Project No and Title: NCERA-101 Controlled Environment Technology and Use
Period Covered: 04-2017 to 04-2018
Date Reporting: 23-April-2018
Annual Meeting: April 15-18, 2018

Minutes of the 2018 NCERA-101 Business Meeting
April 15-18, 2018 Raleigh, North Carolina
Sheraton Raleigh Hotel

To Dos

- Ramesh Kanwar urges the NCERA-101 to nominate this committee for a Research Excellence award by the USDA. Due date is November 19th, 2018
- Chieri Kubota requests for forming a sub-committee to address the need to develop formatting guidelines for sharing data generated by NCERA-101 members.
- Continuing education credits combined with re-wording the description of the NCERA-101 annual meeting activities to better position members to be eligible for continuing educations credits as well as certain federal institutions to approve travel to attend.
- Develop the artwork and plaque for the NCERA-101 Award for Significant Organizational Contributions to the Controlled Environment Sciences and award presented to NCSU and Duke University Phytotrons in commemoration of their 50th anniversary
- Station Reports

NCERA-101 Meeting Participants:
GeorgeAdamson (Ontario Scientific Inc.), Lars Aikala (Valoya Oy), Kayla Allen (Metrolina Greenhouses), Stacey Badders (AgBiome), Mark Baker (Hettich Instruments), Mark Blonquist (Apogee Instruments), Sarah Bonefas, A.J. Both (Rutgers University), Keri Bouchard (Conviron), Tracey Bradley (Heliospectra), Douglas Brinkman (University of Minnesota), Bruce Bugbee (Utah State University), Amirah Burton (North Carolina A & T University), Jimmy Byrtus (Boragen), Chong Cheong Howe (Opulent Americas), Joseph Chiera (North Carolina State University), Sam Cho (North Carolina State University), John Clark (AgBiome), Bobby Clegg (Syngenta Crop Protection LLC), Cristian Collado (North Carolina State University), Joshua Craver (Purdue University), Kristen Curlee (Dow AgroSciences), Christopher Currey (Iowa State University), Matteo del Ninno (Jump Lights), Todd DeZwaan (LemnaTec), Mike Dixon (University of Guelph), Corey Dobbins (Bayer Crop Science), Haijie Dou (Texas A&M University), Claudia Elkins (University of Georgia), Matt Ezzo (Environmental Growth Chambers), Jonathan Frantz (DuPont Pioneer), Patrick Friesen (BioChambers Inc.), Charlie Garcia (Michigan State University), Gary Gardner (University of Minnesota), Charles Gibbs (North Carolina State University), Lawrence Giles (Durham, NC), Daniel Gillespie (Ohio State University), Robert Glass (Cree), Gregory Goins (North Carolina A & T University), Celina Gomez (University of Florida), JORDAN GOULET (OSRAM), George Grant (University of Florida), David Griffin (Dow AgroSciences), Kale Harbick (Cornell University), Edward Harwood (Just Greens, LLC), William Healy (Ball Horticultural Company), Royal Heins (Professor Emeritus - Michigan State University), Ricardo Hernandez (North Carolina State University), Erica Hernandez (Cornell University), Travis Higginbotham (Fluence Bioengineering), Chris Higgins (HortAmericas), Robert Higley (Opulent

Americas), Norman Hill (Duke University), Beng Hooi Khoon (Opulent Americas), Nick Horsley (Hettich Instruments), Brandon Huber (North Carolina State University), Henry Imberti (Percival Scientific Inc.), T.C. Jayalath (University of Georgia), Dave Jenkins (Atlantic Technology Group), Fei Jia (Heliospectra), Andrew Johnson (University of Southern California), Murat Kacira (University of Arizona), David Kane (Iowa State University), Ramesh Kanwar (Iowa State University), Meriam Karlsson (University of Alaska), Dan Kiekhaefer (Percival Scientific Inc.), Marcia Kirinus (Alexandria Real Estate Equities, Inc.), Rebecca Knight (BIOS Lighting), Mary Jo Kopf (LI-COR Biosciences), Brian Krug (DuPont Pioneer), Chieri Kubota (Ohio State University), Paul Kusuma (Utah State University), Mark Lefsrud (McGill University), Joan Leonard (LLK Greenhouse Solutions), David Lewus, Bruce Link, Jun Liu (University of Georgia), Leo Lobato Kelly (Karma Verde Fresh), Roberto Lopez (Michigan State University), Karl Lundy (Percival Scientific Inc.), Tom Manning (Rutgers University), Andie Marsh (Fluence Bioengineering), Michael Martin (University of Georgia), Gioia Massa (NASA - Kennedy Space Center), Erico Mattos (Cornell University), Thomas McKean (Ohio State University), Qingwu (William) Meng (Michigan State University), Matthew Mickens (NASA - Kennedy Space Center), Cary Mitchell (Purdue University), Michael Moore (Bayer Crop Science), Robert Morrow (Sierra Nevada Corporation), David Nicholl (Precision Biosciences), Shane Palmer (University of Georgia), Ron Parker (Ontario Scientific Inc.), Morgan Pattison (Solid State Lighting Services, Inc), Robert Pauls (BioChambers Inc.), Brian Poole (LumiGrow Inc.), Eshwar Ravishankar (North Carolina State University), Sharon Reid (Conviron), Mark Romer (McGill University), Adrian Rule (Environmental Growth Chambers), Erik Runkle (Michigan State University), Nadia Sabeh (Dr. Greenhouse), Carole Saravitz (North Carolina State University), Kaelin Saul (NCSU), Russell Shaver (Opulent Americas), Timothy Shelford (Cornell University), Flip Sheridan (Cycloptics/Benesero, LLC), Gregg Short (GShort.com LLC), Bryan Shubert (Hettich Instruments), Todd Smith (Duke University), Hans Spalholz (North Carolina State University), Eric Stallknecht (University of Georgia), Michael Stasiak (University of Guelph), Gary Stutte (QinetiQ North America), Jennifer Swift (North Carolina State University), Marc Theroux (BioChambers Inc.), Viktor Tishchenko (University of Georgia), David Tremmel (Duke University), Marc van Iersel (University of Georgia), Kellie Walters (Michigan State University), Raymond Wheeler (NASA - Kennedy Space Center), William Wheeler (Utah State University), John Wierzchowski (Environmental Growth Chambers), Xiangnan Xu (North Carolina State University), Yang Yang (Purdue University), Melanie Yelton (LumiGrow Inc.), Neil Yorio (BIOS Lighting), Claudia Zehnpfennig (OSRAM), Mengzi Zhang (Michigan State University), Shuyang Zhen (Utah State University)

NCERA-101 Meeting Industry Sponsors:
Apogee, Bio Chambers Inc., BIOS Lighting, Conviron + Argus, Cycloptics Technologies, Environmental Growth Chambers, Fluence Bioengineering, Heliospectra, Hettich Instruments, HortAmericas, Lemnatec, Licor, LLK Greenhouse, Opulent, OSRAM, Percival + Atlantic Technologies, Valoya

Executive Officers:
Chair: Bob Morrow (Sierra Nevada Corporation), Vice-Chair: Mark Lefsrud (McGill University), Secretary: Neil Yorio (BIOS Lighting), Past-Chair: Gioia Massa (NASA KSC)

Business Meeting
April 16, 2018
Start 8:30 am

Minutes of meeting 2017 – Presented by Neil Yorio
Motion to Pass – Dr. Bruce Bugbee
Second – Dr. Marc van Iersel
Passed

Attendance list from conference at end of this document – 131 attendances

Other Conferences
ASABE Annual Meeting, Detroit, Michigan, July 29-August 1, 2018
ISHS –XXX International Horticultural Congress Istanbul, Turkey, Aug 12-16, 2018
American Society for Gravitational and Space Research, Washington, D.C., October 31-November 3, 2018
ASHS Annual Meeting, Washington, D.C., July 30-August 3, 2018
PGRSA Annual Conference, San Juan, Puerto Rico, June 10-14, 2018
AERGC Annual Meeting, University of Maryland, July 23-26, 2018
Greensys2019, Angers, France, June 16-20, 2019

Administration advisors report – Ramesh Kanwar

- Station reports are due 60 days after this meeting (June 15, 2018 is due) with special emphasis on impact statements included in the reports.
- Strong encouragement to nominate NCERA-101 committee for a Research Excellence award by the USDA. Nominations are due November 15, 2018.
- Ramesh reported that the NIFA representative (Steven Thompson) would not be present at this year's NCERA-101 meeting.

Membership report – Mark Romer

- 43rd Annual Meeting – 4th time in North Carolina
- Heartfelt thanks to Carole Saravitz and her team for hosting the NCERA-101 meeting
- Thanks to industry sponsors for supporting the meeting which helped defray meeting costs as well as support graduate student travel/participation.
- Special acknowledgment by the Membership recognizing Jack Downs contribution to the NCSU Phytotron

166 - Registered members
122 – Institutions represented
32 – States represented
11 - Countries represented

44 – Companies represented

Notes:
Awards – There were no 20 year member awards nominated or presented at this year's meeting.

Web site report – Carol Saravitz
- Recent changes to the website, only ½ year on the new website so no statistics reported for website traffic.
- Reorganized the publications
- Added a Biosafety category to website
- Added meeting sponsors to the website

ASABE Horticultural Lighting Guidelines Update – Mark Lefsrud and Nadia Sabeh
- A new standard in development, X653 focusing on indoor crop production, co-sponsored by ASHRAE
- X640 is now an accepted standard
- X642 out for initial review by committee members
- X644 still in revision, but internally being reviewed

Controlled environment research data sharing – Chieri Kubota
- It was discussed that a common format for data be investigated to aid in grant writing, particularly for USDA grants
- Intent is to have a best practices/recommendations for sharing data among researchers
- Discussion from a number of committee members suggesting existing formats from other groups (Crop Science/Agronomy, Oak Ridge National Lab, Phenomics) to use as baseline examples
- Some committee members volunteered to work with Chieri Kubota

Standardized Labeling – Fei Jia)
- Indicated that the Design Lighting Consortia (DLC) has issued first draft of testing and performance requirements for horticultural lighting
- Draft input/comments are due May 30
- Supports the horticultural lighting facts label development

Instrument package and Financials – Bruce Bugbee
- $33,000 is the treasury for NCERA-101
- $26,000 received in sponsorships for the 2018 meeting
- Instrument package report – unsure if used once this year, but always available upon request
- Quantum sensors in the package are much improved
- Visit NCERA-101 website for more information on requesting instrument calibration package
- Graduate student funding for travel is now handled by USU

Student report update – Jonathan Franz

- This is the sixth year the committee has supported graduate student participation
- 17 graduate students presented at this year's meeting
- 11 students received a travel grant from NCERA-101 ($800 per student)
- All presentations were Lightning talks in addition to poster presentations

Future meetings

- Mark Lefsrud – McGill University, Montreal, Canada April 14-17, 2019
    - Accommodations at the Chateau Vaudreuil
    - Tour of local controlled environment facilities
    - Mark to write letter for meeting participation for attendees
- 2020 Meeting hosted by Murat Kacira, University of Arizona in early-mid March (during their spring break)
- 2021 Meeting hosted by Erik Runkle, Michigan State University in May for both nice weather and optimal time to visit production greenhouses and vertical farm facilities
- 2022 Meeting possibly sponsored by Chris Currey/Iowa State University or Celina Gomez/Univ. of Florida
- 2023 Meeting possibly the next international NCERA-101 (Mexico??)

Election Secretary

Nominations – Murat Kacira – Univ. of Arizona
Motion to close nominations - Bruce Bugbee
Second Neil Yorio
Passed, Congratulations to Murat

New Business –

- Gioia Massa discussed issue with both the continuing education credit for engineering certification and federal government justification for NCERA-101 attendance.
- Need to increase awareness of the committee charter and activities – Gioia to work with Carole to improve definition/scope to justify attendance
- Suggested change from "tour" to "educational site visit" in meeting description and include site visit as part of the overall registration cost
- No discussion or action taken to address suggestion to increase the NCERA-101 executive members to a two year post
- Motion by Mark Romer to create a new NCERA-10 award – The NCERA-101 Award for Significant Contributions to the Controlled Environment Sciences
- Much discussion on working and eligibility of the award by the committee
- Motion tabled until after lunch break. Motion amended by executive committee and approved by Mark
- Presented amended motion after lunch break, seconded by Neil Yorio, and passed by committee
- First recipients to be NCSU and Duke Phytotrons in commemoration of their 50th anniversary
    - Description of new award is as follows:

Title: NCERA-101 Award for Significant Organizational Contributions to the Controlled Environment Sciences

Criteria

An organization that has been deemed by the NCERA101 to have had a significant impact on the field of controlled environment science. Criteria would include aspects such as significant facilities, publications and/or significant technological advances developed in the field of controlled environments for plants. The award shall be decided by the NCERA-101executive committee and presented at the annual meeting.

Eligibility

University, government or commercial facilities or organizations working in the area of controlled environments.

<u>Passing of the gavel:</u>

Bob Morrow to Mark Lefsrud (now chair)

<u>Adjourned</u> 1:30pm. (Mark Lefsrud)

Minutes respectfully submitted by Neil Yorio

Appendix A:

NCERA-101 Membership Summary …… April 2018

Mark Romer, *Membership Secretary*

Membership Number ....March 2017......................167

March 2018......................166

- Additions..................................6
- Deletions..................................7
- Net Gain(Loss).....................(1)

Membership Composition	Institutions	Members
• Phytotrons & Controlled Environment Facilities	11	15
• University Departments, Agr. Exp. Stations	57	80
• Government Organizations & Contractors	10	10
• Industry Representatives	44	61
Total Number of Institutions / Members	**122**	**166**

Total Number of Countries 11

Total Number of US States 32

New Institutions :

- Canada:
  - Capital Greenhouse
  - P.L. Light Systems
- United Kingdom:
  - University of Cambridge, The Sainsbury Laboratory
- USA:
  - Cornell University,
  - Greenhouse Lighting and Systems Engineering (GLASE)
  - Mississippi State University,
  - Agricultural and Biological Engineering
  - Ohio State University,
  - Department of Horticulture and Crop Science
  - Sierra Nevada Corporation,
  - Human Systems & Instrumentation (ORBITEC)

Appendix B:

Accomplishments (17 Reports)
(The complete station reports are available on the NCERA -101 website
http://www.controlledenvironments.org/station_reports.htm)

1. New Facilities and Equipment

At the University of Guelph, the water cooled LEDs installed in 2012 suffered a traumatic failure when the university chilled water supply reached 180 psi. The six original units were replaced this year with nine new 9-channel (UV through to far red) water cooled LED arrays that are now decoupled from the university chilled water supply.

Four ancient yet worthy Constant Temperature Control Ltd. walk in growth chambers at the University of Guelph were converted to Argus Controls by our greenhouse manager Ron Dutton. Switching out the T12 tubes is next on the list.

One of the original BlueBox growth chambers at the University of Guelph was retrofitted with 7-channel (UV to far red) high intensity water cooled LEDs which provide eight 2' x 4' growing spaces in a single chamber to better evaluate plant-light interactions.

University of Guelph delivered five PS-1000 plant photosynthesis units to a licensed marijuana producer in Ontario. These are part of an extended CESRF/UoG laboratory located in a secure licensed production facility and are capable of investigating cannabis growth, development and chemistry under controlled conditions.

TOC-N analyzer acquired and refurbished at the University of Guelph. Applications in irrigation water research.

McGill University upgraded the primary cooling system for the 39 growth chambers installed in the Phytotron. A dedicated chilled water line and heat exchanger was installed while retaining the originally installed cooling tower as a backup. The new system provides a constant and reliable 21C temperature water 24-7. In addition, all the originally installed steel pipelines were replaced with PVC conduit. Phytotron managers were also provided with access to the main Facilities Regulvar controls network to permit monitoring of all mechanical and electrical equipment on site.

McGill University Control System Upgrades: The original Danish greenhouse control system (DGT) installed in 1987 was replaced in all 11 greenhouse zones with new Argus TITAN components and software. In addition, 10 of our 39 Conviron growth chamber control panels (model 3000) were retrofitted with the latest networked controllers (model 6060).

The Department of Horticulture & Landscape architecture at Purdue University welcomed Nathan Deppe as Plant Growth Facilities Manager beginning September 18, 2017. Nathan has 15 year's experience previously managing CEA research facilities, including growth rooms, chambers, and greenhouses, first at the ARS National Center for Agricultural Utilization Research at Peoria, Illinois, then as Plant Care Facilities Manager of the greenhouse/growth-chamber complex dedicated to plant breeding at the University of Illinois, Urbana-Champaign. At Purdue, Nathan is promoting establishment of new technologies for cutting-edge research and education.

In Dr. Nemali's Lab at Purdue, a hydroponic facility with two production systems (nutrient film technique, NFT and deep flow technique, DFT) and capability to conduct replicated trials for different varieties under four nutrient solution concentrations and three supplemental lighting treatments was built for research, extension and teaching purposes was built at Purdue University Greenhouse Facility.

Additionally in Dr. Nemali's lab, a vertical farm production facility to grow leaf greens and herbs under different sole source lighting treatments and nutrient solution concentrations was built for research, extension and teaching purposes as well as an ebb-flow production facility for growing floriculture crops was added in the greenhouse for research activities, and a plant phenotyping station capable of automatically measuring canopy area and crop reflectance at different wavebands was added to controlled environment research.

In Dr. Mitchell's Lab at Purdue, for the Minitron III controlled-environment/gas-exchange system, modified design and assembly progressed towards completion and routine operation. Several improvements were made for ease of operation, for safety compliance, documentation of components, operation, and trouble shooting. Components of the gas-routing board were changed out to not bind CO2 or H2Ov over time of operation, and a booster pump and digital rotameter were installed to ensure return of stirred sample atmospheres from the cuvette space to the IRGA following the large pressure drop.

A 2000 ft2 greenhouse compartment was set up for teaching hydroponic crop production courses by Dr. Chieri Kubota, new professor of Controlled Environment Agriculture at the Ohio State University. This facility includes six 6-m double rows of high-wire crop production (tomato, cucumber and pepper), two sets of 4-channel (8-ft each) NFT systems for leafy greens, and two sets of 4 ft x 4 ft DWC (deep water culture) systems leafy greens. 60% of lights (metal halide) were replaced with LEDs provided by GE (intra-canopy LED lighting) and SpecGrade LEDs (overhead LED lighting).

A 1000 ft2 greenhouse compartment was set up at Ohio State for conducting a research/extension project of soilless strawberry production. Eight five meter raised gutters were installed with a below-gutter misting system for tip-burn control. Custom-designed LED lights (SpecGrade LEDs) were installed to provide approximately ~10 mol m-2 d-1.

New growth chambers (two walk-in rooms each with 90 ft2) are approved to be installed by July 2018 in the basement of Howlett Hall Greenhouse Complex, Department of Horticulture and Crop Science at Ohio State. Inside each growth chamber, there will be four independent units of movable growing systems with three tiers with selected lighting system. This facility will provide ample space to examine different experiments studying light qualities, intensities, CO2 as well as relative humidity.

A mini VF unit 'Veggie Box' was transferred to the Columbus Campus of Ohio State in August, 2017. This is a modular, all-in-one, commercial unit originally imported from Japan (Sankyo

Frontier, Japan). This 60 ft2 footprint, highly insulated and contained structure is equipped with a four-tiered re-circulating hydroponic production system (total production area 50 ft2), LED lighting (300 or 600 umol m-2 s-1), nutrient pH and EC controller, CO2 controller, as well as A/C condensation water recovery system. A new A/C system will be installed and the unit will be operational by September 2018.

At Ohio State, two reach-in sub-freezing temperature control chambers (Thermo Scientific, Precision series) are installed in Howlett Hall for storage of strawberry tray plants.

At Rutgers University as part of a new undergraduate course that focuses on controlled environment crop production, we equipped a 1,600 square feet section in the NJAES Research greenhouses with three different growing systems: Horizontal and vertical hydroponics as well as geoponics. Students are growing a variety of crops in these systems and portions of the harvests are sold to University Dining Services.

Kennedy Space Center recently purchased seven Heliospectra RX30 LED lighting systems that provide nine , selectively dimmable LED wavelengths -- 380, 400, 420, 450, 520, 630, 660, 735 nm, and white (~5700 K), and continue to use four dimmable, 6500 K white LED arrays from BIOS Lighting (Melbourne, FL) and five custom 1:1 red/blue LEDs arrays from AIBC International (Ithaca, NY). Matt Romeyn has begun testing the prototype Phytofy RL LED fixture by OSRAM on microgreens that provides similar wavelength capability to the APH, and Matt Mickens has completed experiments with the Artificial Sunlight Research Module (ASRM) from Specialty Lighting of Holland that employs all LEDs to closely simulate the solar spectrum from near UV, through PAR, to the far-red region. KSC also purchased a LI-6800 portable leaf photosynthesis system this past year.

The University of Georgia installed a new plant factory inside an old walk-in cooler at the Horticulture greenhouses in Athens, GA. The plant factory consists of three racks with three 2' x 8' shelves. Each shelf is divided into two separate growing spaces, resulting in a total of 18 growing spaces. The cooler has temperature, humidity and CO2 control. Light is provided using SpydrX Plus LED grow lights (Fluence Bioengineering, Austin, TX). Each shelf is light using the SpydrX LED bars. The drivers for the LEDs are interfaced with a Campbell Scientific datalogger, which can send voltage signals to the drivers, providing complete control over dimming of the LED lights. The PPFD at the canopy level can be controlled precisely in a range of 100 to 800 µmol·m-2·s-1.

Sierra Nevada Corporation continues to expand hiring and is currently building out a third facility in the Madison WI area that will be used to develop flight hardware for life support and propulsion systems.

Brian Poel joined LumiGrow, April 2017 as a Horticultural Lighting Specialist to coordinate and oversee grower trials and facilitate technology transfer from internal and university research.

In January 2017, LumiGrow launched the Pro Series E fixture, with 15% more light output than the prior Pro Series. The Pro Series E carries an energy efficiency of 1.9 umol/joule, which translates into a 50% energy savings over 400W magnetic ballast HPS fixture, or a 12% savings over a double ended HPS fixture with electronic ballast.

In fall 2017, LumiGrow released an integrated light sensor technology, named the smartPAR Light Sensor Module. This sensor was demonstrated at our booth at NCERA-101, Monterey, 2017. The light sensor is being tested at several commercial production facilities as well as LumiGrow directed work at Harrow Research and Development Centre in Harrow, ON in four identical greenhouse chambers covering 70 m2 each, Cabrillo College in Aptos, CA to in a standard lettuce production hoop house. He purpose was to validate the LumiGrow sensor we are using Apogee SQ-520 quantum sensors as a reference to log light intensity data at multiple locations under each treatment at our commercial trial locations, and at each site, development of an energy monitoring and logging system to compare energy usage between supplemental lighting control systems

The Heliospectra Plant Lab in Gothenburg, Sweden consists of 80m2 of controlled environment plant growth rooms and one Conviron A1000 climate chamber.

Plant scientists conduct in-house light strategy research and commercial crop trials to support customer LED light installations across six continents using Heliospectra's RX (tunable research top lighting), LX (tunable commercial top lighting) and E (fixed spectra top lighting) series LED lamps. The Plant Lab also supports the development and QA testing of prototype Heliospectra light bars and fixtures prior to commercial release.

As of January 2018, all tunable lamps in the Heliospectra Plant Lab are now controlled by the company's new HelioCORE light control software system, integrating Li-Cor Quantum sensors and the HelioCORE DLI controller, On Target PPFD and Schedule controller modules.

In 2018, Heliospectra expanded their research collaboration with Chalmers University on spectral light sensing to include a new focus on image recognition and crop control parameters.

North Carolina A&T Joint School of Nanoscience & Nanoengineering (JSNN), is an academic collaboration between North Carolina Agricultural and Technical State University (NC A&T) and The University of North Carolina at Greensboro (UNCG). JSNN is a $56.3 million, 105,000 square foot state-of -the-art science and engineering research building with nanoelectronics and nanobio clean rooms, nanoengineering and nanoscience laboratories and extensive materials analysis facilities. JSNN builds on the strengths of the universities to offer innovative, cross-disciplinary graduate programs in the emerging areas of nanoscience and nanoengineering. Nanobiology uses engineered nanomaterials to enable diagnosis, imaging and therapy. JSNN also is actively engaged with K-12 outreach with schools.

North Carolina A&T partnered with the Brothers Excelling with Self-sufficiency to Thrive (BEST-a non-profit), and the Guilford County Prison Farm 2000 sq. ft state of the art greenhouses using hydroponics to focus on addressing the concerns that affect males between the ages of 13 and 24 who have high-risk factors. The program offers formal mentoring that takes a comprehensive, holistic, and collaborative that aggressively addresses issues with youth who have been determined could benefit from long-term support. Greenhouses were donated by Guilford County and located in Eastern Guilford County (approximately 2 miles north of Gibsonville, NC). This project has been made possible through a partnership grant with the Guilford County Sheriff's office and a grant from USDA/NIFA. Under the terms of the contract, North Carolina A&T/BEST agree to maintain the property, use it only for the stated purposes, follow environmental laws and pay the cost of the propane needed for the program.

The University of Arizona faculty [Dr. Gene Giacomelli], staff [Tilak Mahato, Neal Barto] and students of the UA-CEAC [University of Arizona-Controlled Environment Agriculture Center] and the Agricultural & Biosystems Engineering Department at CALS [College of Agriculture & Life Sciences] worked closely with industry contacts Ajay Jones [2015 - 17], Brad Hart and Stefanie Boe [2017 - present] of Monsanto Company to establish a new plant production procedure for growing corn in the greenhouse to develop the breeding lines required for developing new varieties of field corn, and to replace the less efficient, current practice of field production. An Ebb & Flood hydroponic nutrient delivery system was created, tested and demonstrated to successfully produce mature seed corn plants with healthy ears with many viable seed kernels. Seedlings were transplanted into individual pots filled with soilless substrate and placed onto water-tight benches. The benches were automatically irrigated by being flooded and drained with automatically formulated nutrient-rich water such that each pot received the similar amount of water and fertilizer for optimum growth. Uniformity of irrigation provided for equal timing of all plant milestones, especially pollination and harvest. All unused water was captured and stored for a future watering cycle. The benches will be designed to transport the pots of corn plants that were grouped onto benches within the greenhouse, allowing access to all the plants to more efficiently complete manual labor tasks, such as transplant, crop maintenance, pollination and harvest. The optimum plant growing environment at the UA-CEAC greenhouses was maintained by the greenhouse climate-controlled systems including: heating, cooling, shading, lighting and pest control. Many crop cycles have been completed substantiating the consistency of the successful procedures. As a result, the company has invested in the design and construction of a 7-acre [2.7 hectare] seed corn production facility, including a 87,000 square foot [8000 square meter] processing lab and office facility, will begin operations in November 2018 in Marana, Arizona.

A 24 x 30 greenhouse and recirculating nutrient delivery system is near completion for the roof top of the Student Union Memorial Center (SUMC) to produce fruiting crops for delivery to the Student Pantry for all food insecure University of Arizona students. Established by Center Director Todd Millay, the facility will be managed by CEAC personnel in conjunction with student employees. CEAC has supported and helped design the facility. Industry support through hardware donations and financial assistance has been provided by AutoGrow, Grodan and PolyTex Greenhouse Co.

The University of Arizona-CEAC recently established vertical farm-based research, education, extension and outreach facility (UAg Farm). Efforts are ongoing with multi-tier based growing beds, LED lighting and environmental monitoring and controls to establish a propagation chamber to grow transplants for the research in UAg Farm facility.

An LED lighting system (Red, Blue, White) was installed in a 300 m2 mushroom research greenhouse at the University of Arizona. The effect of light quality and intensity along with substrate compositions are being evaluated on yield, nutritional content and bio-efficiency in the production (Barry Pryor, PI).

The Johnston, Iowa site for Corteva Agriscience has about 4.5 acres of research greenhouses and is supported by a little over 2 acres of support buildings in which we operate and maintain many dozens of growth chambers in a variety of sizes and capabilities. The Hayward, CA site is considerably smaller with about 8,500 sq ft of greenhouse space supported by a roughly equal headhouse and growth chamber space.

The Controlled-Environment Lighting Laboratory (CELL) at Michigan State University was completed in February, 2017 and the first plants were grown in the facility in March. CELL consists of two independently controlled and refrigerated growth rooms, each with 12 deep-flow hydroponic shelves. Sole-source lighting in CELL utilizes customized LED arrays developed in collaboration with OSRAM Innovation and Osram Opto Semiconductors. The arrays are composed of seven LED types: UV-A, blue, green, red, far red, warm white, and mint white, and each is independently controlled and programmable for each shelf.

Two existing walk-in growth chambers at Michigan State University were retrofitted with white LED arrays; CO_2 injection and scrubbing; four Licor LI90R quantum sensors; and four Apogee ST-100 thermistors per chamber. To facilitate greenhouse hydroponics research, 24 modular deep flow hydroponics systems were installed in six greenhouse compartments.

2. Unique Plant Responses

At the University of Guelph, an undergraduate investigation on common bush bean production using LED inner canopy lighting has shown (as expected) significantly improved yields and shorter stature. This research has led to the inclusion of bush beans in our vertical farming research initiatives.

The University of Guelph demonstrated altered secondary metabolite production in cannabis in response to different light spectral qualities.

The University of Guelph has uncovered early evidence to suggest vertical stratification of secondary metabolite production in cannabis flower buds in response to sub-canopy lighting in which the sub-canopy spectra differed from the overhead light spectra.

At Purdue, Dr. Kim's group has investigated the effects of light source and quality on tomato growth and yield and discovered that far-red light enhanced plant growth and yield of greenhouse tomato via changes in physiological mechanisms (water relations and biomass allocation patterns) leading to earlier crop production and higher yield. Dr. Kim's group also found that far-red-light grown tomatoes have better flavor (greater aroma, texture, and sweetness) compared to high pressure sodium (HPS)-lamp-grown tomatoes. Ion analyses revealed that tomato fruits under far-red light are meaty and contain greater total soluble salts (TSS), and accumulate higher amounts of sodium and sulfur in fruits, possibility contributing to the stronger flavor.

At Purdue, Dr. Nemali's Lab investigates how photosynthetic photon efficiency is commonly used to market sole-source or supplemental lighting fixtures. Research at Purdue using different sole source LED lighting fixtures with different light composition indicated that energy use efficiency (g/KWh) was linearly related to crop light use efficiency (g/mol) and not related to photosynthetic photon efficiency (mol/KWh).

Dr. Nemali's lab, an on-going project involves smartphone based measurement of plant N status. Recent results, based on poinsettia and petunia species, indicated that image analysis technique can be used to remotely measure N content of plant stands in floriculture production.

Also in Dr. Nemali's lab, investigations into comparing hydroponic lettuce commonly grown under NFT and DFT systems. The research indicates that DFT system can yield higher yields than NFT system and the differences were related to better nutrient uptake by roots from the recycling solution under DFT than NFT.

At Purdue in Dr. Mitchell's Lab, Brassica rapa cv. Tokyo Bekana (Chinese Cabbage) were grown in analogue ground-based growth hardware for the international Space Station (ISS) performed poorly under environments designed to mimic those existing on ISS. Plants grown in a greenhouse or in growth chambers in the lab grew productively under typical ground-based growth environments. Even though Chinese cabbage was the number 1 candidate crop species for growth on ISS in preliminary screening tests on the ground at the Kennedy Space Center, it performed poorly in growth chambers under ISS-like conditions (except for micro-gravity).

The Ohio State University demonstrated that a minimum daily dose of UV-B light to prevent intumescence injury was found as 7-12 umol m-2 d-1 (3-5 kJ m-2 d-1 at 0.1-0.2 W/m2). This UV-B supplementation was applied during the nighttime.

At Rutgers, researcher Yuan Li continues to work on the effects of Silicon amendments to the nutrient solution used for hydroponically grown leafy greens.

Kennedy Space Center has initiated a series of tests to grow different leafy crops in controlled environments. These include chard, wasabi green, amara mustard, shungiku (an edible crysanthemum), several radicchio spp., several escaroles, sorrel, bok choi, red mustard, kale, red Russian kale, as well as lettuce. The intent of these tests to assess their potential for supplemental foods crops for space. KSC is attempting to follow some of the protocols used for the "baseline" testing with lettuce and marigold by NCR-101 members in the late 1970s.

At the University of Georgia, soil microbial respiration measurement deploying non-steady-state chambers integrated into Conviron growth chambers was investigated. Soil basal respiration measurement is widely used in studies of soil C cycling, net crop photosynthesis estimations, overall soil biological activity estimations, heterotrophic microbiological activity studies etc. Chamber technique can be adapted to a wide range of experimental objectives and commonly used approach in soil respiration estimations. To efficiently and economically measure soil respiration in large number of samples over extended incubation period, we chose non-steady-state chamber design (static system) that allowed us to integrate Vaisala GMP 222 carbon dioxide probe (widely used in Conviron chambers) into small-volume soil respiration chamber and perform real-time CO2 measurement under controlled environment conditions (PGW36 Conviron chamber). Time-dependent CO2 diffusion error was reduced by adding ventilation inside the respiration chamber (resembling flow-through chamber type), taking measurements at constant chamber deployment intervals, and increasing soil sample surface area. Based on continuous CO2 concentration measurements (18 second interval), the rate of CO2 accumulation ($\Delta C/\Delta T$) was estimated from the slope of the linear regression line. Experimental trial in the Calcisol soil sample showed initial two-fold increase in the respiration rate during the first 3-4 days of incubation and then gradually decreased for 3 weeks. (Viktor Tishchenko (Envirotron, University of Georgia) in collaboration with Nosir Shukurov (Institute of Geology and Geophysics, Uzbekistan))

At the University of Georgia, non-destructive high-throughput root system phenotyping for selective gene function screening of chemically induced mutant sorghum population was studied. There is growing interest in finding genes responsible for environmental stress resistances such as drought, heat, nutrient deficiency. Root morphology plays a crucial role in such adaptations but relatively fewer researches focused on the belowground phenotyping due to its complexity. Our goal was to develop a non-destructive high-throughput root system phenotyping platform to screen plants for various abiotic stress resistances. Ethyl methanesulfonate (EMS)-mutagenized sorghum population of the BTx623 wild type was used as germplasm material for identification of candidate genes. In the first phase of preliminary screening, sorghum plants were grown hydroponically and using paper pouches technique. Plants were grown until they reached paper edges (7-8 days), scanned on a scanner (Plustek OpticPro A320 scanner), and processed with root phenotyping software (RootReader2D). Preliminary generic root morphology data provides access to find association candidate genes with genotype variation or abiotic stress adaptations. Number of lateral roots, length of upper lateral roots, and root/shoot ratios characteristics were used to select candidate plants to screen for P-efficiency using sand-alumina culture. This media provides stable, diffusion limited, slow-release, controlled P availability conditions which closely resembles natural soil environment. Loose sand texture allows to efficiently separate roots from the media and to phenotype root morphology following the same procedure as in hydroponics/paper pouches. The platform we developed here would be useful for plant root morphology assays. (Viktor Tishchenko (Envirotron) in collaboration with Ming Li Wang (USDA, PGRCU))

The University of Georgia investigated why longer photoperiods with the same daily light integral increase daily electron transport through photosystem II. The annual energy cost for horticultural lighting in the US is approximately $600 million. To lower these costs, it is essential to provide light in a way that allows for efficient photochemistry. Because the quantum yield of photosystem II (ΦPSII), the fraction of absorbed light used for photochemistry, decreases with increasing photosynthetic photon flux density (PPFD), we hypothesized that electron transport through photosystem II integrated over 24 hr, the daily photochemical integral (DPI), increases if the same amount of light (daily light integral, DLI) is spread out over longer photoperiods. To test this, we measured chlorophyll fluorescence to determine ΦPSII and the electron transport rate (ETR) of lettuce (Lactuca sativa 'Green Towers'). Plants were grown at a PPFD of ~ 250 µmol·m–2·s–1. Chlorophyll fluorescence measurements were taken in a growth chamber equipped with LED lights. A datalogger controlled PPFD and photoperiod and collected ΦPSII and ETR data. DLIs of 15 and 20 mol·m–2·d–1, provided over photoperiods of 7, 10, 13, 16, 19, and 22 hours, were tested. PPFD during these measurements ranged from 189 to 796 µmol·m–2·s–1. ΦPSII decreased from ~ 0.69 at a PPFD of 189 µmol·m–2·s–1 to ~ 0.29 at a PPFD of 796 µmol·m–2·s–1, while ETR increased from ~54 to 100 µmol·m–2·s–1. DPI increased as a function of photoperiod and this increase was more pronounced at high DLI. At a photoperiod of 7 hours DPI was ~ 2.5 mol·m–2·d–1, regardless of DLI. However, with a photoperiod of 22 hr and a DLI of 15 mol·m–2·d–1, the DPI was ~ 4.2 mol·m–2·d–1 (68% higher than with a photoperiod of 7 hr), and with a DLI of 20 mol·m–2·d–1 the DPI was ~ 5.5 mol·m–2·d–1 (120% higher). Our results show that DPI is significantly higher with lower PPFD over a longer photoperiod than with higher PPFD over a shorter photoperiod, because the light is used more efficiently at low PPFD. Subsequent longer-term growth trials have shown that longer photoperiods with the same DLI do increase crop growth. These short-term physiological trials, combined with results from longer-term growth trials, indicate that applying supplemental light out over longer photoperiods results in more energy-efficient stimulation of crop growth. This research should encourage growers who use photosynthetic lighting to re-evaluate their current lighting protocols and consider using longer photoperiods. (Claudia Elkins, Michael Martin, and Marc van Iersel)

The University of Georgia studied the effects of different photoperiods with constant daily light integral on growth and photosynthesis of mizuna, lettuce, and basil. Most studies of photoperiodic effects on plant growth have used constant instantaneous photosynthetic photon flux densities (PPFD), which leads to different total daily light integrals (DLI) received in each photoperiod. Our objective was to quantify the effect of different photoperiods, all providing the same DLI, on crop growth. Because photosynthesis is more efficient at lower PPFD, we hypothesized that longer photoperiods with lower PPFD would result in faster growth than shorter photoperiods with higher PPFD. Mizuna (Brassica rapa var. japonica), 'Little Gem' lettuce (Lactuca sativa), and 'Genovese' basil (Ocimum basilicum) were grown from seed in a controlled environment chamber (20°C and 800 ppm CO2) under six photoperiods (10, 12, 14, 16, 18, and 20 hr). White LEDs provided light and PPFD was adjusted so each treatment received a DLI of 16 mol·m-2·d-1. Mizuna, lettuce, and basil were harvested 30, 41, and 55 d after planting, respectively. Light interception, chlorophyll content, and quantum yield of PSII were positively correlated with duration of photoperiod in all three species. Mizuna plants grown with a 20 hr photoperiod had 10.9% greater light interception, 94.6% higher leaf chlorophyll content index, and 10.1% greater quantum yield near the end of the growing period than those grown with a 10 hr photoperiod. Lettuce plants grown with a 20 hr photoperiod had 11.4% greater light interception, 13.7% higher leaf chlorophyll content index, and 10% greater quantum yield than those grown with a 10 hr photoperiod. Mizuna and lettuce plants both also had greater shoot dry mass (28.1% and 18% greater, respectively) when grown with 20 hr photoperiods compared to 10 hr photoperiods. There was no apparent correlation between photoperiod and dry mass in basil. Basil plants grown with a 20 hr photoperiod had 13.7% higher leaf chlorophyll content index and 10% greater quantum yield than those with a 10 hr photoperiod. Lettuce plants grown under shorter photoperiods had notably yellower leaves, steeper leaf angle, and more upright growth than those in longer photoperiods. These results show that plants receiving the same DLI can have markedly faster growth when provided light over a longer photoperiod, but the effect appears to be species-specific. This is an important consideration when determining optimal lighting strategies for crop growth. Photoperiod, PPFD, and DLI cannot be studied isolation without accounting for simultaneous effects of the other two variables on plant responses. (Shane Palmer, Eric Stallknecht, and Marc W. van Iersel)

The University of Georgia studied how improved photochemical efficiency of supplemental lighting increased dry mass and leaf area of greenhouse-grown lettuce. Photosynthetic responses to light intensity are generally asymptotic; light is used more efficiently to drive photosynthesis at lower light intensity. Thus, providing supplemental light at low intensities over longer periods should lead to increased photosynthetic gains, compared to an equivalent amount of light at higher intensities and shorter periods. To test this hypothesis, we used an adaptive LED lighting system in a greenhouse, which dynamically controls supplemental LED light intensity to reach, but not exceed, a specified light intensity. Using this system, 'Little Gem' lettuce (Lactuca sativa) plants were grown under a constant daily light integral (DLI) of 17 mol·m-2·d-1 provided over 4 different photoperiods; 12, 15, 18, and 21 hours. The average DLI in the control treatment (no supplemental light) was 7.89 ± 3.02 mol·m-2·d-1. Thus, the 4 treatments received slightly more than half of their light from the LED lights. Threshold light intensity was calculated as:

Threshold PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$) = 1,000,000 x [17 $mol \cdot m^{-2}$ – Current DLI]/Time remaining (s)]. Hence, while each treatment received the same amount of light within each 24-hour period, extending the photoperiod allowed the same amount of supplemental light to be provided at lower instantaneous intensities. The study was terminated after 22 days. Dry weight increased quadratically with photoperiod ($R^2 = 0.50$, $p=0.003$), from an average of 0.53 g/plant with 12-hour photoperiods to 0.75 g/plant with 21-hour photoperiods. In the control treatment, average dry weight was 0.17 g/plant. Leaf chlorophyll content and leaf size of the fully expanded leaves increased linearly as photoperiod increased. Leaf size increased from 57.2 cm^2 in the 12-hour treatment to 68.2 cm^2 in the 21-hour treatment ($p = 0.023$), and chlorophyll content index similarly increased from 9.81 to 12.1 ($p = 0.0015$). Leaf area and chlorophyll content were higher in all supplemental lighting treatments than in the control ($p < 0.0001$). These results may be partly attributed to an increased photosynthetic light use efficiency as photoperiod increased and supplemental lighting was provided at lower intensities over longer photoperiods. However, morphological acclimation to photoperiod or light intensity also occurred, as plants developed larger leaves with higher chlorophyll content under longer photoperiods. In conclusion, providing supplemental light in a photochemically-efficient manner improves overall growth of this lettuce variety. (Geoffrey Weaver and Marc van Iersel)

The University of Georgia investigated development of rapid light response curves as a high-throughput screening method for photochemical responses of bedding plants. Understanding plant photochemical responses to photosynthetic photon flux density (PPFD) is important for developing energy-efficient supplemental lighting strategies. However, the photochemical light response varies greatly among species and cultivars, and a rapid, reliable method to describe species- and variety-specific photochemical responses is needed. Chlorophyll fluorescence measurements were used to determine the electron transport rate (ETR) of six bedding plant species: Begonia semperflorens ‘Ambassador Scarlet’ (begonia), Catharanthus roseus ‘Jams N Jellies Blackberry’ (vinca), Impatiens walleriana ‘Super Elfin Violet’ (impatiens), Pelargonium x hortorum ‘Maverick Violet’ (geranium), Petunia x hybrida ‘Daddy blue’ (petunia), and Salvia splendens ‘Mojave’ (salvia). Diurnal measurements were conducted in a greenhouse with fluorescence measurements taken every 15 min during the day and hourly at night with 5 measurement days per species. Additional measurements were taken in a growth chamber using a hyperbolic series of PPFDs (0, 50, 150, 300, 500, 750, 1050, 1400 $\mu mol \cdot m^{-2} \cdot s^{-1}$), with 20 min acclimation at each intensity, and 5 replications per species. For 4 species, the data collected in the growth chamber was similar to the greenhouse data, but for impatiens and petunia observed ETR was generally lower in the greenhouse. This may have been due to physical damage to the leaves induced by the fluorometer leaf clip. In all cases, an asymptotic rise to a maximum function fit the data well. This function uses only two variables: the initial slope and the asymptote of the ETR response curve: ETR= [asymptote of ETR] x [1- e^ [-(initial slope of ETR/asymptote of ETR) x PPFD]. Accordingly, it was hypothesized that the photochemical light response could be adequately described by determining only the initial slope and asymptote: a rapid light response curve. This was tested in a growth chamber by measuring the ETR of each species at a very low (≈3 $\mu mol \cdot m^{-2} \cdot s^{-1}$) and very high (≈2100 $\mu mol \cdot m^{-2} \cdot s^{-1}$) light intensity for 5 min. The equation generated from this data fit the greenhouse ETRs with a mean $R^2=0.93$ and slope of 0.89; the estimated values were generally 11% higher than the observed ETRs. Similarly, it fit the previous growth chamber data with mean R2=0.96 and slope of 0.94 (estimated ≈6% higher than observed) for all species except for impatiens, which had a much higher slope (m=1.5, R2=0.94), suggesting that the high PPFD used to determine the asymptote was photoinhibitory for impatiens. This high-throughput method accurately describes the ETR response for 5 of the 6 species. (Geoffrey Weaver and Marc van Iersel)

The University of Georgia studied how higher daily light integrals with adaptive lighting control speeds up ornamental seedling growth. Supplemental lighting in greenhouse industry is often needed from late fall through early spring and can account for up to 30% of the value of crops produced. Reduction of this energy cost can be beneficial for profitable greenhouse crop production. Our study focused on quantifying the effect of daily light integral (DLI) on seedling production of bedding plants. We used an adaptive light-emitting diode (LED) control system to precisely control supplemental lighting by taking advantage of the dimmability of LED grow lights. The power of the LEDs was adjusted to provide only enough supplemental photosynthetic photon flux density (PPFD) to reach the threshold PPFD underneath the light bars. The threshold PPFD was recalculated every 2 seconds to assure that the crop received a specific DLI by the end of the 14-hour supplemental lighting period. This high-precision lighting control system provides supplemental light when plants can use it most efficiently, i.e., when there is little sunlight available. Therefore, we hypothesized that our adaptive LED control system stimulates plant growth more than ordinary lighting systems. We compared three adaptive lighting control treatments to achieve DLIs of 8, 12, and 16 mol·m-2·d-1 in 14 hours of supplemental lighting (10 am to midnight) to a treatment that supplied a PPFD of ~100 μmol·m-2·s-1 of supplemental light during the same 14 hours (average DLI was 8.6 mol·m-2·d-1), and a sunlight-only control treatment (average DLI was 5.4 mol·m-2·d-1). We used impatiens (Impatiens walleriana) ‘Accent Premium Violet F1’ and vinca (Catharanthus roseus) ‘Jams ‘n Jellies Blackberry’ for the study. Seedlings were harvested 40 days after seeding. The number of leaves, shoot fresh and dry weight, and plant compactness (shoot dry weight/ plant height) of both species were greatest in the treatment receiving a DLI of 16 mol·m-2·d-1, followed by the treatment receiving a DLI of 12 mol·m-2·d-1. Similar patterns were observed for root dry weight of impatiens, but not for vinca. Seedlings in the treatment that received a supplemental PPFD of ~100 μmol·m-2·s-1 had similar growth as those in the treatment with a DLI of 8 mol·m-2·d-1. The sunlight-only control treatment had the slowest seedling growth. These results suggest that our adaptive LED control system is capable of controlling LED's precisely while stimulating the plant growth more at higher DLIs. However, growers should determine whether the better growth from more supplemental lighting is worth the cost of providing that light. (T.C. Jayalath and Marc van Iersel)

The University of Georgia demonstrated how night interruption with light emitting diodes applied using simulated moving greenhouse booms promotes flowering of petunia x hybrid. Long-day plants (LDP) require night interruption to promote flowering when grown out-of-season (i.e., early spring). Accelerating flower development shortens the cropping cycle and thus reduces crop inputs like water and fertilization. There are multiple ways to promote flowering in

LDP. Cyclic night interruption, night interruption applied in many short periods rather than one long continuous period, is less studied than other methods but can effectively provide night interruption. Many greenhouses use moving booms to apply irrigation, fertilization, and pesticides. Small lighting fixtures attached to these booms can successfully provide cyclic night interruption, often termed “boom lighting”. We hypothesize that boom lighting from light emitting diodes (LEDs) can promote flowering of Petunia x hybrida as well as traditional methods. A growth chamber with programmable lighting fixtures can accurately mimic moving irrigation booms by gradually increasing and decreasing the provided light intensity. The effects of cyclic night interruption on flowering was tested using night interruption lighting provided at 30, 60, 120, and 240 second intervals between simulated boom passes. Cyclic night interruption applied to seven-week-old petunia seedlings slightly reduced days to first open flower, by up to 3 days. Our highest cyclic night interruption frequencies, boom passes every 30 and 60 seconds, increased total number of visible inflorescences, but also increased plants height and resulted in less compact plants. To account for additional light from night interruption we also calculated days to flower and the number of inflorescences divided by the total light over a 24-hour period (daily light integral + treatment light integral). This showed that increasing cyclic night interruption frequency does not proportionally reduce days to flower but does proportionally increase the number of inflorescences. Further exploration into the lowest light intensity and lowest frequency that promote flowering are required to make boom lighting more commercially viable. (Eric Stallknecht and Marc van Iersel)

Heliospectra has ongoing commercial crop research is structured to customers’ specific cultivation and business objectives, identifying the impact of individual light wavelengths, schedules and controls on desired plant characteristics, crop performance and finished quality of lettuces, microgreens, herbs, ornamentals, tomatoes and medicinal cannabis.

Dr. Dan Herr, Joint School of Nanoscience and Nanoengineering at North Carolina A&T studied Hydroponic Routes to Nutritionally Enhanced Nutraceuticals and Functional Textiles. This work uses cotton and flax plants combined with nanosensors and “brightner” dyes in hydroponic nutrient solution. Example of applications could be cotton incorporated in hospital sheets that could analyze the sodium content of a patient’s sweat.

Over the last year, Corteva Agriscience has focused on two plant responses related to growing corn consistently in greenhouses year round: 1) poorly developed tassels and 2) “fusing” disorder in seedlings and rapidly growing vegetative plants. Observations of poorly developed tassels are more common in late January through March in our Johnston, IA greenhouse location (Figure 2). The annual and periodic nature led us to believe it was light related, but the shift in appearance later than the winter solstice when light was most limiting confused the root cause analysis. Additionally, not all germplasm displayed the symptoms at the same time, leading us to wonder if there were multiple factors at play. However, corn tassel development occurs in vegetative phases, and that development can be much earlier (by weeks) than the initial appearance of the tassel. In a series of experiments, we grew different corn genotypes in sufficient light (25 mol m-2 d-1) and placed them into low light (10 mol m-2 d-1) for a week before returning them to sufficient light conditions. We targeted different vegetative stages and staggered the treatments in their development from the 4-leaf stage through to tassel emergence. We found, depending on the genotype, that low light negatively impacted tassel development between the 6 and 8 leaf stages, but had no effect in any other time in development. This led us to alter how we arrange and organize plant growth areas to improve light supply at critical developmental stages. This work and the resulting actions were submitted to IP.com; the final publication was anonymous, but Libby Trecker, Chris Currey, and Brian Krug were key contributors to this work. Similar to the observations on tassel development, we have seen an increase in "fusing" symptoms, especially in young plants, during winter months (Figure 3). Also known as buggy whipping, bull whip, rat tailing, rapid growth syndrome, root-cause analysis was challenging because this persistent problem seems to be triggered by a variety of cultural and environmental conditions. For example, over- and under-watering, low light, specific genotypes, high humidity, low humidity, heavy substrate, and water delivery method have all been blamed on this disorder. It basically presents as a Ca disorder, and can therefore be looked at like lettuce tipburn. In lettuce, conditions leading to rapid growth rates trigger the Ca disorder (e.g. excess light above 17 mol m-2 d-1) and if other environmental factors are not in balance to support such rapid growth rates, crop loss can occur. Applying the same model to corn resulted in finding conditions that support rapid growth rates, are easily controlled at scale, and do not compromise short cycle times needed for high-throughput product pipeline support. High humidity (80% RH), high light (at least 15 mol m-2 d-1 for seedlings and at least 20 for vegetative phase), and full wet-dry cycles in irrigation lead to reduced fusing. There are clear genotype differences in fusing susceptibility, but in a well-managed or automated system, all can be grown successfully with no fusing.

3. <u>Accomplishment Summary:</u>

- Modular Farms container systems (NOT shipping containers), developed in conjunction with the University of Guelph's CESRF, continue to grow with seven units in use producing leafy greens and 10 more currently in production.

- EDEN ISS, an EU 2020 Antarctic 'greenhouse' project coordinated by the German Space Agency and involving a large consortium of European, Canadian and American partners was successfully delivered to Antarctica in December 2017. CESRF provided the hydroponics and control systems. The system will be tested over the Antarctic winter and will provide supplemental food to the overwintering staff at Germany's Neumayer III Station.

- A pilot scale seven-layer (215m2/2300 ft2) automated vertical farm is currently being tested in Toronto and will be used in the University of Guelph's graduate program while producing romaine lettuce for local restaurants.

- Work is underway at the University of Guelph to evaluate the potential of using spectral quality to improve rooting success and manage shoot growth in Kalanchoe to speed production and lower the requirements for PGR's.

- A seed sterilization protocol for Nicotiana benthamiana is in the final stages of testing at the University of Guelph and should help improve commercial production of phyto-pharmaceuticals.

- For the Purdue University NASA ILSRA project, controlled environments proved to be at least part of the reason why Chinese cabbage failed to thrive under ground-based conditions mimicking the ISS cabin environment in which edibles are grown in veggie plant-growth units. Controlled-environment plant-growth rooms on the ground mimicked ISS humidity, temperature, and CO2 concentrations. In addition, the use of ground-based Veggie-analogue growth chambers, called Biomass Production Systems for Education (BPSes), allowed us to re-create the light and controlled-release fertilizer environments that also are used in space, many by default rather than by choice. From the outset, it became obvious that Chinese cabbage was not happy with one or more conditions under which it was being grown. This triggered a systematic investigation of environmental and/or cultural conditions responsible for the impaired growth, chlorosis, and necrosis that were observed for every experiment. Investigations included whether the Veggie "pillows" the plants were growing in (to prevent media and water from floating away in the ISS cabin were causing root zone hypoxia; whether the arcillite plant-growth medium being used was causing micro-nutrient toxicities; whether focused red light from the BPSe was causing photobleaching of leaves leading to chlorosis, necrosis, etc.; and whether the balance of different controlled-release fertilizers was causing nutrient deficiencies. Attempts included different red:blue ratios of light, pre-leaching of arcillite medium, switching from pillows to a larger cylindrical growth system likely to deliver more O2 to the root system, growth in the greenhouse under natural solar light, and more. Other than plants grown in the greenhouse looking normal, all efforts to find limiting factors were ineffective, until supra-optimal CO2 was investigated. The CO2 environment of ISS averages 2800 umol/mol, about 7-fold higher than ambient on Earth. Systematic investigation of Chinese cabbage growth in response to different CO2 concentrations found that growth impairment and likely CO2 narcosis leading to chlorosis and necrosis of leaf tissues began at CO2 concentrations much lower than 2800 umol/mol. It is possible that other lines of investigation that led to seemingly blind alleys interacted with supra-optimal CO2, but most growth limitations seemed to be alleviated by correcting the CO2 environment per se.

- The Ohio State University participated in the Ohio Winter Strawberry Day and Open House which was organized on January 6, 2018 with 52 participants from Ohio and neighboring states.

- The 2018 Greenhouse Management Workshop was organized by Peter Ling of Ohio State with 88 participants. This year's focus was hydroponics and the program included controlled environment production practices of different crops (tomato, lettuce, and strawberry), lighting technologies, as well as humidity management, pest/disease management, as well as food safety.

- The Macdonald Campus of McGill University is researching means to use biomass for heat and carbon dioxide enrichment in controlled environments with a focus on greenhouses. The system combines an electrostatic chamber and a cyclone section that allow for extended operation of the traditional air filter. This last year we worked on developing technology to extend the operation of the electrostatic chamber and remove VOC that may be generated and present in the combustion gas. Stability of the system has been very good with up to 7 days of continuous operation possible with longer term testing required. We are continuing this research and are hoping to enter into an option agreement with an industry partner to build a commercial unit.

- McGill University cntinues 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 have begun to add in amber LEDs to the red and blue mixture with improved production of lettuce plants. Research is expanding to include Arabidopsis and tomato plants and will be publishing these results this coming year.

- McGill University has continued to develop a cooling systems for a greenhouse called the NVAC, with test units build at campus, inside a greenhouse and at Barbados. The data collected from the NVAC is expected to be published this coming year.

- The design of a northern greenhouse is continuing at McGill University with further testing and improvements required. A successfully grown a crop of lettuce and fruit set on tomato plants inside the unit was accomplished. There is an extensive collaboration with northern partners and are hopeful that this research will result in a northern operation in the coming year.

- McGill University has begun testing on using porous concrete for plant growth. The porous concrete was tested using different concentrations of Hoagland's solution with the slag based porous concrete. The double Hoagland treatment porous concrete had similar dry mass values as the rockwool treatment. The radish in the double Hoagland treatment yielded a lower fresh mass with respect to rockwool (84.7%) but a higher dry mass than rockwool (125.4%). The nutrient absorption in the slag porous concrete treatments was observed to be different than the nutrient absorption in the control rockwool treatment. The elevated EC and pH in the slag porous concrete treatments did not hinder the rate of germination and produced plants with lower water contents. The slag porous concrete proved phosphate adsorption and did create noticeable phosphorus deficiencies in the tomato plants grown. Similarly, nitrogen deficiencies were seen in radish plants in the Hoagland treatment. It is suggested that plant nutrient uptake is dependent per plant species and the ideal range of nutrient concentrations could have been located between the single and double strength Hoagland.

- Rutgers continues 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. We published a paper that proposes the use of a standardized product label for lighting products used in horticultural applications. We are working on a comprehensive evaluation of ventilation strategies for high tunnel crop production. We are working on an evaluation of energy use in commercial greenhouses and comparing the information to model-based predictions. A variety of outreach presentations on the engineering aspects of high tunnels, greenhouse production, and energy consumption have been delivered at local and out-of-state venues.

- Gioia Massa of Kennedy Space Center continued to oversee some of the "validation" testing with Veggie plant growth systems on the International Space Station (ISS), which included a third trial with red romaine lettuce, and the first two tests with Chinese cabbage. Gioia has a 3-yr NASA grant to conduct the first official plant testing using Veggie (with leafy greens and dwarf tomato in 2018). Ray Wheeler, Mary Hummerick, Matt Romeyn and LaShelle Spencer 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 leads this research at KSC and continues to run ground studies as we prepare for flight. The focus of this research is to assess fertilizer and light quality impacts on crop growth, nutrient content, and organoleptic appeal. We have worked closed with Florikan Inc. to assess different controlled release (CR) fertilizer combinations. In addition to lighting and fertilizer, we are testing a new Veggie water delivery systems called PONDS (Passive Orbital Nutrient Delivery System), which holds a container of solid growth media (e.g., arcillite and CR fertilizer) that is surrounded by a small reservoir of water. The concept was designed by Howard Levine, Jeff Richards, and Larry Koss and KSC, and a flight system has been developed by Techshot Inc. and Tupperware Brands. Proof-of-concept flight testing of PONDS should start soon with the first set launched to the ISS April 2, 2018.

- KSC researchers LaShelle Spencer, Matt Romeyn, and Ray Wheeler, along with super undergraduate and graduate interns, initiated several of growth chamber tests with lettuce, mizuna, radish, dwarf tomato and dwarf peppers to assess their microbial counts, and are comparing these to similar vegetables purchases in local grocery stores. The intent of these studies is to establish some baseline or "norm" for acceptable microbial counts and food safety considerations for edible space crops.

- KSC researchers Matt Romeyn, Oscar Monje, and Larry Koss have set a several test bed to compare different watering techniques that might be considered for space applications (primarily looking at systems for μ-gravity operations). These challenges are not new but we want to establish some baseline data for a possible new NASA mission to develop a "deep-space gateway", which would be positioned somewhere near the moon and provide a staging point for lunar surface or Mars transit missions. The Gateway would only be "manned" for perhaps 1 month out of a year, so the ability to have autonomous operations, start-up, and shut-down would be an important consideration.

- NASA post-doc researcher Matt Mickens completed his comparison of lettuce growth under white LEDs supplemented with various narrow-band LEDs of red (635 nm), blue (460 nm), green (525 nm), and far red (745 nm). The white LED control treatment had a ~2800 K color temp. A sixth treatment utilized a Heliospectra light fixture with LEDs at 425, 525, 660, and 735 nm. Using a PPF of about ~200 μmol m-2 s-1 with an 18-h photoperiod, we saw the best overall growth for lettuce with the Heliospectra LEDs, and lowest biomass under red and blue LEDs only. When applying similar treatments to Red Pak Choi, conversely the optimal light recipe for edible biomass and leaf area were red (660 nm) and blue (460 nm) LEDs only, and any addition of green, far red, or broad spectrum light reduced leaf area, while increasing stem elongation.

- The University of Georgia has shown that 'adaptive' lighting control, which adjusts the amount of supplemental light provided based on the amount of current sunlight, can be used to provide precise daily light integrals in user-defined photoperiods. The method provides growers a consistent day-to-day light environment, even if weather conditions are highly variable.

- The University of Georgia has shown that identical daily light integrals result in greater photosynthetic efficiency and biomass production when that light is spread out over longer photoperiods. For non-photoperiodic crops, longer photoperiods can increase production without increasing power use.

- Sierra Nevada Corporation is continuing work on 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). Current efforts include development of aeroponic and nutrient film technique (NFT) hydroponic systems for use in the space environment as a way to significantly reduce the mass, power, and volume of plant nutrient delivery systems while maintaining good plant productivity.

- Sierra Nevada Corporation continues to work with the Kennedy Space Center (KSC) to support the Veggie plant growth system hardware that is on-board the ISS. A second Veggie unit was installed on the ISS in 2017.

- Sierra Nevada Corporation delivered the Advanced Plant Habitat hardware to the Kennedy Space Center. The Advanced Plant Habitat system was installed on the ISS in late 2017 to be used for a wide range of microgravity plant research. This system is the largest plant growth system put in space to date. An initial check out with Apogee wheat and Arabidopsis was completed in the spring of 2018.

- Sierra Nevada Corporation continues to work with Commercial Crew Integration Capabilities partners for development of human Life Support and Thermal Control systems for space habitats.

- Sierra Nevada Corporation is continuing development of a deep space, long-duration, human habitat prototype for NASA.

- LumiGrow has conducted experiments investigating the effect of photoperiod while maintaining identical daily light integral on the vegetative growth of leafy greens, and vegetable seedlings. In general, in the growth chamber environment a 21-h photoperiod resulted in increased growth and coloration when economically significant.

- LumiGrow has Beta-tested of light sensor-mediated daily light integral control was implemented at multiple commercial partners to compare lighting control against current greenhouse control methods and expand user interface with specific grower use scenarios.

- LumiGrow completed first full year of a multi-phase production study comparing production of high-wire indeterminate greenhouse cucumbers under supplemental lighting from HPS lamps and LED overhead lighting. After two harvest cycles, production is greater under LED supplemental lighting through increased DLI resulting from flexibility of lighting delivery, specifically because total energy load is lower and there is greater ability to control intensity via software.

- Heliospectra secured funding in 2017 from the European Agricultural Fund for Rural Development in collaboration with Hushållningssällskapet, Swedish University of Agricultural Sciences (SLU) and Research Institutes of Sweden (RISE) for a research project on year-round greenhouse cultivation of Swedish strawberries. Sensory and nutritional analysis will determine the impact of supplemental lighting and spectra composition on the taste, aroma and color of fruit.

- Heliospectra began work with Dr. Youbin Zheng and his research associate David Llewellyn at the University of Guelph on a LED control system. The initial 2017 study investigated cut gerbera production under threshold-controlled HPS with intelligently controlled LED using the Heliospectra HelioCOREÔ feedback-controlled system to manage multichannel intelligent LED grow lights. The LED control strategies demonstrate opportunity to enhance crop productivity by attenuating fluctuations in DLI and canopy-level PPFD while simultaneously minimizing energy cost by 15%.

- During the first quarter of 2018, three Heliospectra customer facilities were also installed as beta sites for the HelioCORE light control system to document consistency in crop quality, real-time dynamic response of supplemental lighting based on changes in local weather and environmental conditions, and the potential for commercial growers to accelerate harvest cycles. Customer sites include: John Innes Research Centre with supplemental lighting and control for glasshouse in Norwich, United Kingdom, Greenbelt Microgreens with supplemental lighting and control for greenhouse in Hamilton, Ontario, Canada, and The Grove Nevada with sole-source lighting for indoor vertical cultivation in Las Vegas, Nevada, United States.

- Dr. Gregory Goins, Dept of Biology NCA&T, collaborators NCCU
  Was awarded funding for the project entitled: Building Diverse and Integrative STEM Continua Using Socio-environmental Systems In and Out of Neighborhoods (DISCUSSION) National Science Foundation ($300,000 over 2 years) - Inclusion across the Nation of Communities of Learners of Underrepresented Discovers in Engineering and Science. NSF INCLUDES is a comprehensive initiative to enhance U.S. leadership in science and engineering discovery and innovation by proactively seeking and effectively developing science, technology, engineering and mathematics (STEM) talent from all sectors and groups in our society. By facilitating partnerships, communication and cooperation, NSF aims to build on and scale up what works in broadening participation programs to reach underserved populations nationwide.

- Dr. Tonya Gerald-Goins, Dept of Chemistry and Biochemistry, NCCU, NCA&T and Bennett College was awarded funding for the project entitled: Bio-monitoring of Persistent Xenobiotic Contaminants in Natural and Constructed Wetland Ecosystems (NSF HBCU UP Excellence in Research – ($1 million over 3 years). This research investigates the bioremediation of xenobiotic contamination. We proposed the following research questions to address our hypothesis: The identification of GenX/HFPO-DA in the Cape Fear River has caused great concern in NC. Recent research suggests that duckweeds - small, simply constructed, floating aquatic plants, are well suited to addressing this concern. Research questions include; can model wetland organisms help remediate xenobiotic contaminated water sources by facilitating their removal? And can model wetland organism serve as diagnostic biomarker agents for the presence of xenobiotics? The ability of duckweeds to grow rapidly on nutrient-rich water and to facilitate the removal of many substances from aqueous solution comprises the potential of these macrophytes for the remediation of xenobiotic-polluted aqueous sources, while producing usable biomass containing the unwanted substances having been taken up. Their ease of cultivation under controlled and even sterile conditions makes duckweeds excellent test organisms for determining the harmful effects of xenobiotics to the ecosystems. Duckweeds are also valuable for establishing biomarkers for the harmful effects of xenobiotics on aquatic higher plants, but the current usefulness of duckweed biomarkers for identifying these xenobiotics is limited. The recent sequencing of a duckweed genome holds the promise of combining the determination of xenobiotic harmfulness with contaminant diagnostics by means of gene expression profiling of know biomarkers.

- Dr. Adrienne Smith, Dept of Biology NCA&T earned a Google Innovation Award for Automated Hydroponics with an Arduino in Desktop Deep Hydroponic Culture Systems. Students are incorporating high technology systems which are currently being used in new automated manufacturing facilities. Students are integrating use of robots and work cell components, switches, proximity, vision and photoelectric sensors, with the automated control and data gathering in hydroponic systems. Upon completion, students should be able to install, program, and troubleshoot an automated system and collect associated data with their cell phones with affordable small desktop hydroponic systems.

- FFAR awarded a Seeding Solutions grant to AeroFarms, an indoor vertical farming company with global headquarters in Newark, New Jersey leading the industry since 2004. The project aims to improve crop production by defining the relationships between stressed plants, the phytochemicals they produce and the taste and texture of the specialty crops grown. The work will result in commercial production of improved leafy green varieties and yield science-based best practices for farming. This new approach will investigate how to harness environmental conditions to improve the characteristics of plants grown indoors, where conditions like temperature and humidity can be maintained with precision."

- Dr. Kacira at the University of Arizona, in collaboration with Grafted Growers LLC., completed a USDA-SBIR Phase II project. CFD based modeling evaluated various air flow distribution systems and proposed a design that improved air flow uniformity and environment in transplant production beds for multi-tier based vertical farm system. The proposed design is being implemented by the company in their scaled-up production system.

- In 2017 at the University of Arizona, six, 5-day Intensive Grower crop specific courses (116 attendees @ 40 hours each); and one, 6-day General Greenhouse course (65 attendees @ 32 hours each); total of 181 attendees in 7 courses for 6720 contact-hours. Intensive courses offered by Myles Lewis (Lettuce) and Stacy Tollefson (Tomato) with organizational help by Gene Giacomelli and program coordinator Austin Smith.

- Annual CEAC Research Retreat, 25 students, 6 faculty, 3 staff and University of Arizona CEA enthusiast and friends presented introduction to their current CEA activities, August 11-

2017, moderated by Kacira and organization support with Austin Smith, CEAC Program Coordinator.

- GHP/GAP Certificate training class, Stewart Jacobson, Food Safety Projects Coordinator, Agricultural Consultation and Training, Arizona Department of Agriculture, June 13, 2017, at the CEAC, 29 attended, organized by Gene Giacomelli of the University of Arizona.

- University of Arizona CEAC organized the 17th Greenhouse Crop Production and Engineering Design Short Course (March 12-16, 2018) with 110 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 with theory and practical use.

- A one-week tomato production intensive course was offered by Dr. Stacy Tollefson of the University of Arizona to 20 participants in January 2018.

- Two one-week lettuce production intensive course was offered by Myles Lewis of the Arizona Vegetable Company to a total of 30 participants in January and March 2018.

- Dr. Cuello of the University of Arizona has been directing the Arizona Green Box, a modular vertical farming project using a shipping container in which students grow crops hydroponically using artificial lighting. Dr. Cuello and his students designed an original cultivation system, the V-Hive Green Box, that is intended to achieve maximum crop productivity per unit volume in a vertical farm facility, is amenable to automation, and for which a provisional patent has been secured by the UA. Sponsored by the UA Green Fund, the Arizona Green Box has been providing educational outreach to students and members of the community to foster awareness of food security and environmental sustainability.

- The Secure, Sustaining & Sensational CEA Dinner and 'awareness-raiser' (April 6) was hosted for University of Arizona CEAC stakeholders and the Tucson community to showcase regional gastronomy and the staple CEA is for securing local food sources. The Carriage House Downtown, Fund-raiser, 130 people attended.

- The CEA Leadership Forum Southwest (April 7) brought together University of Arizona CEAC stakeholders for a pre- Advisory Board meeting, to discuss the positioning of CEAC's research, education and extension activities with industry demand, 40 people, CEAC faculty, staff, students, and industry participants attended.

- Presentation to the USDA NIFA Listening Session "NIFA Listens: Investing in Science to Transform Lives", stakeholder meeting November 2,2017, Sacramento, CA. Prepared/Delivered informational documents by Gene Giacomelli of the University of Arizona.

- Member of EDEN ISS FRR - SAB Scientific Advisory Board for the DLR EDEN-ISS Antarctic project, Daniel Schubert, June 2017 by Gene Giacomelli of the University of Arizona.

- Gene Giacomelli of the University of Arizona completed a 6-month Sabbatical visiting California, Florida, New Hampshire, and the Netherlands with focus on the wine grape, strawberry, raspberry and blueberry production capitols of the US.

- M.S. student Mengzi Zhang and adviser Erik Runkle assessed the effectiveness of hybrid supplemental lighting on greenhouse cut lettuce quality (growth, yield, and leaf coloration) when provided at different growth phases. Supplemental lighting produced a more compact lettuce and increased yield. A combination of red and blue light was more effective at reducing lightness and yellowness and increased red pigmentation for red-leaf lettuce.

- Ph.D. candidate Qingwu (William) Meng and advisor Erik Runkle investigated the role of green light in growth and morphology of lettuce and kale grown hydroponically indoors. Similar to far-red light, green light antagonized blue light effects, promoting leaf expansion and biomass accumulation.

- Ph.D. student Yujin Park and adviser Erik Runkle investigated the cause of stem elongation and subsequent flowering promotion in some ornamental seedlings grown under mint white LEDs for sole-source lighting compared to under a mixture of blue and red light.

- Ph.D. student Kellie Walters and advisor Roberto Lopez quantified the influence of temperature and daily light integral on growth and development of greenhouse-grown sweet basil and the influence of sole-source light intensity and CO_2 concentration during seedling development. In general, increasing temperature resulted in greater biomass at higher light intensities. By increasing sole-source light intensity from 100 to 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$, fresh mass of seedling transplants increased resulting in a subsequent harvestable basil yield increase of 80%.

- Ph.D. student Joshua Craver and advisor Roberto Lopez evaluated the morphological and physiological responses of petunia seedlings to varying light intensities, light qualities, and CO_2 concentrations for indoor production. While seedlings showed significantly higher photosynthesis per unit leaf area under increased intensities of blue radiation, the increase in leaf area observed under increased intensities of red radiation ultimately led to greater light interception and dry mass accumulation. Additionally, acclimation to elevated CO_2 concentrations (reduced carboxylation efficiency) may limit potential gains from this input.

- MS student Alison Hurt and Ph.D. student Kellie Walters and advisor Roberto Lopez evaluated the photoperiodic responses of several foliage annuals. Some species were day neutral while others were obligate short-day plants requiring a 14-h photoperiod or longer to inhibit flower.

- M.S. student Charlie Garcia and advisor Roberto Lopez evaluated the photoperiodic responses of basil species and cultivars. Ocimum basilicum var. citriodora and O. tenuiflorum can be classified as facultative short-day plants and O. basilicum and O. ×citriodorum as day-neutral plants.

- M.S. student QiuXia Chen and adviser Ryan Warner utilized a genetic mapping population in Petunia grown at four field locations around the country (CA, PA, NC and FL) to identify chromosomal regions (QTL) that control field flowering performance traits. These data were then used to identify greenhouse production traits that may be predictive of field performance.

4. Impact Statements:

- After 30 years in operation, the McGill University Phytotron facility continues to provide scientists with high quality, reproducible environmental conditions for the study of plants and organisms. Our facility averages 75-80% occupancy and serves numerous McGill departments and 3 external universities in the province of Quebec. A total of 35 projects were conducted over the past operating year involving 125 academic and support staff & students.

- The MP3 (McGill Plant Phenomics Platform) is utilizing two LemnaTec phenomics platforms (HTS & Scanalyzer 3D) to examine non-coding RNAs in Camelina sativa and other species with the aim of discovering agricultural breeding trait-improvements.

- Dr. Nemali's Lab at Purdue has developed a new course 'controlled environment production of horticulture crops' was taught during spring 2018. First batch of 11 students completed the course with flying colors! Student projects included building hydroponic production systems, studying economics of growing lettuce under sole source lighting and economics of supplying growing lettuce with artificially heated nutrient solution under colder air temperatures.

- Two hydroponic workshops were conducted in 2017 at Purdue University. A total 95 growers attended the workshops. Growers learned about artificial lighting and nutrient requirements of hydroponic crops and were exposed to research being conducted at Purdue.

- Dr. Nemali manages controlled environment agriculture website (www.purdue.edu/hla/sites/cea) specifically developed for growers, extension educators, students to visit extension and applied research pages. The extension page hosts Purdue Greenhouse Newsletters, Extension Bulletins and Greenhouse Archives. In November, December 2017 and January 2018, Dr. Nemali's website had total unique site visits of 3172, 2625 and 2909, respectively averaging 2902 unique views per month (source:

Angelfish).

- Dr. Mitchell's Lab at Purdue has discovered that screening species for growth on the ISS, it is important to mimic all environmental and cultural parameters occurring in space that it is possible to mimic during initial screening on the ground. Because other species that have been grown on ISS, such as 'Outredgeous' leaf lettuce, grow very well under ambient IIs cabin conditions, Chinese cabbage 'Tokyo Bekana' appears to be a genotype that does not react well to those conditions. Whether the negative growth reaction is unique to that cultivar of Chinese cabbage has not been investigated.

- The Ohio State University has shown that the custom LEDs designed for targeting photons over short crops grown in a fixed narrow row configuration (such as strawberry plants on raised gutters or table top systems) were found effective to reduce the electricity costs. In a small greenhouse application (1,000 sq ft), replacing six 1000-W metal halide lamps with 24 155-W LEDs (38% energy saving) while increasing the PPFD by nearly 100%.

- The Biomass Production Laboratory at McGill University has shown that plant growth on porous concrete is possible with very strong results growing plants at pH up to 9. We are working with our industry partners to refine this substrate technology and allow for it to reach commercial scale production. The results have shown that plants have a very strong ability to grow at elevated pH levels and with proper nutrient management can reach and surpass the yield on rockwool. We are working with our industry partners to develop applications of this material including architecture, coastal restoration and ecological locations in addition to horticultural applications.

- Nationwide, Extension and NRCS personnel at Rutgers University and commercial greenhouse growers have been exposed to research and outreach efforts through various presentations and publications. It is estimated that this information has led to proper designs of controlled environment plant production facilities and to update operational strategies that saved an average sized (1-acre) 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 and regional audiences. Greenhouse growers who implemented the information resulting from our research and outreach materials have been able to realize energy savings between 5 and 30%.

- Thanks to many hard working colleagues at KSC, Orbitec, and numerous universities, and the controlled environment plant research community, we have successfully extended their reach to the International Space Station with a second Veggie plant growth unit and now the Advanced Plant Habitat (APH). The APH is the largest plant growth chamber ever flown (~0.2 m2 growing area) and will be used for fundamental plant research in space. APH uses porous steel watering tubes embedded in trays of arcillite, and provides a well-controlled, closed environment that will allow tracking of whole canopy photosynthesis, respiration, and transpiration. As with the prior Astroculture and BPS chambers flown in space, the humidity is condensed and recycled back to the plants. Lighting is provided by a range of narrow-band along with white LEDs, and can provide up to ~800 µmol m-2 s-1 at the plant level. Initial validation tests in APH using dwarf wheat and Arabidopsis thaliana were recently completed and follow on testing is planned.

- Electricity costs for supplemental lighting can be a major cost for greenhouses. The adaptive LED lighting control system, developed in the Horticultural Physiology Lab at the University of Georgia, automatically provides supplemental light when it can be used most efficiently by the plants (when there is little sunlight). The adaptive LED lighting control system also can assure that specific, consistent daily light integrals are provided to crops, regardless of weather conditions. Using the adaptive lighting control to provide the same daily light integral over longer photoperiods can enhance crop growth.

- Sierra Nevada Corporation is working toward development of hybrid life support systems for space applications, integrating biological and physical/chemical technologies.

- Sierra Nevada Corporation 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.

- Sierra Nevada Corporation is developing LED lighting configurations and control strategies for plant and human lighting applications to provide increased lighting system utility for aerospace and gravitational biology applications.

- Sierra Nevada Corporation 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 Greenhouse Lighting and Systems Engineering (GLASE) consortium is bringing together industries and researchers from different sectors in an open platform to integrate advanced energy-efficient LED lighting with improved environmental controls for more efficient and sustainable greenhouse production.

- The GLASE consortium is developing a framework to support collaboration with lighting companies aimed to promote technology development and increase the adoption of horticultural lighting and control systems by CEA producers. Having identified lighting companies as the consortium’s primary beneficiaries and CEA producers as target customers, GLASE will work with its industry members to demonstrate the benefits of energy-efficient technologies and expand the market for all segments of the CEA supply chain.

- Guided by both the needs of CEA producers and GLASE researchers’ findings new technologies will be validated through multi-phase processes from scientific proof of concepts to implementation in commercial greenhouses.

- GLASE has secured a $5 million investment to develop a multi-year holistic research program with more than 350 specific technical milestones ranging from new LED encapsulants and drivers to integrated greenhouse control systems implementation.

Working together, Cornell University, Rensselaer Polytechnic Institute and Rutgers University are combining complementary areas of expertise to design and develop innovative greenhouse lighting and control systems.

- In the greenhouse, LumiGrow demonstrated that the same DLI over a 21-h photoperiod compared to a 12-h results in greater fresh weight, increased coloration and reduced tip burn in two varieties of red-leaf lettuce. Providing supplemental lighting at 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ resulted in a more profitable production system compared to 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ or no supplemental lighting for winter production of hydroponic greenhouse strawberries in the Great Lakes region.

- Heliospectra collaborates with leading research institutions, scientific agencies and commercial growers to further the technical development, knowledge transfer and market adoption of LED lighting technologies and light control systems. Heliospectra's customer applications identify opportunity for businesses to standardize yields year-round, ensure highest quality crops and maintain consistent nutritional profiles while reducing the energy demand of controlled environment agriculture and facilities between 15% and 40%.

- North Carolina A&T has used hydroponics to link university expertise to school systems that strengthens educational opportunities. This provides opportunities for students to envision and pursue careers in science. Hydroponics and controlled environments can help empower teachers with new approaches to increase science learning at minimal cost. We feel that this strengthens the education foundation for economic development and prosperity for underserved communities.

- University of Arizona demonstrated how using the controlled environment changed the future in the development of new varieties of field corn for animal feed. Stefanie Boe, Monsanto Company's Community Relations/Site Enablement Lead stated that: "CEAC has been an instrumental partner in developing the necessary technology and capacity to conceive and build our new $100M Marana, Arizona Greenhouse Complex, creating 40 - 60 new local jobs which range from HVAC engineers to plant biologists, and access for others within the company." The Marana facility represents a highly automated greenhouse hydroponic crop production system for the continuous yearly production of seed corn for breeding new varieties. Future benefits to the farmer include new breeding lines, developed up to 3 years faster (7 rather than 10 years), that ultimately create new corn varieties with attributes farmers will need, such as drought or salt tolerance to meet the effects of climate change. Given that the Monsanto Company supplies 70% of the world's feed corn production our science and engineering technology will be affecting billions of dollars of the global agricultural economy. This new system recycles all its irrigation water and nutrients for seed corn production, and it requires only 20% of the total amount that is used in field production. Furthermore, with recycling, there is no discharge to the environment of waste water or plant nutrients. The closed environment of the greenhouse makes IPM [Integrated Pest Management] highly effective for control of pests and diseases, effectively eliminating the need for chemical pesticides.

- Supplemental lighting with light-emitting diodes during different growth phases can help growers customize the shape and color of the lettuce product, increase yield, and potentially reduce electrical costs.

- Substituting green light for blue light in vertical farming increased lettuce leaf expansion by up to 37% and shoot dry weight by up to 54%. This would allow indoor growers to achieve a marketable mass in less time and increase turnover and revenue. The inclusion of green light in sole-source lighting renders the natural appearance of crops, creating a visually pleasant environment that facilitates crop assessment.

- Compared to blue and red LED arrays commonly used for indoor lighting of plants, an increase in green and far-red radiation from white LEDs can promote stem elongation and flowering in some ornamental crops. In addition, the visual quality of a broader spectrum is substantially improved and creates a more pleasant working environment.

- Optimizing the inputs of light and CO2 in an indoor production environment can potentially increase ornamental seedling quality and decrease production time. Although petunia seedlings grown under elevated CO2 concentrations showed increased biomass accumulation, acclimation responses to this enriched environment and inadequate light intensities ultimately limited the potential benefit of this input. While this research establishes a foundation for understanding seedling responses to light and CO2 in an indoor production environment, future studies are required to optimize production regarding the timing and extent of these inputs.
- Due to increased plant densities during herb seedling production, fewer inputs per plant are required, creating the potential to increase production efficiency. Faster growth rates with increased light intensity can reduce production time, potentially increasing the harvestable yield and thus, grower profitability.

- Flowering of foliage annuals is not desired due to growth inhibition and aesthetics; therefore, flower inhibition by photoperiodic control is possible.

- Under long-day photoperiods, growers may be able to prevent or delay flowering of cultivar ‘Holy Basil’ (Ocimum tenuiflorum) by 6, 7, or 10 days under a 15-h, 16-h, or NI treatment, respectively, in comparison to a 9-h short day.

- Molecular markers useful for breeding new petunia cultivars with improved greenhouse and field performance were developed.

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