers), Mark Thompson (DOW), Abhay Thosar (Philips Lighting), Marc van Iersel (Univ. Georgia), Sydney Wallace (Univ. Maryland), Jeff Werner (Chena Hot Springs), Martha Westphal (Univ. Alaska-Fairbanks), John Wierzchowski (EGC), Cameron Willingham (Univ. Alaska-Fairbanks), Dave Wilson (Stanford Univ.), Rachelle Winningham (Philips Lighting), Yang Yang (DOW), Zach Yohannes (Stanford Univ.), Neil Yorio (Lighting Science Group), H.P. Zhou (Syngenta).

Brief Summary of Minutes of Annual Meeting

Executive Officers: Chair: Henry Imberti (Percival Scientific), Vice-Chair: Meriam Karlsson (Univ. Alaska-Fairbanks), Secretary: Carole Saravitz (NCSU Phytotron), Past-Chair: Peter Ling (Ohio State University)

Henry Imberti called the meeting to order and asked if there were any announcements. Mark Lefsrud of McGill University announced that Montreal will be hosting the 2014 ASABE and CSBE | SCGAB Annual International Meeting from July 13 to 16, 2014.

Gioia Massa announced that the ASHS meeting will be in Orlando Florida July 28 to 31, 2014. At the meeting, there will be a colloquium on the "Importance of Light Quality for High Value Plant Products and also a workshop on LED lighting. Members of NCERA101 will be speaking at both the colloquium and workshop.

Administrator advisory report (Ramesh Kanwar). Ramesh welcomed the 74 attendees to the 2014 annual NCERA101 meeting. He has been the advisor for 17 years and is happy to see the dedication the group has toward this committee. He thanked Meriam Karlsson for organizing the meeting. Ramesh congratulated the group for preparing a very successful report for the midterm review. He commended the group for strong graduate student interest, participation from a wide audience including private industry, universities and federal agencies. With its strong international ties, the committee should look for opportunities around the world such as: using distance education to offer certificate programs for greenhouse managers in developing countries. The annual report for the committee is due in 60 days (on June 13) and should highlight meeting attendance, multidisciplinary (industry, fed agency, & university) collaborations, training of future professionals (our mentoring role) & diverse work of the group. Ramesh presented a PowerPoint from Experiment Station Directors and said it was available to anyone that is interested. Priorities should focus on promoting sustainability and adapting to climate change for food systems, energy and fiber and support for use of energy from renewable resources. A global leadership role in improving human health, and heightening environmental stewardship is also important.

NIFA (National Institute of Food and Agriculture) Representative Report (John Lea Cox). Dan Schmoltdt was not able to attend the meeting due to a travel ban. John Lea Cox presented a summary report. The Farm Bill was approved 2 months ago and John provided a copy of the summary report prepared by Mary Meyer (2013/2014 president of ASHS). SCRI will go through a 2 panel review. Dr. Sonny Ramaswamy, the new NIFA Director brings a fresh perspective to NIFA. It would be nice to get him to one of our meetings.

Membership Report (Mark Romer). This year marks the 39th annual meeting of the group and the first time meeting in Alaska. The group is very strong and we now have 167 official members. The official members are from 114 institutions, 35 US states, and 9 different countries. There is a net gain of 12 from last year and it is significantly from industry. We are getting more interest from different sectors of industry. Many were previously graduate students or previously had an academic position. On a sad note, one of our founding fathers, Art Spomer passed away July 25, 2013. Next year will be our 40th anniversary. Let's think of something special we can do to celebrate. As a component of next years meeting maybe we can do a tribute to the past 40 years and to the next 40 years. One suggestion Mark received was to give equal time to past memories and future promise.

Website Report (Carole Saravitz). Carole has been maintaining and updating the website. For new members, she reminded the group that the website moved to NC State University in 2010 and pointed out that the website could be found at controlledenvironment.org, NCR101.org and NCERA101.org. Not much has changed from last year, mainly just housekeeping. She suggested modernizing the design. The old format is well done, but dated. The page could easily be rearranged. She showed several of the current templates with an updated design.

Student Poster Competition (Jonathan Frantz). For the last few years, we have supported graduate students through subsidized meeting registration. This year registration was completely free for graduate students and last year, the registration fee was heavily subsidized. During this past year, a group worked together via email to discuss how we could further support graduate students. For future meeting hosts, we hope that registration can be free at domestic meetings. This can be done with the help of generous corporate sponsorships. For the last few years, we have also had a poster competition for graduate students and we are continuing the tradition with first place \$300, second \$200 and third receiving \$100. The next proposal is to provide travel grants. The target is 4 per domestic meeting, and 5 for international. The dollar amount depends upon the number of applicants. The goal is \$500 for domestic and \$1000 of international meetings. The funds will come from corporate sponsorship and past year's surplus. The process will begin with the student's advisor filling out an application that includes the student's CV, a letter of support from the advisor, and an abstract of the student's research submitted 3 to 4 months prior to the next meeting. Applications will go to Jonathan and he will select 3 or 4 others to help evaluate applications. The check would be cut from the Utah State account. Students would be expected to present a poster in the competition at a domestic meeting and explain their research.

Greenhouse Guidelines (AJ Both). The final version is not yet available, but the most recent version is in the meeting packet. The UK group has offered to pay for printing and is currently adding pictures before printing the high quality copies of the document. After it is printed, it will be distributed to our membership. The process is almost complete. Once they are available, the guidelines will also be down loaded to the website and then copies will be distributed as soon as possible. The Greenhouse Guideline Committee members are in the process of making the document into a formal peer-reviewed publication for in an open source journal, Plant Systems.

Instrument Package/Financial Report (Bruce Bugbee). The spectroradiometer has continued to be shipped around regularly in the past year, but there was no charge because we didn't need the funds. Four instrument packages are available for rental by members. Information about the instrument packages and how to rent them, is posted on the NCERA-101 website. We are now approaching \$25,000 in the treasury for the group. Options for investing our surplus funding are: to use funds to help graduate students with meeting expenses, purchase additional equipment such as handheld

spectroradiometer with a display monitor from Quibit systems or a reference anemometer or web based summarization of controlled environment (CE) wisdom.

Future meetings (Mark Romer).

Our next meeting will be a joint meeting with AERGC. AERGC is made up mainly of people who manage facilities. The joint meeting will be a chance to receive and share information between the 2 groups. Joan Leonard and Peter Ling will organize the meeting together. The meeting will be in Columbus, Ohio, but the group will also tour the Wooster campus. The meeting will be held **July 8 to 11, 2015**. The meeting will be dovetailed with AmericanHort's (formerly referred to as OFA) annual convention and trade show, Cultivate (formerly known as OFA short course) in Columbus, Ohio on July 11-14, 2015

International Meeting (Mark Romer). Mark Romer spoke about the planning of our 5th international meeting. Mark is not sure if it will be spring or fall, but the commitment to have the meeting has been renewed by CSIRO. The current proposal is to have the meeting in Canberra. Tony Agostino in Canberra and Denis Greer in Wagga Wagga will be the organizers in Australia. We will meet in Canberra and have first night registration and mixer, followed by 3 days of sessions. We will have 24 speakers and each of the 3 groups (NCERA101, UK-CEUG, and ACEWC) will work on one third of the talks for the scientific program. Following the talks, we will tour the local facilities in Canberra at the Australian Plant Phenomics Facility which has been completely renovated, the Canberra phytotron which celebrated 50 years in 2012 and then we would then go down to Wagga Wagga to see the National Wine And Grape Industry Centre (NWGIC) and Dennis Greer's lab. Two committees are organizing the international meeting: one headed by AJ Both is working on the scientific content and the other headed by Marc van Iersel is working on funding. The meeting themes proposed by the Australian group (ACEWC) are "The Growth Chamber of the Future" or "Advances in Controlled Environment Agriculture. AJ Both will bring any suggestions for a theme from our group to ACEWC. The funding committee consists of Marc van Iersel, Mark Lefsrud, Cheri Kubota, & Ray Wheeler. They haven't been able to do much yet because there is no program in place. They have identified several opportunities such as NSF & AFRI, but they have not been able to write proposals because they need to be able to explain the program. Marc would like to have a program in place this Fall so they can start submitting proposals during the next funding cycle

Future Meetings (Henry Imberti). Henry said Nicole Waterland from University of West Virginia said she would host sometime in the future, but he was not sure when. Carl Sams at The University of Tennessee was suggested as a host. Mark Romer suggested having an industry member organize a meeting.

Election of the New Secretary (Henry Imberti). Henry nominated Gioia Massa to be secretary for 2014/2105 and Mark Romer seconded the nomination. The group unanimously elected Gioia secretary. Henry passed the gavel to Meriam.

Mark Romer made a motion to adjourn and Gary Gardner seconded it. The Business Meeting was adjourned at approximately 2:14 PM.

Minutes respectfully submitted by Carole Saravitz

Accomplishments

(The complete station reports are available on the NCERA-101 website)

The University of Arkansas has investigated the effect of heat stress on *in vivo* pollen tube growth, changes in energy reserves and calcium-mediated oxidative status in the pistil. The conclusion was that the energy demands of growing pollen tubes could not be met under heat stress due to decreased source leaf activity, and a calcium-augmented antioxidant response in heat-stressed pistils that interferes with enzymatic superoxide production needed for normal pollen tube growth. A comparison of the physiological and biochemical responses of a thermosensitive cultivar (ST4554B2RF) from the US Cotton Belt and thermotolerant cultivar (VH260) from Pakistan, showed that maintaining a sufficient antioxidant enzyme pool prior to heat stress is an innate mechanism for coping with rapid leaf temperature increases that commonly occur under field conditions.

The University of Arkansas also conducted a diurnal study of pollen tube growth in the cotton pistil. Microclimate measurements included photosynthetically active radiation, relative humidity, and air temperature. Pistil measurements included surface temperature, pollen germination, and pollen tube growth through the style, fertilization efficiency, fertilized ovule number, and total number of ovules per ovary. Subtending leaf measurements included leaf temperature, photosynthesis, and stomatal conductance. Results showed that under high temperatures the first measureable pollen tube growth through the style was observed earlier in the day (1200 h) than under cooler conditions (1500 h). Also, high temperature resulted in slower pollen tube growth through the style (2.05 mm h^{-1}) relative to cooler conditions (3.35 mm h^{-1}). We concluded that diurnal pollen tube growth is exceptionally sensitive to high temperature.

At the University of Arkansas, growth chamber studies showed that there were considerable stress-related adjustments during anthesis. Ovaries from the day before flowering, during flowering, and the day after flowering were analyzed along with its subtending leaf for cell membrane damage, antioxidant, and carbohydrate changes. Membrane leakage indicated significant damage caused by the heat, but this effect decreased to that of the control by the fourth day, indicating an acclimation. Protein concentrations decreased with high temperature in the leaves, but not in the ovaries. The activity of antioxidant enzymes, peroxidase and glutathione reductase, decreased in

the stressed leaves compared to the ovaries during all stages of anthesis. Carbohydrate analysis indicated no differences amongst the leaves, but the ovaries had significant differences in fructose, sucrose, and starch concentrations during different stages of anthesis. High night temperature (30C compared to 24C) significantly increased leaf respiration, reduced, and decreased carbohydrates. In the flower pistil there was an increase in respiration and an accumulation of glucose, sucrose and starch indicating a perturbation in carbohydrate metabolism that contributes to poor fertilization and seed development. The result was increased boll abscission and decreased the weight of lint per seed, which would have decreased final lint yield. The overall result of high temperature is that available carbohydrate and energy levels will be reduced and may not be sufficient to satisfy all the plant's needs, resulting in poor pollen tube growth and fertilization, with increased boll shedding, fewer seeds per boll, less fiber per seed, and lower yields.

At the University of Arizona, methodology from a multi-camera based machine vision system was developed and evaluated to timely identify crop water stress as part of graduate student (D. Story) research project in the Kacira Lab. The developed methodology consisting of multiple variables determined the locality of the emerging water stress as good as visual stress detection with lettuce plants, dealing with the uncertainty of light intensities and incidents of shadows amongst the plant canopy in a greenhouse setting. A web based platform was also developed and implemented to serve as a decision support and management module performing as interface between the NASA Steckler Space Grant Program's Lunar Greenhouse (LGH) Prototype (as BLSS) with capabilities of real time data and system monitoring, data analysis, access point for operational and processed data, system alarms setting and monitoring, and inputs/discussions from system operators for improved management of the LGH system. The development of this web based platform also targeted future transfer and potential applications of decision support and production system monitoring to improve food production capabilities and resource utilization efficiency of Earth based CEA production systems.

The Kacira Lab designed, built and completed evaluating an off grid greenhouse system (OGGH) powered by solar energy as an alternative food production system for deployment in challenged regions which would not have steady and immediate access to resources for production. Polly Juang (MS Student) worked with cherry tomatoes grown in sand culture in the OGGH system and demonstrated that production yields from OGGH were comparable to that of the grid tied system (GCGH), and were 0.96 and 0.95 kg m⁻² week⁻¹, respectively. The research also determined that the integrated OGGH produced 19.8 MJ m⁻² with its PV power generation system while greenhouse system demanding 18.3 MJ m⁻² energy. Energy productivity of the OGGH was 85.6 kg MJ⁻¹.

At Kennedy Space Center (KSC), 'Outredgeous' red romaine lettuce was grown in the Veggie flight hardware as part of the payload verification test for the flight of this

hardware. The hardware validation test of Veggie on the international space station is scheduled to commence in April.

Controlled environment studies at KSC have shown that prolonged exposure to SE-CO₂ resulted in increased stomatal conductance and decreased water use efficiency by plants. Levels of CO₂ in space shuttle cabin typically range between 4000-6000 μmol mol⁻¹ and can exceed 10,000 μmol mol⁻¹ with large crews. In order to use plants for life support (i.e., O₂ and food production, CO₂ removal, water purification) it is imperative that we understand how plants respond to super-elevated CO₂ (SE-CO₂) (>5000 μmol mol⁻¹). To understand this phenomenon, we continued to grow plants in controlled environment chambers and expose them to varying levels of CO₂. Using molecular genetics and Next Generation Sequencing (NGS) tools we are trying to dissect the mechanism behind plant responses to SE-CO₂. At the same time we are also using reverse genetics tools, such as T-DNA insertional mutants, to answer specific questions related to starch metabolism, which could be a key aspect of plant's response to SE-CO₂.

At Kennedy Space Center, Growth Chambers are currently being used to characterize a range of plant dwarfing tools and procedures that could be applied to Advanced Life Support. The ability to dwarf standard crops will help meet volume and mass limitations of spaceflight and planetary exploration. The following tools and procedures are currently under consideration:

- Mechanical stimulation (e.g., thigmomorphogenesis, seismomorphogenesis)
- Atypical temperature profiles (e.g., dip/diff)
- Root restriction
- Pruning and training
- Genetic manipulations (e.g., FT constructs)

Researchers from the USDA/ARS and NASA are collaborating to evaluate a rapid-cycle crop breeding system as a mechanism for using tree fruit crops for Advanced Life Support. In the past, tree fruits have not been a serious consideration due to long juvenile phases, dormancy requirements, large canopy architectures, and low harvest indices. Controlled environment chambers are being used to evaluate the performance the FT transformed plums (*Prunus domestica*) under spaceflight relevant conditions.

University of Georgia has continued their testing of wireless sensor networks in commercial greenhouses and nurseries and found that soil moisture sensors can be very effective in automatically controlling irrigation. Growers see multiple benefits from these sensor networks, including water savings, shorter crop production cycles, less disease, and better quality. Based on estimates from the University of Maryland, implementation of these sensor networks by ornamental producers, assuming a 50% adoption rate, would result in annual water savings of 223 billion liters/year (enough for 400,000 U.S. households) and reduce N and P discharges by 282,000 kg N and 182,000 kg P per year (Majsztrik et al., 2013). We expect a commercial release of the sensor networks in summer 2014.

University of Georgia has developed an irrigation controller that can trigger irrigation based on soil moisture sensor readings and store the soil moisture data, as well as information on how often different plots get irrigated. Using an Arduino Uno microcontroller, we can build a system that can control irrigation in four separate plots for about \$40. The system can easily be scaled up to 14 plots using an Arduino Mega microcontroller (at a cost of \$90). Cost estimates do not include the needed soil moisture sensors or irrigation systems. Prototype systems have been running successfully at the University of Georgia and Purdue University.

At the Georgia Envirotron, automatic water-tension-sensor based irrigation in controlled environment growth chambers improved watering efficiency due to direct response to plants' water needs. Integration with data logging systems enhanced data collection and improved irrigation control.

The Georgia Envirotron is studying simultaneous measurement of greenhouse and ambient temperature and multi-level manipulation of ridge vents and evaporative cooling supplies data that can be used to analyze greenhouse cooling effectiveness. This analysis will then be used to improve greenhouse temperature control.

The Macdonald Campus of McGill University is continuing its research into controlled environments with work on the impact of biofuel heating systems with a focus on greenhouse heating using wood pellets with carbon dioxide utilization. The greenhouse heating research has resulted in the filing of a US provisional patent for the use of the exhaust gas from a wood pellet furnace to heat and use the CO₂ for improved production in the greenhouse. We are continuing this research and are working on design improvements to develop a commercial unit.

The Macdonald Campus of McGill University researchers are continuing with light emitting diodes research with industry collaboration from Urban Barns a company specializing in urban agriculture food production (lettuce and other leafy greens). This project is to determine the proper wavelengths and ratios of light emitting diodes to maximize production. This research is ongoing but has already resulted in a published paper confirming intercanopy lighting as an improved lighting system when compared to overhead LED or HPS systems. This research also found that at a 5:1 (red to blue) ratio of LED lights resulted in the maximum fruit production for greenhouse tomatoes but also led to an occurrence of powdery mildew on these plants prior to others as well as increased branching from the fruiting clusters of the plants.

The Macdonald Campus of McGill University researchers have begun the design and tests on two different greenhouses specifically a greenhouse designed for the tropics that uses water misting to create a natural ventilation loop and a northern greenhouse that maximizes natural solar light with supplemental LED lighting. Both of these designs are in the early stages of the patent process and full scale prototypes are projected to be built in the coming year.

At the University of Michigan, Qingwu (William) Meng and Erik Runkle performed experiments to better understand how red, far red, and blue light provided during the middle of the night influence flowering of daylength-sensitive crops. Plants were grown in research greenhouses under different ratios of red, far red, and blue light from LEDs, as well as under white light. In most crops, red with far red, with or without blue light, was the most effective at promoting flowering. Blue light alone was not effective at promoting flowering. We conclude that the addition of blue light to red and far-red lighting does not influence flowering for the crops studied.

Qingwu Meng and Erik Runkle worked with five commercial greenhouse growers to test the efficacy of a new commercial Philips LED “flowering” lamp for flowering applications. Growers in CA, IN, MI, and NJ received plants in January and grew them under LEDs that emitted red, white, and far-red light or under one or two other conventional lighting treatments. In most instances, flowering time under the LEDs was similar to that of plants grown under traditional light sources.

At the University of Michigan, Ryan Warner and Nathan DuRussel quantified the impact of temperature on crop timing and quality for the Divine series of seed-propagated New Guinea impatiens for both an early-season and late-season crop. While plants generally flowered earlier as temperature increased, the influence of temperature on days to flower varied widely among cultivars and one cultivar, ‘Divine Cherry Red’ flowered at a similar time across temperatures. This was a result of an increase in node number below the first flower at the higher temperatures.

Paul Fisher (Univ. of Florida), Erik Runkle and Matt Blanchard (Michigan St. Univ.) and John Erwin (Univ. of Minnesota) developed a Microsoft Excel spreadsheet, [FlowersOnTime](#) that allows users to predict the effect of modifying greenhouse temperature on crop production time. A user first selects among the 70+ floriculture crops (many of which are bedding plants) in the drop-down list, then specifies their typical finish crop time at a particular temperature. The model then predicts the effect of increasing or decreasing temperature at 2 °F intervals, assuming all other conditions are the same. Most of the crop models were based on data generated at Michigan State Univ. and the Univ. of Minnesota in controlled research greenhouses or growth chambers.

Erik Runkle and colleagues at Michigan State University and Sonali Padhye of Pan American Seed developed a [Wave® Smart Scheduling tool](#). This Excel program enables growers to predict time to first open flower for 15 Wave petunia varieties at specific average daily temperatures and daily light integrals. This tool allows growers to schedule specific petunia varieties on precise dates and help select varieties that flower uniformly under their environmental conditions.

Purdue University researchers are developing a combined LED lighting array / crop-stand gas-exchange cuvette / hydroponic culture system that will be a powerful tool allowing real-time optimization of light, CO₂, and temperature conditions at every

developmental stage of a small-statured crop stand. Instead of having to wait for entire crop-production cycles to be completed under fixed set points of these three environmental factors, a computer operator can quickly challenge photosynthetic rate responses whenever desired with incremental up/down tweaks of the growth environment and observe real-time photosynthetic rate responses. As growth-optimizing levels change with crop-development stage, adjustments can be applied one or more times daily. For high-energy inputs such as light, this tool has potential to define when such inputs are needed for productivity, and when they are not.

At Rutgers University, Ariel Martin (PhD, 2013) developed a decision support system (DSS) to manage the electricity generated by a 250 kW microturbine driven combined heat and power system installed at the EcoComplex Research and Demonstration Greenhouse. Using an hourly cycle and based on a simple crop growth model and information about electricity prices, the DSS determines optimum use of the generated electricity: onsite (for supplemental lighting of a tomato crop), export to the utility grid (for additional income), or a combination of the two.

ORBITEC is developing larger scale supplemental lighting systems for greenhouse productivity testing. These systems will be about 80ft² in area with multiple control zones and waveband options. They will be also used to investigate the impact of light quality on secondary plant metabolites.

ORBITEC is working with the Kennedy Space Center (KSC) to fly our Veggie plant growth system hardware. It is currently loaded aboard the Space-X Dragon Capsule and scheduled for flight at any time (after 2 scrubs so far). The ultimate goal is to supplement the ISS crew diet with fresh produce.

ORBITEC is also supporting KSC to design and fabricate the Advanced Plant Habitat system that will be used for plant research aboard the International Space Station. One of the subsystems ORBITEC is developing is the solid state lighting subsystem. When flown, this system will be the largest plant growth system put in space to date. It is expected to fly in 2015.

Cornell's Controlled Environment Agriculture (CEA) group trained three interns during summer 2013. Summer interns received instruction on several CEA topics, developed and conducted independent research projects on hydroponic crops, and took field trips to commercial greenhouse facilities.

Greenhouse water recirculation can lead to high salts accumulation. The Cornell group has addressed short term needs by developing salt management guidelines (i.e. threshold levels) for several common floriculture species. Results of this effort were published as a two article series in *Greenhouse Grower Magazine* and in *HortTechnology*. We are also using molecular techniques to learn more about processes that plants use to mitigate salt toxicity. Using petunia as a model floriculture species we conducted high throughput RNA sequencing to determine transcriptome level responses

to NaCl. This research will identify candidate genes/markers for selecting petunia varieties for tolerance to high salts.

While closed irrigation systems limit water pollution, most New York State greenhouse producers have not adopted these systems, in part, due to expensive costs of installation. Controlled release fertilizers (CRF) may represent a tool to reduce nutrient leaching in open irrigation systems. The Cornell group compared growth of bedding plants, poinsettias, and garden mums in response to different rates of CRF and conventional liquid fertilizers (LF). We found that CRF adoption at the label medium to high rate led to plant growth equal to conventional LF in all but the most vigorous plants. CRFs applied at the medium to high rate led to a reduction in nitrogen and phosphorus runoff by five- to ten-fold compared with LF.

Impacts

- The NCERA-101 group held its annual meeting at University of Alaska, Fairbanks, Alaska from April 12-to 15, 2014.
- The NCERA-101 group has 167 members in 35 US states and 9 countries. The membership has steadily increased since NCERA101's inception in 1976 (Appendix B in the minutes of the 2014 business meeting).
- A student poster competition was organized at the annual meeting. Six graduate students presented posters and 3 participated in the competition.
- The NCERA-101 group is working with the UK and Australasian controlled environment groups in developing guidelines for reporting environmental conditions in greenhouses. The guidelines are close to completion and will be finalized this year. Two sets of reporting guidelines for growth chambers and tissue culture facilities, have already been completed, in collaboration with the controlled environment groups in UK and Australia, and are available on the website.
- The NCERA-101 group maintains and regularly updates a website. The website provides information about current and past annual meetings, minutes of the business meetings, the instrument packages, membership lists, publications lists, annual station reports, winners of student poster competitions, reporting guidelines for growth chambers and tissue culture facilities, and other topics relevant to the group.
- The NCERA-101 group maintains four instrument packages. These packages are available for rental by members as calibration references.

- The NCERA-101 group is working with the AERGC group (Association Education and Research Greenhouse Curators) to plan a joint annual meeting in 2015.
- NCERA-101 is working with the UK and Australasian controlled environment groups to plan an international meeting for 2016 in Australia.
- Controlled environment studies at the University of Arkansas have shown that high night temperatures may be more important than high day temperatures for effects on the growth and yield development of cotton. Both high day and high night heat stresses decrease carbohydrates and energy levels in the flower, causing decreased pollen tube growth and fewer ovules being fertilized, resulting in fewer seeds per ovary and decrease cotton fiber quality.
- UA-CEAC organized the 13th Greenhouse Crop Production and Engineering Design Short Course (April 9-12, 2013) with ~100 participants. Hands-on workshops were given to attendees during the short course. These workshops included demonstrating vegetable grafting techniques, hydroponics crop production and systems basics, greenhouse sensors and instrumentation basics with theory and practical use.
- Rorabaugh, Lewis & Giacomelli organized the 3rd Annual Intensive Greenhouse Tomato and Lettuce Crop Production Short Course (January 5-12, 2014) with 32 participants. The program included morning classroom lectures and afternoon hands-on practice with crops.
- Two one-day workshops of 'Arizona Strawberry Day' were held (December 7, 2013 and February 22, 2014) at the University of Arizona attracting 62 participants from states of AZ, CA, CO, NM, OH, OR, WA and Mexico.
- At the University of Arizona, multi-camera, variable based machine vision system was developed. The methodology is a unique technology advancement which can be suited for real-time monitoring of crops, crop diagnostics, and stress locality detection in controlled environments based food production systems, potentially improving production quality and crop management. The system can also be used as part of a greenhouse based plant phenotyping system significantly reducing the time it takes to collect and analyze the data and laborious work required for data collection for phenotyping.
- Off-grid greenhouse food production system (with 1500 m² greenhouse foot print) generated tomato produce yields comparable to those from a grid-tied system while eliminating the need of energy from the grid (18.3 MJ m⁻²),

contributing to greening the greenhouse food production system, eliminating substantial amount of CO₂ emissions was developed at the University of Arizona.

- The Veggie Vegetable production system built by ORBITEC has been tested at Kennedy Space Center (KSC) for flight and will soon be installed on the International Space Station (ISS). The hardware validation test for Veggie will be conducted with red romaine lettuce, which the crew will harvest, freeze, and return to Earth for food safety analysis.
- At University of Georgia, Wireless sensor networks can effectively control irrigation in commercial nurseries and greenhouses, based on soil moisture sensor readings. Growers have seen shorter production cycles, less disease, and better quality, along with large water savings. Implementation of this technology in greenhouses and nurseries will benefit both growers and society. Societal benefits include reduced water use and a decrease in agrochemical runoff.
- At the Georgia Envirotron, development of an automatic watering system with logging of water applications provides data essential for experiment design development. Multiple configurations have improved experiment options to meet researchers' goals and requirements.
- At the Georgia Envirotron, improved greenhouse temperature control and cooling management are needed in warm and humid climatic zones. The low efficiency of the current evaporative cooling system shows the need to investigate more effective methods of greenhouse temperature control.
- The McGill University has been researching in two target areas: plant growth in controlled environments focusing on identifying the potential of greenhouse heating using wood pellets and investigating light emitting diodes for plant production. We have filed three provisional patents: 1) a wood pellet furnace exhaust gas enrichment system for greenhouses, 2) a design for a tropical greenhouse and 3) a northern Canadian greenhouse design. We are working with Urban Barns on an improved LED lighting system for urban agricultural hydroponic lettuce production and in addition have completed a rainwater harvesting system for greenhouse irrigation.
- Growers nationwide are using the Michigan State University crop scheduling tools to more precisely plan the production of their crops and help weigh trade-offs between cropping time and energy inputs. For example, Nash Greenhouse in Kalamazoo used the Wave Smart Scheduling tool to schedule all of their Wave petunias in 2013, which occupied about half of their 1.1 million ft² of greenhouse

space. Research-based information on temperature and energy consumption was also disseminated through the [Greenhouse Energy Cost Reduction Strategies](#) website, trade magazine articles on temperature, and electronic newsletters.

- The commercial LEDs tested in Michigan State University research and commercial trials consume 18 W and can replace 100- or 150-W incandescent lamps, reducing energy load and consumption by 82 to 88%. In addition, the LEDs can last over 20 times longer than incandescent bulbs. Depending on electricity prices, usage, and utility rebates, LEDs can be a more economical way to deliver long-day lighting to ornamental crops.
- At Purdue University, intracanopy lighting with LEDs allows significant power and energy savings for greenhouse high-wire tomato supplemental lighting compared to traditional overhead lighting with hot light sources because LEDs are cool enough to be placed close to photosynthetic tissues without overheating them. Thus, adequate photon fluxes of highly efficient wavelengths can be applied from within the foliar canopy of an otherwise overhead shaded crop with very low power density and thus significant electrical energy savings.
- At Rutgers University, extension personnel and commercial greenhouse growers have been exposed to research and outreach efforts through presentations, publications and evaluation tools. It is estimated that this information has led to proper greenhouse designs and updated operational strategies that saved an average sized (1-acre) greenhouse business a total of \$20,000 in operating and maintenance costs annually. Greenhouse energy conservation presentations and written materials have been prepared and delivered to local, regional, and national audiences. Growers who implemented the information resulting from our research and outreach materials have been able to realize energy savings between 5 and 30%.
- ORBITEC is advancing the technology of controlled environment systems to meet the performance and quality needs of long duration space applications. Some of this technology may be transferable and scalable to protected agriculture systems.
- ORBITEC is developing LED lighting configurations and control strategies that provide increased lighting system utility in addition to increased operating efficiency.
- ORBITEC is using its space biology controlled environment work to spark interest in high school and college students in protected agriculture technology and STEM.

- At Cornell University, four years of experiments have been conducted to compare the production of spring bedding plants and hanging baskets in unheated high-tunnels as compared to heated greenhouse environments. Several cold tolerant bedding plant crops (such as pansy, petunia, snapdragon, and dianthus) seem to be well suited to this production method, which yields substantial savings in energy and capital expenditures as compared to traditional heated greenhouse production.
- At Cornell University, a subject of on-going research is strategies to fertilize vegetable and herb transplants organically. A comparison of several different organic substrates was conducted both on-campus and by 14 grower collaborators. Results, which have been shared with 1,000+ growers by presentations and newsletter articles are providing crucial information to help meet the needs of the expanding market for organic plants and produce in New York State and the Northeast.

Publications

NCERA 101 Member Publications

In addition to the efforts described above, the NCERA 101 group reported 115 publications. The publication list below is compiled from the NCERA-101 station reports, and does not include publications from members not submitting reports. In addition to the publications listed here, the NCERA-101 members reported numerous presentations at scientific meetings, workshops, grower conferences, educational outreach, and informational public events.

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