Project No and Title: NCERA-101 Controlled Environment Technology and Use
Period Covered: 07-2015 to 09-2016
Date Reporting: 14-November-2016
Annual Meeting: September 18-23, 2016

NCERA Meeting Participants:
Tony Agostino (CSIRO), Jonathan Allred (Cornell Univ.), Stephen Andrews (Univ. of Cambridge), Mark Blonquist (Apogee Inst), A.J. Both (Rutgers Univ.), Keri Bouchard (Conviron), Bruce Bugbee (Utah State Univ.), Christopher Choi (Univ. Wisconsin), Sruti Das Choudhury (Univ. Nebraska-Lincoln), Joshua Craver (Purdue Univ.), Mike Dixon (Univ. Guelph), Yurij Duda (Argus), Gary Gardner (Univ. Minn.), Dennis Greer (Charles Sturt Univ.), Kale Harbick (Cornell Univ.), Royal Heins (Mich. State Univ.), Ricardo Hernández (NCSU), Henry Imberti (Percival Scientific), Ramesh Kanwar (Iowa State Univ.), Rob Kerslake (Kerslake & Assoc.), Molly Kreiser (Univ. Minnesota), Chieri Kubota (Univ. Arizona), Jason Lanoue (Univ. Guelph), John Lea-Cox (Univ. Maryland), Mark Lefsrud (McGill Univ.), Joan Leonard (Ohio State Univ.), Peter Ling (Ohio State Univ.), Roberto Lopez (Mich. State Univ.), Gioia Massa (NASA KSC), Anastasios Mazis (Univ. Nebraska-Lincoln), Matthew Mickens (NASA KSC), Sarah Mills (West Virginia Univ.), Cary Mitchell (Purdue Univ.), Sergio Moroni (Charles Sturt Univ.), Keach Murakami (Univ. of Tokyo), Hendrik Poorter (Forchungszentrum Jülich), Sharon Reid (Conviron), Mark Romer (McGill Univ.), Erik Runkle (Mich. State Univ.), Carole Saravitz (NCSU Phytotron), Toshio Shibuya (Osaka Prefecture Univ.), Christopher Steele (Heliospectra), Gary Stutte (NASA KSC), Marc Theroux (Biochambers), Michael Turner (Univ. Sydney), Raymond Wheeler ((NASA KSC), John Wierzchowski (EGC), Ying Zhang (Univ. Arizona)

Executive Officers:
Chair: Carole Saravitz (NCSU Phytotron), Vice-Chair: Gioia Massa (NASA KSC), Secretary: Bob Morrow (ORBITEC), Past-Chair: Meriam Karlsson (Univ. Alaska-Fairbanks)

Meeting Background:

The 2016 meeting was the 5th International Controlled Environment Conference and held in combination with the Australian Plant Phenomics Facility Conference. It was held in Canberra, Australia, September 18-23rd. See AusPheno 2016 Conference program: http://www.controlledenvironments.org/minutes/2016/Conference Program.pdf

Brief Summary of the Minutes of the 2016 NCERA-101 Business meeting

Minutes for 2016 NCERA-101 Business Meeting
Canberra Australia, Tuesday, September 20, 2016

Meeting opened at 5:12 PM

Sign-up sheet circulated – list of attendees provided above.

Business Meeting Agenda approved.

Announcement of Other Relevant Conferences

Ray Wheeler brought up the 2016 Annual American Society of Gravitation and Space Research (ASGSR) meeting. Mentioned that this was the venue where NASA KSC would talk about the Advanced Plant Habitat for ISS. Identified himself as a point of contact. Bruce Bugbee asked if that group has continued to meet annually and Ray confirmed.

Gary Stutte mentioned the 2017 meeting of the American Council for Medicinally Active Plants that will meet June 20-23 at Clemson University in South Carolina. This is a venue for medicinal plants in controlled environments. There will be a session devoted to controlled environments. Gary Stutte identified himself as point of contact.

Erik Runkle mentioned the Greensys 2017 International Symposium on New Technologies for Environment Control, Energy-Saving and Crop Production in Greenhouse and Plant Factory that will be held Aug. 20-24 2017 in Beijing China. Abstracts due Nov 1.

Joan Leonard mentioned Association of Education and Research Greenhouse Curators (AERGC) that will be held at Iowa State University the 1st week of July 2017.

Administrative Advisors Report- Ramesh Kanwar

Dr. Kanwar provided a brief report. Thanked all who travelled here to participate. Said that the NCERA-101 group was a good professional family. Provided congratulations for a successful meeting. Said we should explore Asia for future meetings as there are more funding opportunities for meeting in Asia. Lots of activities there and opportunities. Presented a reminder that minutes of this meeting need to be on National Information Management and Support System (NIMSS) by November 19th. Also we need to look at who is serving next (which is on agenda). Suggested we look at unsolicited joint grants with CSIRO. Looked at a nominating committee for the NCR Directors award. Will volunteer himself to nominate us. Said that Dan Schmolt from USDA is still involved and helps us directly.

Approval of 2015 Minutes- Gioia Massa

Jon Allred moved that Minutes of the 2015 NCERA-101 Business Meeting be approved. Bruce Bugbee seconded and the minutes were approved.

Membership report – Mark Romer

Mark mentioned that NCERA-101 started international meetings 16 years and that this is our 5th. Mentioned he was very grateful to Tony Agostino and the crew here in Australia for

organizing an excellent meeting. Said we have also had considerable support within our group with kudos to the Scientific Committee and Funding Committee. He was very proud of the efforts of the funding group who obtained a USDA-NIFA-AFRI grant which gave many students and members the opportunity to attend.

Mark presented the annual membership summary and indicated that our numbers remain constant at 167 members. Very diverse group from 35 US states and 11 countries. Mark also noted that the membership list does not include students as members but they continue to be very active. Students get added as members when they receive their diplomas. New institutions- Said there is continued interest in industry members. Provided thanks to the industry members who contribute to the group.

Mark noted the passing of one of our original members, Dr Jack Downs, on Oct 28, 2015. Dr Downs was very active since joining the group in 1979 and was awarded the Significant Contributor award in 2002.

Website Report- Carole Saravitz

Stated that the NCERA-101 website hasn't really changed very much. Hoping to move it into WordPress in the coming year which will allow the involvement of a few other people in working on the website. She said it needs a big facelift and she will be working to try and get it to another level. She also said to think about adding interesting and updated publications. These can be sent to her. Suggestions were solicited and there were none. She hopes to have updates by next meeting.

Travel Awards

Chieri and A.J. Both were thanked for making the Travel Awards possible. Chieri stated that the biggest contributor was Dan Schmolt at the USDA. He helped us expedite the process. Said we should continue to form a strong connection with AFRI who is promoting conferences. Thanked Mark Romer for making it work and keeping us all in line.

Greenhouse Guidelines Report - A.J. Both

Hoped that everyone got a copy of the final document. Stated that he has 2000 copies to distribute. Published the guidelines in Plant Methods journal. This is open access, a way of publicly having the guidelines available. He also wanted a document to distribute to help people in their institutions and make people aware, which had a cost involved. The Executive Committee approved printing and shipping costs for this. The next step is to distribute the document in North America. He hopes NCERA-101 can rely on commercial partners to help with shipping costs. In the past, 50 copies were sent to one representative at an institution. Also, asked how many copies the membership need or want. He was asked if a PDF version was available and he said not yet from English partners, but that he made his own copy. Stephen

Andrews said he will make a point to get the PDF to A.J. Topic of tracking guideline downloads on website was brought up but was rejected due to need and available time. The topic of a brochure was brought up, similar to Minimum Reporting Guidelines brochure. A.J. aid we don't currently have them but solicited a volunteer to put one together. Topic of giving one copy each to the AERGC members who are not industry was raised. Bruce B. thought it would further elevate our profile with that group and Mark R. stated that this would be following our mandate. It was also brought up that the American Society of Horticultural Sciences and the American Society of Agricultural and Biological Engineers are other groups that work with greenhouses. Jon Allred stated that a PDF is easiest way to do a mass distribution, that we can do a highlight piece for the website. A.J. thanked everyone for input and solicited further comments or suggestions.

Instrument Package and Financial Report – Bruce Bugbee

Bruce stated that the NCERA-101 is financially healthy, with about $20K in the treasury. He stated we funded five students at about $1000 each and paid for printing. Therefore we found ways to invest our resources. He said we started an instrument trading exchange but the treasury has grown and suggested that we continue to fund students and invest in dissemination of knowledge in controlled environments. The meeting next year is in a more expensive location and we were about to invest some money in that. In regards to the instrument package, he has stated that instruments have got better so the package is less necessary and the instruments get older each year. Cary Mitchell said that since industry is a major source of funds we want to keep encouraging that and acknowledge them. Bruce stated that money comes from annual meeting and that extra from industry goes into the treasury. Bruce stated that upgrades to the instrument package were not generally met with great enthusiasm. We could consider addition of calibration instruments.

Future Meetings-

The 2017 meeting will be held in California. On behalf of Dave Bubenheim – the NASA Ames Research Center has been working since last summer in nailing down the annual meeting. It will be held at Asilomar in Monterey, California – an old retreat. The dates will be April 9-12. It will be slightly different as the facility will take $ for rooms and food in one daily ticket. The organizers are hoping that sponsors will cover the rest of costs for that meeting. The organizers are working on those details and covering deposits from the NCERA-101 account. They are asking the group to book early since if we don't meet our room block we will be in trouble. Attendees should book as soon as the notice comes out. Carole Saravitz is set for NC State and Duke to host the 2018 meeting. It will be the group's 50th anniversary. More details will be provided at the next meeting. Venues in downtown Raleigh are being looked at and dates in March or April being considered. Volunteers for the 2019 Meeting were solicited. Mark Lefsrud suggested McGill University in Montreal. Chieri Kubota said the University of Arizona was

interested in potentially hosting an International meeting in 2021. No dates yet. Murat Kacira would lead that meeting. Carole suggested that the UK and Australian groups check with their membership to see how they feel about meeting in 2021 in Arizona.

Elections of Future Secretary

Carole Saravitz nominated Mark Lefsrud as Secretary. Gioia Massa seconded the nomination. There were no objections and Mark was approved as the incoming Secretary. Congratulations Mark.

New Business

Peter Ling asked the first 1st time attendees to introduce themselves.

Meeting Adjourned 6:15PM

-Minutes respectfully submitted by Bob Morrow.

Accomplishments
(The complete station reports are available on the NCERA-101 website http://www.controlledenvironments.org/station_reports.htm)

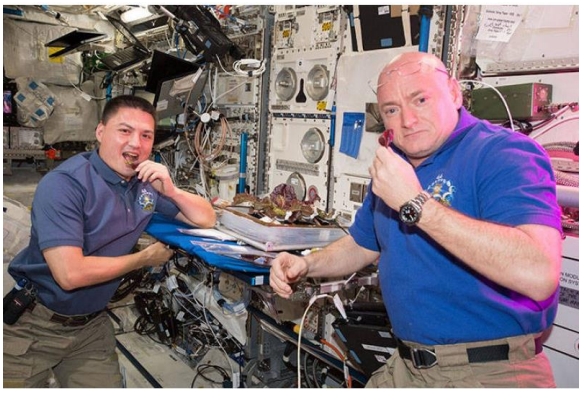
The University of Georgia has developed a control system for LED lights that automatically adapts to changing light levels, providing more light, when there is little sun light and dimming as there is more sunlight. To the best of our knowledge, this is the first lighting control system that controls LED lights based on the amount of sunlight that reaches the crop. The system has been tested with multiple crops and has shown to be greatly reduce power requirements for supplemental lighting. We expect that implementation of this technology in greenhouses will give growers better control over crop growth and will reduce electricity costs. The system also has great value for research facilities, since it can reduce experimental variability induced by varying light levels.

Our work on spectral effects on photosynthetic efficiency has clearly shown that far-red light can increase photosynthetic light use efficiency of crops that are grown with LEDs as sole-source lighting. The effects of far-red light are greater when red/blue LEDs are used than when white LEDs are used, presumably because white LEDs already provide some far-red light. These findings have important implications for the design of LED grow lights, if they are intended for use as sole-source lights. Including far-red LEDs in such light allows plants to use the provided light more efficiently.

Michigan State. M.S. student Brian Poel and Erik Runkle grew seedlings in greenhouses under four different Philips toplighting LED modules or under high-pressure sodium lamps at the same light intensity and temperature. Generally, plant quality attributes (e.g., stem length, leaf area, and weight) were similar, suggesting that light quality has relatively little effect on plant growth

when supplementing sunlight. Ph.D. student Yujin Park evaluated growth of ornamental seedlings under blue light and different intensities of red and far-red radiation in a refrigerated growth chamber. The inclusion of far red in the radiation spectrum increased leaf expansion, resulting in an increase in whole-plant photosynthesis. Significant effort went into planning the 8th International Symposium on Light in Horticulture, held in East Lansing, MI from May 22 to 26, 2016. This symposium was held in coordination with the International Society for Horticultural Science and was sponsored by 25 lighting, horticulture, or agricultural companies including several NCERA-101 industry members. M.S. student QiuXia Chen and Ryan Warner evaluated a *Petunia axillaris* × *P. exserta* recombinant inbred line population for numerous crop growth and quality traits under a range of temperatures. Quantitative trait loci (QTL) were identified for all traits. Some of these QTL were robust across the temperature range while others were temperature specific.

Kennedy Space Center. Gioia Massa oversaw the "validation" testing with Veggie plant growth systems on the International Space Station (ISS) last spring. Veggie has come a long way from Bob Morrow's back of the envelope concepts in the mid-1990s to actually growing plants (red romaine lettuce) on the ISS in 2014!



NASA astronauts Kjell Lindgren and Scott Kelly on the International Space Station eating lettuce plants grown in the Veggie plant growth system.

Veggie crop varieties of red romaine lettuce and Chinese cabbage were planted in the White House Kitchen Garden becoming part of a tradition the First Lady began in 2009 to inspire children to develop healthier eating habits. Gioia also received a 3-yr NASA grant to conduct the first official plant testing with Veggie (with leafy greens and dwarf tomato). 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 at KSC is a new scientist with our group who has been running the ground studies as we prepare for flight.

We completed a series of tests to compare dwarf tomato and pepper varieties as possible space crops, and LaShelle Spencer and Mary Hummerick deserve much of the credit for this

work. Fruits from the various cultivars were sent to NASA Johnson Space Center for sensory evaluation (taste testing). The overall winners were cv. Red Robin tomato and cv. Pompeii pepper (Fig. 3).

Ani Dixit in our group completed his testing with *Arabidopsis* plants grown under elevated and super-elevated CO_2 (400, 1500, 4000 and 8000 ppm). Transcriptome analysis of the plants showed the various secondary metabolites, including lignin related genes, are up-regulated in plants grown for 30 days at super-elevated CO_2. We are still pondering these findings.

Tom Graham completed a series of red-blue spectral quality tests with seedlings of tomato, pepper, soybean, cucumber, snow pea, and radish. Like many others in NCERA-101, we are seeing a general effect of reduced stem or hypocotyl growth with more blue in the spectrum. But similar to our stalwart colleagues, Ricardo Hernandez and Chieri Kubota, we saw a peculiar increase in elongation under pure blue (~450 nm) light. In looking back through John Sager's phytochrome photostationary state papers, we think some species see the pure blue light as a "far-red" like source, even though cryptochrome signals are likely saturated.

Matt Mickens has initiated growth comparisons of lettuce, and under white LEDs supplemented with red (635 nm), blue (460 nm), green (525 nm), and far red (745 nm) LEDs. A sixth treatment is using a Heliospectra light fixture with LEDs at 425, 525, 660, and 733 nm. The white LEDs are about 2800 K color temp. Next year's report should have full results. An invaluable member of the team was our summer intern Emilie Skoog from USC. If that name looks familiar, yes, Folke was one of her relatives!

Orbital Technologies Corporation (ORBITEC) is working toward the development of Exploration Life Support Salad Crop production as an early stage implementation of hybrid life support systems (combination of bioregenerative and physical-chemical life support technologies). ORBITEC continues to work with the Kennedy Space Center (KSC) to support the Veggie plant growth system hardware that is on-board the ISS. Currently, Veggie has been used to grow two crops of lettuce and one crop of Zinnias, and to conduct multiple experiments such as APEX-3. The Veggie team was able to obtain clearance from NASA to allow ISS crews to consume lettuce produced in the Veggie hardware. A second Veggie unit is planned for the ISS next year.

ORBITEC also continues to support KSC in the development of the Plant Habitat system that will be used for plant research aboard the International Space Station. When flown, this system will be the largest plant growth system put in space to date. It is expected to fly in 2017. The Plant Habitat flight units are currently undergoing testing.

ORBITEC continues to work with Commercial Crew Integration Capabilities partners for development of human Life Support and Thermal Control systems.

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 combined with carbon dioxide enrichment. This greenhouse heating research has resulted in the filing of a second provisional patent for the removal of

particulate matter from the exhaust gas, through the addition of an electrostatic and traditional cyclones that allows for extended operation of the traditional air filter. This design allows for the soot free exhaust gas to then be treated in the catalytic system and used to heat and provide CO_2 for improved production in the greenhouse. We are continuing this research and are working on design improvements to develop a commercial unit.

We are continuing our light emitting diode research. This project is to determine the proper wavelengths and ratios of light emitting diodes to maximize production. This research is ongoing, but we have begun to add in amber LEDs to the red and blue mixture with improved production of lettuce plants.

Finally, we are continuing to build and test on two different greenhouses. More 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. A second tropical greenhouse was completed in Barbados with very strong results during the misting operation. The northern greenhouse is still in the construction phase but we have begun to grow plants in the unit as an initial proof of concept. Full results are expected in the coming year.

The University of Arizona - As part of the SCRI vegetable grafting project funded by USDA, Dr. Kubota organized two international field trips to Asia (Taiwan and Japan) in August 2015 and Europe (Italy) in March 2016. A total of 23 participants from US industry and academia had visited commercial grafting nurseries to see their technologies of controlled environment and automation, including indoor plant production system and grafting robot. Trip reports are available at http://www.vegetablegrafting.org/resources/solanaceae/prepare-solanaceae/publications-and-presentations/.

In collaboration with an industrial partner, Kacira Lab evaluated a unique greenhouse design incorporating a spectral separation film for enabling PAR for crop and harvesting NIR for potential energy production while demonstrating production of acceptable yield and maintaining quality with lettuce crops.

Kacira Lab developed and validated computational fluid dynamics models capable of providing detailed information on climate uniformity, within several hours of computational time compared to months of experimental and numerical analysis, saving costs and labor required, offering design recommendations for industrial partners using multi-tier based vertical farm systems. Kacira Lab further enhanced the novel multi-wavelength based optical density sensors, for algae biomass growth and health monitoring in real-time. The sensor unit enabled autonomous system operations compared to traditional lab spectrofluorometers requiring several hours to make measurements and interpret the results for decision making and system operation with indoor or outdoor based microalgae production systems. A full U.S. patent has been filed for the sensor unit.

UA CEAC organized the 15th Greenhouse Crop Production and Engineering Design Short Course (March 22-24, 2016) with 70 participants. Hands-on workshops were given to attendees during the short course. These workshops included demonstrating hydroponics crop production and systems basics, greenhouse sensors and instrumentation basics with theory and practical use.

An online non-credit professional course 'Greenhouse Plant Physiology and Technology' was offered in August - October, 2015 (9 weeks, 25 enrollment). They also organized and hosted National Greenhouse Manufacturers Association (NGMA) Annual Meeting tour at UA-CEAC which included professional interaction and introduction of all CEA students with the 50 companies represented. April 11th, Tucson, AZ.

Three graduate students (5 MS) were graduated with degrees with focus on Controlled Environment Agriculture.

Rutgers University continued to evaluate a variety of lamps for light output, light distribution and power consumption using our 2-meter integrating sphere and a small dark room. A variety of outreach presentations on greenhouse operation and energy consumption have been delivered at several local and out-of-state venues. A variety of publications were completed, including the long-awaited "Guidelines for measuring and reporting environmental parameters for experiments in greenhouses" (as a scientific paper and as a stand-alone publication).

Percival installed the first controlled environment inside the Enviratron building located at the Iowa State University Ag Engineering and Agronomy Research Farm. In a separate project with Iowa State University, twenty large walk-in Percival chambers will be used in a state of the art bioscience facility for advanced teaching and research. The chambers will be shared among several departments and expose students to applications requiring controlled environments.

Percival was recognized for its commitment to plant research around the globe by receiving the President's "E" Award for Exports. Percival chambers can be found in 79 different countries, aiding researchers worldwide in a broad spectrum of projects using precisely controlled conditions.

Total grow lights - Testing at West Virginia University under Dr. Youyoun Moon has been conducted over the past two years with TotalGrow Lights along with various other grow light sources with several crops. HPS, metal halide, several LEDS, induction and LEP have been tested at different intensities over diverse crops, including tomatoes, basil, lettuce, kale, and petunias, in sole source environments. The results have provided strong support for the value of the breadth and spectral emphases of the TotalGrow Broad Grow Spectrum. As Dr. Moon reports, "All plants we have tested looked healthier under TotalGrow lighting and used far less energy than the competing light sources."

Impacts

- The NCERA-101 group held its annual meeting (and 5th International Controlled Environment Conference) in combination with the Australian Plant Phenomics Facility Conference in Canberra, Australia, September 18-23rd, 2016. Final meeting attendance was 160 persons.
- The NCERA-101 group has 167 members from 118 institutions, representing 35 states and 11 countries. The membership has steadily increased since NCERA-101's inception in 1976.
- A total of 13 graduate students attended the meeting. All North American graduate students were supported by USDA-NIFA-AFRI funding and participated by presenting conference talks or poster displays.
- 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.
- Electricity costs for photosynthetic lighting make plant production in controlled environments very expensive. The adaptive lighting system, developed in the Horticultural Physiology Lab at the University of Georgia, can greatly reduce energy use by automatically dimming the lights in response to increasing sun light. The technology is easy and cheap to implement and thus has a very quick return on investment.
- Many commercial LED grow lights use red and blue or white light. Research in the Horticultural Physiology Lab at the University of Georgia has shown that adding far-red light allows plants to use the provided light more efficiently. Adding far-red light to red/blue or white LED grow lights that are intended to be used as sole source lighting (*i.e.* indoor production) can thus increase photosynthesis and the overall energy efficiency of controlled environment production systems.
- Although there were few growth differences under greenhouse supplemental lighting from LEDs or high-pressure sodium lamps, the LEDs consumed less than half the amount of electricity. Thus, the potential energy savings can be substantial for commercial greenhouse operations that transition to LEDs.
- Preliminary research indicates that inclusion of far-red radiation in sole-source lighting can increase quality attributes in some crops by increasing leaf size, which

subsequently increases radiation capture and plant biomass. In some crops, the inclusion of far red can also accelerate subsequent flowering. Both of these crop responses can increase crop value and thus, the price growers receive compared with greenhouse-grown plants.

- Identifying QTL for important crop timing and quality traits aids discovery of genes underlying those traits, which will facilitate breeding efforts to develop new varieties that can be produced with reduced energy and labor inputs.
- 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. NASA and ORBITEC are planning to build an even larger (0.2 m^2), more highly controlled plant research chamber called the Advanced Plant Habitat, or APH. Hopefully we can keep the momentum.
- In collaboration with Fairchild Tropical Botanic Gardens in Miami, a school challenge was developed, which 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. 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. Fairchild Gardens plans to continue and expand this program with help from a NASA grant to informal learning institutes that they were awarded.
- 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. We are also developing LED lighting configurations and control strategies for plant and human lighting applications to provide increased lighting system utility in addition to increased operating efficiency.
- ORBITEC is using its space biology controlled environment work and human life support work to spark interest in high school and college students in controlled environment technology and STEM.
- The biomass heating group at McGill University has been trying to identify methods to utilize both the heat and carbon dioxide that result from the combustion process. A second challenge of this research has been to develop a method to remove the soot from the exhaust gas stream. We have filed a patent that describes our ability to remove the soot and allow for a cleaner exhaust gas before conversion and removal of the noxious gases with the catalytic conversion system. We are currently testing the unit and hope to begin testing in a commercial greenhouse in the coming year.

- Light emitting diodes are slowly replacing all supplemental lighting systems in greenhouses, growth chambers and urban agricultural systems. Our research has been to determine the optimum wavelength of light for plant production and we have begun to alter light composition by adding amber wavelengths to the red and blue LEDs with improved production of the lettuce.
- The 5-year project of SCRI vegetable grafting (Kubota) brought multiple new businesses of grafting nurseries and robotics investing into the U.S. market. One example is a newly opened ~$7 million greenhouse nursery complex of a new company TriHishtil (Mills River, NC) whose primary purpose is to sell grafted vegetable plants into the U.S. market starting in 2016. Another example is the first automated grafting operation for processing tomato industry in California developed in 2015 in collaboration with a seed company based in Israel (http://www.rootility.com/newsevents/rootility_appears).
- The greenhouse strawberry production research program (Kubota and Kroggel) helped to develop the capacity of commercially growing strawberries in greenhouses in the US. In AZ, a grower in Phoenix and Willcox areas (a total of 27 acres of greenhouse space) became the first AZ greenhouse strawberry producer for the local market. There are also several projects nationwide conducted by different companies.
- Nationwide, 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%.
- The Enviratron project will be used to study the impact of a changing climate on plant performance and health. This is the first step in solving tomorrow's threats to agriculture and food security.
- Percival is committed to customizing environmental chambers to meet the research needs of any customer. This approach to manufacturing allows plant scientists and growers set up experiments with chambers tailored to their exact needs.
- TotalGrow™ lights deliver a high quality light spectrum for optimal plant growth using Solid State Volumetric Lighting (SSVL), a next generation light emitting diode technology. Using as little energy as possible, TotalGrow™ lights blanket plants with uniform light in the wavelengths plants need most for quick and healthy growth.

Publications

NCERA 101 Member Publications

In addition to the efforts described above, the NCERA 101 group reported 82 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.

1. Niu, F., D. Zhang, Z. Li, M. van Iersel, and P. Alem. 2015. Morphological response of eucalypts seedlings to phosphorus supply through hydroponic system. *Scientia Horticulturae* 194:295-303.
2. Ferrarezi, R.S., M.W. van Iersel, and R. Testezlaf. 2015. Uso da subirrigação para imposição de estresse hídrico em sistema semi-contínuo para medição de CO_2. (Use of subirrigation for water stress imposition in a semi-continuous CO_2-exchange system). Advances in Ornamental Horticulture and Landscaping 21:235-242. (in Portuguese)
3. Ferrarezi, R.S., G.M. Weaver, M.W. van Iersel, and R. Testezlaf. 2015. Subirrigation: Historical overview, challenges, and future prospects. *HortTechnology* 25:262-276.
4. Bayer, A., J. Ruter, and M.W. van Iersel. 2015. Optimizing irrigation and fertilization of *Gardenia jasminoides* for good growth and minimal leaching. *HortScience* 50:994-1001.
5. Alem, P., P. A. Thomas, and M.W. van Iersel. 2015. Controlled water deficit as an alternative to plant growth retardants for regulation of poinsettia stem elongation. *HortScience* 50:565-569.
6. Alem, P., P.A. Thomas, and M.W. van Iersel. 2015. Substrate water content and fertilizer rate affect growth and flowering of potted petunia. *HortScience* 50:582-589.
7. Ferrarezi, R.S. and M.W. van Iersel. 2015. Monitoring and controlling ebb-and-flow subirrigation with soil moisture sensors. *HortScience* 50:447-453.
8. Alem, P., P.A. Thomas, and M.W. van Iersel. 2015. Use of controlled water deficit to regulate poinsettia stem elongation. *HortScience* 50:234-239.
9. Bayer, A., J. Ruter, and M.W. van Iersel. 2015. Automated irrigation control for improved growth and quality of *Gardenia jasminoides* 'Radicans' and 'August Beauty'. *HortScience* 50:78-84.
10. Ferrarezi, R.S., S.K. Dove, and M.W. van Iersel. 2015. An automated system for monitoring soil moisture and controlling irrigation using low-cost open-source microcontrollers. *HortTechnology* 25:110-118.
11. van Iersel, M.W. and J. Lea-Cox. 2015. Precision irrigation: how and why? Society of American Florists, 2015 Pest and Production Management Conference Proceedings: 64-69.

12. van Iersel, M.W., J. Lea-Cox, and S. Burnett. 2015. Precision irrigation: how and why? *Greenhouse Grower* 33(1): 60, 62, 64, 66.
13. Burnett, S., R.S. Ferrarezi, M. van Iersel, J.G. Kang, and S. Dove. 2015. Gain greater control of fertilizer with automated fertigation. *Greenhouse Grower* 33(1): 50, 52, 54, 56.
14. Evans, JM, Vallejo, VA, Beaudry RM and Warner RM. 2015. Daily light integral influences steviol glycoside biosynthesis and relative abundance of specific glycosides in stevia. HortScience 50:1479-1485.
15. Guo, Y, Wiegert-Rininger, KE, Vallejo VA, Barry CS, Warner RM. 2015. Transcriptome-enabled marker discovery and mapping of plastochron-related genes in Petunia spp. BMC Genomics 16:726.
16. Kim, Y.J., D.J. Yu, H. Rho, E.S. Runkle, H.J. Lee, and K.S. Kim. 2015. Photosynthetic changes in Cymbidium orchids grown under different intensities of night interruption lighting. Sci. Hort. 186:124-128.
17. Meng, Q. and E.S. Runkle. 2015. Low-intensity blue light in night-interruption lighting does not influence flowering of herbaceous ornamentals. Sci. Hort. 186:230-238.
18. Meng, Q. and E.S. Runkle. 2015. The role of blue light in night-interruption lighting of petunia. Acta Hort. 1107:101-105.
19. Mitchell, C.A., M.P. Dzakovich, C. Gomez, R. Lopez, J.F. Burr, R. Hernández, C. Kubota, C.J. Currey, Q. Meng, E.S. Runkle, C.M. Bourget, R.C. Morrow, and A.J. Both. 2015. Light-emitting diodes in horticulture, p. 1-88. In: J. Janick (ed.). Horticultural Reviews vol. 43. John Wiley & Sons, Hoboken, NJ.
20. Newton, L.A. and E.S. Runkle. 2015. Effects of benzyladenine on vegetative growth and flowering of potted Miltoniopsis orchids. Acta Hort. 1078:121-127.
21. Runkle, E. 2015. Environment and PGR interactions. Greenhouse Product News 25(12):74.
22. Runkle, E. 2015. Keys to successful seedling production. Greenhouse Product News 25(11):50.
23. Runkle, E. 2015. Lighting metrics… And what matters. Greenhouse Product News 25(10):62.
24. Runkle, E. 2015. Photoperiodic vs. photosynthetic lighting. Greenhouse Product News 25(9):74.
25. Runkle, E. 2015. Dealing with nonuniformity. Greenhouse Product News 25(8):62.
26. Runkle, E. 2015. Interactions of light, CO2 and temperature on photosynthesis. Greenhouse Product News 25(6):54.
27. Runkle, E. 2015. Crops with relatively low “optimum” temperatures. Greenhouse Product News 25(5):50.

28. Runkle, E. 2015. Trending: PGR sprenches. Greenhouse Product News 25(4):42.
29. Runkle, E. 2015. Light wavebands & their effects on plants. Greenhouse Product News 25(3):42.
30. Runkle, E. 2015. The PGR ancymidol. Greenhouse Product News 25(2):42.
31. Runkle, E. 2015. Dealing with the cold. Greenhouse Product News 25(1):50.
32. Runkle, E. and R. Heins. 2015. Boom lighting. Greenhouse Product News 25(7):66.
33. Vaid, T. and E.S. Runkle. 2015. Low temperature diminishes the photoperiodic flowering response of three petunia cultivars. Acta Hort. 1104:185-190.
34. Wollaeger, H.M and E.S. Runkle. 2015. Growth and acclimation of impatiens, salvia, petunia, and tomato seedlings to blue and red light. HortScience 50:522-529.
35. Massa, G.D., Wheeler, R.M., Morrow, R.C., Levine, H.G. 2016. Growth chambers on the International Space Station for large plants. Acta Hortic. 1134: 215-222. DOI: 10.17660/ActaHortic.2016.1134.29
36. Graham, T., R. Scorza, R. Wheeler, C. Dardick, B. Smith, A. Dixit, D. Raines, A. Callahan, C. Srinivasan, L. Spencer, J. Richards, G. Stutte. 2015. Over expression of FT1 in plum (*Prunus domestica*) results in phenotypes compatible with spaceflight: A new candidate crop for bioregenerative life-support systems? Gravitational and Space Research 3 (1): 39-50.
37. Graham, T., R. Wheeler, R. Scorza, C. Dardick, A. Callahan, D. Raines, A. Dixit, A.L. Paul, B. Smith, G. Stutte, L. Spencer, R. Ferl, C. Srinivasan, G. Massa, J. Richards. 2015. Trees in Space: No longer the forbidden fruit. Amer. Assoc. Gravitational Space Res. Ann. Conf., Alexandria VA, November 10-15, 2015.
38. Graham, T., R. Wheeler, R. Scorza, G. Stutte, C. Dardick, A. Callahan, B. Smith, R. Barker, A. Dixit, L. Spencer. Space orchards: No longer the forbidden fruit. The making of spaceflight compatible fruit trees. 7th AgroSpace Intl. Workshop, Sperlonga, Italy. May 26-27, 2016.
39. Graham, T., and Ray Wheeler. Revisiting mechanical plant dwarfing mechanisms for improving volume utilization efficiency in spaceflight plant production systems. Amer. Assoc. Gravitational Space Res. Ann. Conf. Alexandria, VA, November 10-15, 2015.
40. Massa, G.D., T. Graham, T. Haire, C. Flemming, G. Newsham, and R. Wheeler. 2015. Light-emitting diode light transmission through leaf tissue of seven different crops. HortScience 50(3):501–506.
41. Massa, G.D., E. Chase, J.B. Satini, and C.A. Mitchell. 2015. Temperature affects long-term productivity and quality attributes of day-neutral strawberry for a space life-support system. Life Sciences in Space Research 5:39-46.

42. Massa, G.D., R.M. Wheeler, G.W. Stutte, J.T. Richards, L.E. Spencer, M.E. Hummerick, G.L. Douglas, and T. Sirmons. 2015. Selection of leafy green vegetables varieties for a pick-and-eat diet supplement on ISS. 45th Intl. Conf. on Environ. Systems, ICES-2015-252.
43. Massa, G.D. and J. Norrie. 2015. LEDs electrifying horticultural science: Proceedings form the 2014 colloquium and workshop. HortScience 50(9):1272- 1273.
44. 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.
45. O'Keefe, C.M., G.W. Stutte and M. McKeon-Bennett. 2015. Ragwort: Invasive weed and potential pharmaceutical. In: J. Janick, (*ed*.), Horticultural Reviews 43:145-178.
46. Stutte, G.W., O.A. Monje, R.M. Wheeler. 2015. A. Rai and N. Hosein (*eds*). A Researcher's Guide to International Space Station Plant Science. NASA NP-2015-03-014-JSC, 47 pages.
47. Stutte, G.W. 2015. Commercial transition to LEDs: A pathway to high-value products. HortScience 50(9):1297-1300.
48. Kopsell, D. A., Sams, C. E. and Morrow, R. C. (2016), Interaction of light quality and fertility on biomass, shoot pigmentation and xanthophyll cycle flux in Chinese kale. J. Sci. Food Agric.. doi:10.1002/jsfa.7814
49. Remiker, R.W., R. J. Surdyk, R.C. Morrow, and M. Thiyagajaran. 2016. Non-Thermal Fresh Food Sanitation by Atmospheric Pressure Plasma. 46th International Conference on Environmental Systems ICES-2016-430.
50. Richter, R., B. Onate, R. C. Morrow, G. D. Massa. Advanced Plant Habitat Capabilities. ISS R&D Conference, 12 July 2016
51. Treichel, T.H. 2016. Human Factor Analysis of Light Emitting Diode Technologies for Aerospace Suitability in Human Space Flight Applications. 46th International Conference on Environmental Systems ICES-2016-95.
52. Wetzel, J.P., R. C. Morrow, D.A. Wyman3, R.R. Wallace, G. J. Ladwig, R. J. Surdyk6, D.A. Barkow, and Robert C. Richter. 2016. Mass Measurement Capability for Small Masses in a Microgravity. Environment46th International Conference on Environmental Systems ICES-2016-32.
53. Naznin, M. T., M. Lefsrud, V. Gravel, X. Hao. 2016. Different Ratios of Red and Blue LED to improve the Growth of Strawberry Plants. ISHS 8th International Symposium on Light in Horticulture. East Lansing, MI. ACTA Horticulturae 1134:125-130.
54. Both, A.J., L. Benjamin, J. Franklin, G. H. Holroyd, L. D. Incoll, M. G. Lefsrud and G. Pitkin. 2015. Guidelines for Measuring and Reporting Environmental Parameters for Experiments in Greenhouses. Plant Methods11(43):1-18
55. Kubota, C. 2015. Plant factory business and R&D in the world – current status and perspectives -- North America. P.59-61, In: (T. Kozai, G. Niu, and M. Takagaki eds.) Plant

factory: An indoor farming system for efficient quality food production. Elsevier, London, UK.

56. Kubota, C. 2015. Growth, development, transpiration and translocation as affected by abiotic environmental factors. P.151-164, In: (T. Kozai, G. Niu, and M. Takagaki eds.) Plant factory: An indoor farming system for efficient quality food production. Elsevier, London, UK.
57. Kubota, C. 2015. Biological factor management (1) Controlling algae. P.285-286, In: (T. Kozai, G. Niu, and M. Takagaki eds.) Plant factory: An indoor farming system for efficient quality food production. Elsevier, London, UK.
58. Eguchi, T. and C. Kubota. 2015. Cotyledonary axillary shoot control by fatty alcohol application for grafting tomato. HortTechnology. 25:569-574
59. Eguchi, T., R. Hernández, and C. Kubota. 2016. Far-red and blue light synergistically mitigate intumescence injury of tomato plants grown under UV-deficit light environment. HortScience. 51:712-719.
60. Hernández, R. and C. Kubota. 2015. Physiological, morphological, and energy-use efficiency comparisons of LED and HPS supplemental lighting for cucumber transplant production. HortScience. 50:351-357.
61. Hernández, R. and C. Kubota. 2016. Physiological responses of cucumber seedlings under different blue and red photon flux ratios using LEDs. Environ. Exp. Bot. 121:66-74.
62. Jia, F., M. Kacira, K. Ogden. 2015. Multi-Wavelength Based Optical Density Sensor for Autonomous Monitoring of Microalgae. Sensors, 15(9): 22234-22248. DOI:10.3390/s150922234
63. Zhang, Y., Kacira, M., and An, L. 2016. A CFD Study on Improving Air Flow Uniformity in Indoor Plant Factory System. Biosystems Engineering, 147: 193–205
64. Eguchi, T., R. Hernández, and C. Kubota. 2016. End-of-day far-red lighting combined with blue-rich light environment to mitigate intumescence injury of two interspecific tomato rootstocks. Acta Horticulturae 1134:163-170.
65. Hernández, R., T. Eguchi, and C. Kubota. 2016. Growth and morphology of vegetable seedlings under different blue and red photon flux ratios using LEDs as sole source lighting. Acta Horticulturae 1134:195-200.
66. Kacira, M., M. Jensen, T. Robie, S. Tollefson, G. Giacomelli. 2016. Use resources wisely: waste management and organic liquid fertilizer use in greenhouse production system. ActaHorticultrae [In Press]
67. Kozai, T., C. Kubota, M. Takagaki, and T. Maruo. 2015. Greenhouse environment control technologies for improving the sustainability of food production. Acta Horticulturae 1107:1-13.
68. Kubota, C., M. Kroggel, A.J. Both, J.F. Burr, and M. Whalen. 2016. Does supplemental lighting make sense for my crop? – Empirical evaluations. Acta Horticulturae 1134:403-411.

69. Romero, E. J. B., and Kacira, M. 2016. Greenhouse technology for cultivation in arid and semi-arid regions. Acta Horticulturae [In Press]
70. Zhang, Y. and M. Kacira. 2016. Improving crop canopy boundary layer dynamics in multi-tier indoor plant factory system. Acta Horticulturae [In Press]
71. Ishii, M. S. Sase, H. Moriyama, L. Okushima, A. Ikeguchi, M. Hayashi, K. Kurata, C. Kubota, M. Kacira, and G.A. Giacomelli. 2016. Controlled enviornment agriculture for effective plant production systems in a semiarid greenhouse. Japan Agricultural Research Quarterly. 50:101-113.
72. Wallace, C. and A.J. Both. 2016. Putting lights to the test. GrowerTalks, June issue. pp. 60, 62, 64.
73. Wallace, C and A.J. Both. 2016. Evaluating operating characteristics of light sources for horticultural applications. Acta Horticulturae 1134:435-443.
74. Kubota, C., M. Kroggel, A.J. Both, J.F. Burr, and M. Whalen. 2016. Does supplemental lighting make sense for my crop? – Empirical evaluations. Acta Horticulturae 1134:403-411.
75. Ishii, M., L. Okushima, H. Moriyama, S. Sase, N. Fukuchi, and A.J. Both. 2015. Experimental study of natural ventilation in an open-roof greenhouse during the summer. Acta Horticulturae 1107:67-74.
76. Both, A.J., L. Benjamin, J. Franklin, G. Holroyd, L.D. Incoll, M.G. Lefsrud, and G. Pitkin. 2015. Guidelines for measuring and reporting environmental parameters for experiments in greenhouses. Plant Methods 11(43). 18 pp.
77. Both, A.J., J.M. Frantz, B. Bugbee. 2016. Carbon dioxide enrichment in greenhouses. Submitted for publication in 'Light Management in Controlled Environments' (R. Lopez and E. Runkle, eds.) to be published by Meister Media.
78. Runkle, E. and A.J. Both. 2016. Delivering long-day lighting – Technology options and costs. Submitted for publication in 'Light Management in Controlled Environments' (R. Lopez and E. Runkle, eds.) to be published by Meister Media.
79. Both, A.J. and J.E. Faust. 2016. Light transmission: The impact of glazing material and greenhouse design. Submitted for publication in 'Light Management in Controlled Environments' (R. Lopez and E. Runkle, eds.) to be published by Meister Media.
80. Fisher, P., A.J. Both, and B. Bugbee. 2016. Supplemental lighting technology, costs and efficiency. Submitted for publication in 'Light Management in Controlled Environments' (R. Lopez and E. Runkle, eds.) to be published by Meister Media.
81. Johnson, M., T.S. Villani, J.E. Simon, A.J. Both. 2016. Effects of nitrogen, CO2 and harvesting method on various algae species grown on vertical substrates. Submitted for publication in the Journal of Applied Phycology.

82. Ishii, M., L. Okushima, H. Moriyama, S. Sase, N. Fukuchi, T. Maruo, and A.J. Both. 2015. Evaluating environmental conditions in open-roof greenhouses. Accepted for publication in Acta Horticulturae.

Some Controlled Environment Websites supported by NCERA-101 members submitting reports.

1. 8th ISHS International Symposium on Light in Horticulture, http://www.lightsym16.com
2. Developing LED lighting technologies and practices for sustainable specialty-crop production, http://leds.hrt.msu.edu
3. Michigan Garden Plant Tour, http://planttour.hrt.msu.edu
4. MSU Floriculture Production, http://www.flor.hrt.msu.edu
5. CEAC Website: http://ceac.arizona.edu/
6. CEAC Facebook: https://www.facebook.com/UA.CEAC
7. Facebook for Controlled Environment Plant Physiology and Technology Lab: https://www.facebook.com/CEPPTLAB/
8. Strawberry information site: http://cals.arizona.edu/strawberry