2023 Annual Report

NCERA-101 Controlled Environment Technology and Use

Project Number: NCERA-101

Project Title: Controlled Environment Technology and Use

Period Covered: 09-2022 to 04-2023

Date of This Report: June 2023

Annual Meeting Date: April 19-21, 2023

2023 NCERA-101 Annual Meeting

April 19 to 21, 2023

Hosted by:

Md Shamim Ahamed,

Organizer, University of California Davis

**Participants**

**NCERA-101 Participants List 2023 Annual Meeting**

|  |  |  |
| --- | --- | --- |
| **Last name** | **First name** | **Institution** |
| Addo | Philip | McGill University |
| Ahsan | T M Abir | University of California, Davis |
| Barickman | Casey | Fluence |
| Beck | Michael | Royal Gold |
| Bellizzi | Nick | Gotham Greens |
| Biradar | Kishan | University of Delaware |
| Birtell | Eva | University of Delaware |
| Blonquist | Mark | Apogee Instruments, Inc. |
| Both | A.J. | Rutgers University |
| Brenner | Tammy | Colorado State University |
| Bubenheim | David | NASA |
| Bugbee | Bruce | Utah State university |
| Burgner | Samuel | McGill University |
| Concollato | Luke | Blue Marble Space Institute of Science |
| Dyanko | Laurent | University of Bologna |
| Eddy | Rob | Resource Innovation Institute |
| Ertle | John | The Ohio State University |
| Eylands | Nate | University of Minnesota |
| Ezzo | Matt | Environmental Growth Chambers |
| Farinacci | Joe | BFG Supply |
| Fatzinger | Brendan | Utah State University |
| Feng | Xiaoyu Iris | North Dakota State University |
| Friesen | Patrick | Bio Chambers Incorporated |
| Frymark | Jenn | Gotham Greens |
| Gandy | Brian | Valoya Inc. |
| Gardner | Gary | University of Minnesota |
| George | Ben | BFG Supply |
| Giacomelli | Gene | University of Arizona - CEAC |
| Gildersleeve | Michael | Purdue University |
| Goodrich | Payton | UC Berkeley |
| Grimsley | Wendell | Fluence |
| Grist | Glen | Conviron |
| Ha | Mya | Koidra Inc. |
| Hammad | Ahmed | Conviron |
| Hao | Xiuming | Agriculture and Agri-Food Canada |
| Harland-Dunaway | Marcus | University of California Riverside |
| Heins | Royal | HRT Services/Michigan State University |
| Hernandez | Edmundo | BrightFarms, Inc. |
| Hernandez | Ricardo | NCSU |
| Hershkowitz | Julie | Utah State University |
| Hollick | Jason | The Ohio Sate University |
| Humphrey | Samson | North Carolina State University |
| Hupp | Jason | LI-COR Environmental |
| Imberti | David | Percival Scientific, Inc. |
| Ivans | Sinisha | PP Systems |
| Jeong | Sangjun | Texas AM University |
| Jia | Fei | Heliospectra |
| Jia | Xinhua | North Dakota State University |
| Jinkerson | Robert | UC Riverside |
| Kacira | Murat | The University of Arizona |
| Kang | Hyeonjeong | Michigan State University |
| Kanwar | Rameshwar | Iowa State University |
| Karlsson | Meriam | University of Alaska Fairbanks |
| Kaufmann | Christopher | University of Arizona |
| Kennebeck | Emily | University of Delaware |
| Kiekhaefer | Daniel | Percival Scientific, Inc. |
| Kim | Changhyeon | The Ohio State University |
| Kiss | Thomas | Fluence |
| Kohler | Annika | Michigan State University |
| Kopf | Mary Jo | LI-COR Environmental |
| Kuniyoshi | Harumi | Brightfarms |
| Langenfeld | Noah | Utah State University |
| Lantin | Stephen | University of Florida |
| Lee | Daniel | Current Lighting |
| Lefsrud | Mark | McGill University |
| Levesque | Serge | University of Guelph |
| Lin | Yiyun | The Ohio State University |
| Ling | Peter | The Ohio State University |
| Liu | Jun | Utah State University |
| Lopez | Roberto | Michigan State University |
| Mamrocha | Brian | Conviron |
| Martin | Aaron | PathoSans Technologies |
| Massa | Gioia | NASA KSC |
| Mattson | Neil | Cornell University |
| Mauss | Claire | University of California, Riverside |
| McCollum | Will | Valoya Inc. |
| McKean | Tom | Plenty |
| Meng | Qingwu William | University of Delaware |
| Meyer | Hannah | Genective USA Corp |
| Mitchell | Cary | Purdue |
| Moore | Andrew | Corteva Agriscience |
| Moreno | Andy | Ceres University |
| Morrow | Robert | Sierra Space |
| Mortley | Desmond | Tuskegee University |
| Narvaez | Andres | University of California Riverside |
| Niu | Genhua | Texas AM AgriLife Researhc |
| Park | Yujin | Arizona State University |
| Pauls | Robert | Bio Chambers Incorporated |
| Peng | Ying | Bayer Crop Science |
| Proven | John | Conviron |
| Putra | Ketut | Koidra Inc. |
| Qian | Yufei | University of California, Davis |
| Ramsey | Ronald | Sensei Ag |
| Reid | Sharon | Conviron |
| Reusch | Tim | Dramm Corporation |
| Ries | Jonathan | Arizona State University |
| Rooijakkers | Pieter | Light4Food |
| Rowan | Beth | UC Davis Genome Center |
| Ruebelt | Martin | NatureSweet Brands |
| Runkle | Erik | Michigan State University |
| Saravitz | Carole | North Carolina State University |
| Sayle | Erik | Consultant |
| Schlick | Greg | NASA/Ames Research Center |
| Schwieterman | Michael | Plenty |
| Settles | A. Mark | NASA Ames Research Center |
| Sharma | Charu | Gotham Greens |
| Sheibani | Fatemeh | Purdue University |
| Shelford | Timothy | Cornell/Rutgers University |
| Shelton | Annie | University Of California Riverside |
| Shi | Xiaonan | North Carolina State University |
| Short | Gregg | Greenhouse Design LLC |
| Skabelund | Hikari | Utah State University |
| Smith | Ron | Valoya Inc |
| Spalholz | Hans | Current Lighting |
| Stoochnoff | Jared | Canadian Spatial Agency |
| Stutte | Gary | SyNRGE LLC |
| Swenson | Nate | Royal Gold/ Cal Poly Humboldt |
| Szenteczki | Mark | UC Riverside |
| Taylor | Gail | University of California, Davis |
| Theroux | Marc | Bio Chambers Incorporated |
| Timmons | Bret | Cornell University |
| Tripathi | Pooja | The Ohio State University |
| Valle de Souza | Simone | Michigan State University |
| Veach | Ashley | Fluence |
| Vickroy | Elizabeth | Corteva Agriscience |
| West | Lee | Hiphen Ag Imaging Solution |
| Westmoreland | Mitchell | Utah State University |
| Wheeler | Raymond | NASA Kennedy Space Center |
| Willson | Graham | Conviron |
| Wright | Rustin | Biora by MineARC Systems |
| Yelton | Melanie | Grow Big Consultants |
| Yorio | Neil | Maui Greens Inc. |
| Zhang | Ying | University of Florida |
| Zhen | Shuyang | Texas AM University |
| Zheng | Youbin | University of Guelph |
| Zylstra | Alan | DRAMMwater |

**Summary of minutes of annual meeting**

NCERA-101 Business Meeting Summary

Meeting started at 8:04AM, April 19, 2023

Introduction and Welcoming Remarks from meeting host, Shamim Ahamed, and Prof. Fadi Fathallah, Chair, Department of Biological and Agricultural Engineering, University of California, Davis

NIFA Representative Report (Steven J. Thomson)

* Steven noted that NIFA has about 65 National Program Leaders (NPLs), due to turnover about 80% have less than 2 years’ experience
* Each NPL is assigned a state to review their annual AREERA Plans of Work and Annual Reports of Accomplishments as part of federal capacity grant programs
	+ Each state’s FY2022 annual reports of accomplishments are due May 1, 2023
* The relatively new Urban, Indoor, and Emerging Agriculture Program has gone through it’s first funding round, awarding 12 grants for $9.4 M
* NIFA is always searching for volunteers to be a grant review panelist, you can enroll online through the NIFA portal or contact Steven directly: steven.j.thomson@usda.gov

Introduction of the NCERA-101 Executive Officers by Marc Theroux (BioChambers)

* Chair: Marc Theroux (BioChambers)
* Chair Elect: Dr. Ricardo Hernandez (North Carolina State University)
* Secretary: Dr. Neil Mattson (Cornell University)

Recognition of Industry Sponsors by Marc Theroux (BioChambers)

Thanks to our sponsors (in particular their support contributes to student travel scholarships)

|  |  |
| --- | --- |
| Apogee Instruments | Heliospectra |
| Ball Horticultural | Koidra |
| BioChambers | LI-COR |
| Biora by MineARCSystems | Light4Food |
| BrightFarms | NatureSweet |
| Consolidated Greenhouse Solutions | P.L. Light Systems |
| Conviron | Percival |
| Corteva Agscience | PP Systems |
| Current | SyNRGE |
| Dramm | UC Davis Dept. of Plant Sciences |
| Environmental Growth Chambers | Valoya |
| Fluence |   |

Approval of Minutes from 2022 by Dr. Ricardo Hernandez (North Carolina State University)

* Motion to approve the minutes by Dr. Bruce Bugbee (Utah State University). Motion seconded by Dr. Gary Stutte (SyNRGE) approved. Minutes approved unanimously.

Announcements of Other Relevant Conferences (All)

* + 2023 International Workshop on VF - China, May 22-24
	+ 2023 Advancing CEA workshop co-hosted by University of Toledo, USDA ARS, DOE, and NASA – Toledo OH, June 27-29 (<https://www.utoledo.edu/research/advancing-controlled-environment-agriculture/>)
	+ 2023 ASABE - Omaha NE, July 9-12 (https://asabemeetings.org/)
	+ 2023 ASHS - Orlando FL, July 31 to August 4 (https://ashs.org/)
	+ 2023 Greensys - Cancun MX, October 22-27 ([http://www.greensys2023.org/)](http://www.greensys2023.org/%29)
	+ 2024 VertiFarm2024: III International Workshop of Vertical Farming – Bologna Italy, January 16-19 (<https://site.unibo.it/vertifarm2024/en>)
	+ 2024 X International Symposium on Light in Horticulture, Seoul Korea, May 19- 22 ([https://www.ishs.org/symposium/716](http://www.ishs.org/symposium/716%29))

Administrative Advisor’s Report by Dr. Ramesh Kanwar (Iowa State University)

* Climate smart agriculture/horticulture and minimizing carbon footprint and water use are becoming large research/outreach opportunities
* Our NCERA committee is distinguished in the extent of industry participation, and international participation (esp. Canada)
* Chair, Marc Theroux, submitted an application on behalf of NCERA-101 for the 2023 Nomination for Excellence in Multistate Research Award. We were very close to being accepted but didn’t quite make it – encouraged to resubmit.
* We have 60 days from the annual meeting to submit our meeting with key outcomes/impacts (3 pages)

Membership Report submitted by Mark Romer (McGill University) and reported by Dr. Carole Saravitz (North Carolina State University)

* This year marks the **48th annual meeting** of the group
* We are grateful to **Shamim Ahamed** and the team at UC Davis for the organization of this meeting – our first at Davis!
* Our current membership stands at **175** members, up 2 from last year.
* We have **142** different institutions from **34** US states and **9** different countries.
* We continue to have strong participation and **sponsorship support from our 56 industry member institutions**. Thank you to all for your contributions which allow us to support the graduate students who are the future of this organization and CE research & industry.

Membership Number March 2022 173

 March 2023 175

1. Additions 5
2. Deletions 3
3. Net Gain (Loss) 2

Membership Composition Institutions Members

1. Phytotrons & Controlled Environment Facilities 8 10
2. University Departments, Agr. Exp. Stations 67 87
3. Government Organizations & Contractors 12 12
4. Industry Representatives 55 66

Total Number of Institutions / Members **142** **175**

Total Number of Countries 9

Total Number of US States 34

### New Institutions:

* University of Florida, Dept. Agricultural and Biological Engineering
* University of Queensland (Australia), Plant Growth Facility
* BrightFarms
* RedSea Science and Technology Company
* Sierra Space Corporation

Website Report by Dr. Carole Saravitz (North Carolina State University)

Website Summary, October 2022 to April 2023, <https://www.controlledenvironments.org/>

|  |  |  |
| --- | --- | --- |
| Website location | Page views | % page-views |
| Meetings | 2116 | 23.8% |
| Landing page | 1859 | 20.9% |
| Growth-chamber-handbook | 686 | 7.7% |
| Members | 416 | 4.7% |
| Activities | 325 | 3.7% |
| Past-meetings | 250 | 2.8% |
| International-controlled-env-guidelines | 218 | 2.5% |
| Reporting-guidelines | 195 | 2.2% |
| Officers | 191 | 2.2% |
| Station reports | 146 | 1.6% |

* Carole noted she keeps the website update including posting station reports (and a list of which institutions submitted them in a specific year)
* Carole noted that meeting info gets the most hits followed by the main page, and nice to know that the growth chamber handbook is still relevant at #3 most frequent hits.
* Any website comments, questions, suggestions, send them to Dr. Saravitz’s (NCSU) email (carole@ncsu.edu)

Graduate Students Travel Grant Update by Dr. Ricardo Hernandez (North Carolina State University)

* This year there were 22 students that received travel awards ranging from $250-500 per student. Fifteen different universities were represented. Awards are provided to the university as a travel reimbursement. Thank you to our generous sponsors
* To get the reimbursement the university should complete an invoice (template provided) and submit to Bruce Bugbee at Utah State University

Lighting Talk Competition Update (Ricardo Hernandez) by Dr. Ricardo Hernandez (North Carolina State University)

* Students will compete in lighting talks. The top 3 students will be recognized at the gala dinner.
* Winners for 2023 were:
	+ 3rd place (tie): Noah J. Langenfeld, Utah State University, *Hydroponic Nutrient Solutions Designed Using Mass-balance Enable Continuous Recirculation Without Wasting Water or Fertilizer*
	+ 3rd place (tie): Kishan Biradar, University of Delaware, *A Calcium-Mobilizing Biostimulant Mitigates Lettuce Tipburn*
	+ 3rd place (tie): Sam Humphrey, North Carolina State University, *Impact of Elevated CO2 and Two Daily Light Integrals on Strawberry Stock*
	+ 2nd place: John Ertle, The Ohio State University, *Reduced Finishing Light can Limit Tipburn Incidence and Severity of Lettuce with a Yield Penalty*
	+ 1st place: Mitchell Westmoreland, Utah State University, *Optimizing Temperature for Yield and Quality of Medical Cannabis*

Instrument Package & Financial Report by Dr. Bruce Bugbee (Utah State University)

* Utah State University maintains 4 instrument packages on behalf of NCERA-101 which can be rented for instrument calibration. It’s important to have reference sensors to check if discrepancies are due to sensor error or user error.
* Utah State maintains the treasury for NCERA-101. Our balance is currently at $28,000. Funds are used for student travel awards, maintaining the instrument package, etc.
* The Marc van Iersel student travel fund has been set up to honor Marc: <https://marcvanierselfund.org/>
	+ Three companies have made a seed donation of $30,000 to initiate this award: Campbell Scientific, Meter Group, and Apogee Instruments.
	+ Bruce was able to get this set up with no University overhead, not considered an endowment in perpetuity to avoid university overhead – but it is intended this fund will have a long life

Guidelines: ASABE Standards efforts by Dr. Mark Lefsrud (McGill University)

* There has been a push (ex. utility companies) to update/publish various CEA standards.
	+ ES-311 - X640 - Definition of Metrics of Radiation for Plant Growth (Controlled Environment Horticulture) Applications. *Published.* Will be *Renewed. New committee created to modify and include ePAR.*
	+ ES-311 - X642 Recommended Methods of Measurements and Testing for LED Radiation Products for Plant Growth and Development*. Published,* undergoing a review and will need an update when S640 is updated.
	+ PAFS - 30 - X653 Recommended Practice for Heating, Ventilation and Air Conditioning (HVAC), and Lighting Systems Used for Indoor Plant Growth without sunlight. *Published ANSI/ASABE/ASHRAE EP 653.*
	+ ES-311 - X644 Performance Criteria for Optical Radiation Devices and Systems Installed for Plant Growth and Development. *On hold and anticipated to be published in 2024.*
* Other standards of interest: ANSI/UL 8800-2023 Standard for safety for horticultural lighting and equipment and systems which is a revision of ANSI/UL 8800-2021.

Controlled environment research data sharing task force by Dr. Neil Mattson (Cornell University)

* The CEA Open Data Project (CEAOD) is a public repository and structure for submitting CEA data (climate, crop measurements, and metafiles) <https://ceaod.github.io/>
* Users may be interested in submitting data to:
	+ Increase available CEA data which can lead to new data analytics tools
	+ As part of the public dissemination of data for scientific journal publication and as part of the data management plan for federal grants
* Data from several crops are currently online

Future Meetings:

* 2024 – co-hosts Dr. Chris Currey (Iowa State University) and Dr. Jonathan Frantz (Corteva)
	+ Rought framework: planning around the end of March or early April. The meeting will likely take place in Ames. Our tour day will likely include the Des Moines Botanical Garden, Corteva, and other stops.
* 2025 – Dr. Leo Lobato (Karma Verde, Mexico)
	+ Our executive committee will contact Leo to discuss his interest hosting the international meeting.
* 2026 – Dr. Rhuanito Ferrarezi (University of Georgia)

Election of New Secretary

* Dr. Celina Gomez (Purdue University) was nominated by Marc Theroux (BioChambers) and the nomination was seconded by Dr. Gioia Massa (NASA). The vote passed unanimously to elect Dr. Gomez.

New Business Open Discussion

* Excellence in Multistate Research Award (Marc Theroux) was submitted (for a second time) did not win – but will try again
* Membership Secretary Funding (Marc Theroux)
	+ A proposal was brought forward for NCERA-101 to provide support for the membership secretary position with compensation for up to $1,500 for travel and accommodations to attend the annual meeting (reimbursed from NCERA-101 account) plus annual registration fees (covered by the meeting host)
	+ The executive committee would be responsible for selecting the new Membership Secretary (when applicable)
	+ Responsibilities of the membership secretary:
		- Maintain the membership list (accept/add/remove members)
		- Provide a membership summary at annual meetings
		- Maintain and manage the NCERA-101 email distribution list (used for job postings, annual meeting notifications, etc..)
		- Maintain the membership meeting attendance records (used for 20 Year member awards)
		- Maintain the list of past executive members (used for 20 Year member awards)
		- Support annual meeting host (typical meeting format, fees, sponsorship, etc..)
		- Support executive (new member responsibilities, selecting new award candidates, etc...)
		- Maintain NCERA-101 archives (6000+ files)
	+ The above motion was made by Dr. Bruce Bugbee (Utah State University) and seconded by Dr. Carole Savitz (North Carolina, State University). The motion met unanimous approval.
	+ Our current longstanding secretary Mark Romer was acknowledged for his many contributions maintaining our membership list, sending out email notifications (including job positions), sending records to include on the website and serving as a source of continuity for the group (the executive committee passed through on 3-year terms).
* NCERA-101 Significant Organization Award (Marc Theroux)
	+ A proposal was brought forward by Marc Theroux for a new award to be periodically recognized by NCERA-101: Award for Significant Organizational Contributions to the Controlled Environment Sciences:
		- Criteria: An organization that has been deemed by the NCERA-101 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-101 executive committee and presented at the annual meeting.
		- Eligibility: University, government or commercial facilities or organizations working in the area of controlled environments.
		- Nomination Process: Organization must be nominated by an NCERA-101 member and provide supporting information of significant contributions made to the controlled environments sciences.
		- Award: Plaque to be awarded at annual meeting
		- Summary of significant contributions to present and post on the website
	+ Recipients: NCSU Phytotron (approved at 2018 NCERA-101 meeting, not yet awarded) and Duke Phytotron (approved at 2018 NCERA-101 meeting, not yet awarded)
	+ Discussion:
		- Award would be on an ad hoc basis (not a yearly award)
		- Proposed amendment: “When a nomination is put forward, the executive committee will appoint a subcommittee that will review the nomination and make a recommendation.”
	+ Marc Theroux (BioChambers) moved to proceed with the motion (including the amendment with the subcommittee). The motion was seconded by Dr. Erik Runkle. The vote passed by large majority (1 no vote).
	+ Marc Theroux requested if Carole Saravitz would put together a paragraph on the accomplishments of the two recipients: NCSU Phytotron and Duke Phytotron
	+ The executive committee will check with Mark Romer regarding the procedure for procuring the plaque.
* Passing of the Gavel to Dr. Ricardo Hernadez (North Carolina State University) new Chair

MEETING ADJOURNED

**Accomplishments**

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

<https://www.controlledenvironments.org/station-reports/>

**Accomplishments**

***Short-term outcomes***

Team members have contributed research outcomes across several themes:

* Lighting strategies to improve crop yield, quality, nutrition and reduce energy use:
	+ Experiments at Cornell under sole-source lighting found plants that received 20% far-red (vs. 2% far-red control) had a 70-80% larger fresh and dry weight
	+ Developed artificial lighting systems for Hawaiian leafy green cultivars (HI)
	+ MI investigated the influence of photoperiodic lighting on specialty cut flowers. Results indicate that flower initiation of both *Caryopteris* and *Craspedia* occurs regardless of daylength, while floral development of *Caryopteris* requires SD.
	+ MI quantified flowering time of several petunia cultivars grown in greenhouses at a gradient of temperatures (12 to 24 °C ) under a low or high light intensity. Light intensity had little effect on flowering time at the higher temperatures but had a greater effect at low temps.
	+ MSU collaborated with an LED company to study the effects of partly substituting some of the red light from cool-white LEDs with red LEDs for lettuce and kale. Plant growth was similar, indicating that a “Horti White” LED-based solution enabled greater use of the most efficient red LEDs.
	+ Red-fluorescent greenhouse shading material increased the biomass accumulation of floriculture, leafy green, and fruiting crops. We are currently conducting emulated lighting experiments indoors to determine if increasing or decreasing the concentration of the red-fluorescent plastic additive can be optimized to further increase biomass accumulation (MI).
	+ Butterhead lettuce plants had increased leaf area, plant height, and fresh weight at a 24 h photoperiod compared to an 18 and 21 h photoperiod at 17.82 DLI (Fluence).
	+ Beta testing novel vertical farm light qualities with increased efficacy with and without far-red light impacts sweet crisp lettuce morphology, yield, biomass accumulation. There was a 13 and 24 % increase in Danstar and Finstar fresh mass, respectively, when comparing the far-red LED light quality to the novel standard light quality (Fluence).
	+ Rutgers University continues to evaluate a variety of lamp fixtures for light output, light distribution and power consumption using our 2-meter integrating sphere and a small darkroom.
	+ Texas A&M: while adding UV-A or FR to white LEDs had subtle impacts on growth, morphology, and nutrition. Considering the costs of LEDs with UV-A and FR spectrums, commonly available white LED lights are recommended for commercial production.
	+ Texas A&M: Supplemental lighting (SL) of greenhouse hydroponic leafy greens was not responsive to light quality (including treatments with UV-A, red and blue LED, and full-spectrum white) but does response to quantity.
	+ FR light and temperature regimes interactively affect plant morphology, growth, and biomass in lettuce and basil (Texas A&M).
* Plant nutrition and cultural management:
	+ A chemical biostimulant was effective at reducing tipburn of greenhouse hydroponic lettuce by 88% compared to the control (DE)
	+ Secured a 5-yr research grant to advance CEA production of medicinal and high value crops (Guelph)
	+ MI investigated the influence of reducing the air temperature and providing blue + red end-of-production sole-source lighting on red-leaf lettuce. Results indicate that reducing the air average daily temperature to 8 or 14 °C increased anthocyanin content but negatively impacted fresh mass and rate of leaf unfolding.
	+ Preliminary results suggest that vernalizing ranunculus corms for 2 to 3 weeks at ≤7.5 °C and forcing plants under long days hastens flower development (MI).
	+ Growth and development of tropical foliage plants was promoted at air temperatures between 24 to 28 °C. However, 32 °C and continuous 24-h of light had a negative impact on all crops (MI).
	+ Growth chamber experiments with *Evolvulus* found a combination of higher relative humidity and cheesecloth covering decreased tipburn occurrence and severity (MI).
	+ Rutgers University completed a comprehensive evaluation of ventilation strategies for high tunnel crop production.
	+ Biostimulants resulted in significant positive effects on shoot and root morphology or biomass for onion seedlings including early bulb growth (Texas A&M).
	+ Texas A&M compared the effects of three organic fertilizers (Sustane 4-6-4, Nature Safe 7-7-7, and Dramatic 2-4-1) at four application rates with conventional fertilizer with matching rates of nitrogen (N) on watermelon seedling growth and morphology. The best performance on aerial morphological characters was observed in the highest fertilization rates of control and Dramatic 2-4-1 treatments (0.84 g/L N). However, root performance showed different trends among fertilizers from aerial morphology of watermelon seedlings.
* Plants and space applications:
	+ Participation in Phase 2 of the Canadian Space Agency and Impact Canada Deep Space Food Challenge (Guelph)
	+ Barley seeds were exposed to the harsh space environment for 338 days on the ISS and subsequently successfully germinated in the lab (Guelph)
	+ Completed a lunar lander plant production concept design study (Lunar Exploration Agriculture Feasibility (LEAF)) (Guelph, McGill and Canadensys)
* Developed and tested new sensors, control systems, and instrumentation:
	+ Texas A&M: A deep learning model using color imaged-based disease detection was developed to detect the bacterial wilt disease in greenhouse tomato crops. The system achieved more than 90% accuracy.
	+ LI-COR has developed a new LI-600 Porometer/Fluorometer solution offers an unprecedent approach to measuring stomatal conductance on narrow and needle like leaves.
	+ Ames Research Center transferred remote sensing, satellite-based, Floating Aquatic Vegetation (FAV) mapping and biomass assessment tool to State of California Department of Boating and Waterways for operational testing. The project involved modeling ecosystem response to environmental variability and predicted climate change trends utilizing FAV growth models parameterized (light, temperature, nutrients) with environmental response studies in Controlled Environment facilities.
* Investigated/enhanced plant responses to abiotic stress:
	+ Salinity negatively impacts crop productivity, yet neutral and alkali salt stresses are not often differentiated. McGill University designed experiments to separately test these effects and found fresh mass of romaine lettuce grown in the 24 mM Na+ saline–sodic solution was significantly greater than romaine lettuce grown in the alkaline solution with the same sodium concentration.
	+ Texas A&M evaluated heat tolerance of eight spinach cultivars at temperatures of 22, 26, and 32 ◦C based on plant growth index, biomass, and chlorophyll fluorescence, and performance index. Among the eight cultivars, Lakeside, Lizard, Seaside and Red Tabby grew more uniformly and were better quality at harvest than Space, Mandolin, Kolibri, and Koiwa.

***Outputs***

* In February/March 2023, the Greenhouse Lighting and Systems Engineering (GLASE) consortium led by Cornell, RPI, and Rutgers with 30 industry members, held a virtual climate control short course spanning six weeks. The course drew 239 participants.
* Guelph University gave numerous presentations to student groups on CEA and bioregenerative life-support (e.g., Students for the Exploration and Development of Space (SEDS); multiple ‘space challenge’ grade school groups)
* The University of Delaware collaborated with Michigan State University on two peer-reviewed publications involving unique flowering response of chrysanthemum to light quality and factors that impact hydroponic lettuce broad-spectrum LED lighting.
* Michigan State University coordinated several outreach programs that delivered unbiased, research-based information on producing plants in controlled environments, including the 2022 Michigan Greenhouse Growers Expo and the 2022 Floriculture Research Alliance annual meeting.
* Texas A&M hosted the 4th Annual Conference in urban horticulture – Controlled environment conference at the Dallas Center with about 100 participants. An SCRI planning meeting was held the day before on leafy greens in hot/humid climates.

***Activities***

* Project members conducted several research projects including: indoor chrysanthemum response to light quantity (DE and MI), biostimulants to mitigate lettuce tipburn (DE), daily light integral and far-red impacts on petunia flowering (NY), collaboration with commercial vertical farms on substrate use and composting and light selection (Guelph), AI-plant biofeedback systems (Guelph), electrochemical water treatment technologies (Guelph), life cycle assessment and environmental impact of switching from HPS to LED lighting (Rutgers), profitability/sustainability of indoor leafy greens with SCRI funding (AZ, MI, Purdue, OH, USDA-ARS), controlled environment herb production with SCRI funding (IA, MI, NC, TN, TX, USDA-ARS).

***Milestones***

* Several university/industry research partnerships are underway including: testing advanced lighting control systems at 8 commercial greenhouses (Cornell), project renewal of multistate NE-1835 Resource Optimization in Controlled Environment Agriculture (Delaware, Cornell, Rutgers, Texas A&M, Univ. of Ariz., Univ. of Florida, etc.), collaborations with the Dutch greenhouse industry for everbearing strawberries and commercial lettuce vertical farms (Fluence), and transparent photovoltaic panels in greenhouses (Michigan State).
* Starting in the fall of 2022, the USDA-NIFA Specialty Crop Research Initiative program funded the ADVANCEA project. This $3.7M, 4-year project is co-led by Chieri Kubota (The Ohio State University) and A.J. Both. The team consists of researchers from The Ohio State University, Rutgers University, Cornell University, and the University of Arizona. Commercial team members include Koidra, Inc. and Hort Americas.

**Impact statements**

* Over 80 percent of surveyed participants of the GLASE (Cornell and Rutgers University) climate control short course plan to implement new practices in their operation as a result of the course including: light respacing, installing controllers for dehumidification, evaluation sensor location and calibration, integrating new sensors and controls and implementing energy saving tips.
* Tipburn of lettuce is a major crop physiological disorder that severely affects crop quality and leads to economic losses in the controlled-environment agriculture industry. The collaboration between the University of Delaware and Croda, Inc. has leveraged a chemical biostimulant as an effective solution to mitigate lettuce tipburn by 88% in greenhouse conditions. This product thus has potential for wider industry adoption.
* Black cloth application is required to induce flowering of many summer-fall garden chrysanthemum production programs, but it is laborious and incurs material wear. The University of Delaware has investigated photoperiodic flowering responses of chrysanthemum cultivars to develop effective strategies that reduce black cloth use while ensuring flowering decreasing labor costs by 43%.
* Experiments on commercial horticulture crops, such as leafy greens, strawberry, and vine crops have focused on research that leads to generating new novel LED spectrums with increased energy efficiency (>3.6 umol/J) compared to baseline HPS efficacy (ca. 1.8 umol/J) this represents a 50% energy savings with LED adoption.
* University of Guelph’s engagement with Tomatosphere™, a free science outreach program available throughout North America, has engaged over 4 million students since its inception. The program is designed for K-12 students to to investigate the effects of space on seed germination and ultimately contribute to human space travel.
* Hawaii: ‘UH Manoa’ lettuce and ‘Hirayama’ kai choy, commonly grown in the field or in greenhouses, were successfully grown indoors under LED lighting.
* The Michigan Greenhouse Growers Expo, Electronic Grower Resources Online, OptimIA, and The Floriculture Research Alliance meetings delivered unbiased, research-based information to over 3,000 greenhouse growers in 2022, plus additional growers and marketers of vegetable and fruit crops.
* Representative leafy green, floriculture, and culinary herb crops tolerated up to a moderate decrease in (extended) photosynthetically active radiation when grown under transparent photovoltaic panels from spring to fall in Michigan. However, there was a decrease in yield of fruiting crops (e.g., tomato), and tolerances to shading of most other crops are unlikely during seasonally light-limited conditions.
* Information generated on the effects of temperature and light on growth and flowering of petunia can be used by commercial growers to schedule plants more precisely for specific market dates.
* Information from Texas A&M on heat tolerant spinach cultivars can provide hydroponic growers to produce spinach in greenhouses in the southern region with extended growing season. Normally, spinach can’t be grown in the long summer season even in the greenhouse. With root zone cooling and selection of heat tolerant cultivars, the growing season can be extended to early summer.
* Results from Texas A&M experiments with supplemental lighting at the end-of-production can boost the quality, especially for red leaf lettuces, without significantly increasing production costs on supplemental lighting.
* Partly substituting red and green light from white LEDs with red light from more effective red LEDs practically has no effect on growth and coloration of leafy greens grown indoors. Using this approach, energy consumption can be decreased by 15-25%, depending on the baseline spectrum and fixture characteristics.
* Nationwide, Extension and NRCS personnel 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 updated operational strategies that saved an average sized (1-acre) business a total of $25,000 in operating and maintenance costs annually. Energy conservation and crop lighting presentations as well as written materials on controlled environment crop production techniques 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%.
* Sierra Space is working toward development of hybrid life support systems for space applications, integrating biological and physical/chemical technologies, advancing this technology to meet the performance and quality needs of long duration space applications. Some of this technology may be transferable to terrestrial protected agriculture systems.

[Material not used]

* Sierra Space is currently working on three large flight systems. These include Dream Chaser, a winged space vehicle (https://www.sierraspace.com/space-transportation/dream-chaser-spaceplane/), LIFE, a large inflatable habitat (https://www.sierraspace.com/space-destinations/life-space-habitat/), and Orbital Reef, a large integrated space station being developed in partnership with Blue Origin (https://www.sierraspace.com/space-destinations/orbital-reef-space-station/).
* Sierra Space continues to develop 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 Space continues to use its environmental control, gravitational biology, and human life support work in our outreach efforts to spark interest in middle school, high school, and college students toward STEM fields.
* The Veggie units fabricated by Sierra Space were delivered to the ISS in 2014 and 2017. The 2014 unit was replaced with a new unit in 2022. These units continue to be actively used to support plant research, crop production testing, and technology demonstrations on the ISS.
* Sierra Space also continues to support the Advanced Plant Habitat Unit on ISS. The APH was delivered to orbit in 2017 and is being regularly used for academic & government plant research.
* XROOTS was designed with multiple independent growth chambers used in parallel to evaluate aeroponic and hydroponic nutrient and water delivery in microgravity. XROOTS was launched on NG-17 in February 2022. The Technology Demonstration completed operations on ISS at the end of October 2022 and components are in the process of being returned to Earth. As a middeck locker equivalent sized payload, XROOTS was mounted in an EXPRESS Rack below a Veggie lighting module. XROOTS allowed for root zone and plant observation through video and still images, and short periods of crew observations. Sierra Space monitored and controlled payload operations from our Payload Operations Center (POC) in Madison, WI. Operations were conducted over a six-month period, with individual tests lasting between 10 and 80 days. Species grown during these tests included: Micro Tina Dwarf Tomato, Cherry Belle Radish, Earligreen Dwarf Pea, Apogee Dwarf Wheat, Mizuna Mustard, Outredgeous Lettuce, Little Gem Lettuce.
* XROOTS demonstrated the feasibility of using aeroponic and hydroponic techniques for plant growth in microgravity (Figure 3). Results of these tests will help optimize design and performance of hydroponic systems for large scale plant production in space.
* Texas A&M: Manual crop scouting is time-consuming and laborious, as well as the spatial variability of the disease severity in the field is overlooked. Thus, the detection of the disease symptoms and hotspot regions is essential to stop the spread to other plants. This is ongoing work; the benefits and impact can be quantified after the completion of the project. In the future, the deep learning models will be integrated into the edge devices and overhand gantry system for automatic scanning of crops that will allow growers to get an instantaneous report on the disease symptoms and frequency or severity of the issue. The management decisions considering the variability will result in chemical savings, reducing the production cost and enhancing the sustainability of the industry, thus contributing to the broader public benefits. Implementing this technology for smart or precision spraying will improve crop safety and reduce chemical usage, lowering production costs and environmental pollution due to excessive chemical applications, thus contributing to the broader public benefits.
* Texas A&M’s fourth controlled environment conference was held in December 2022 and was well received and attended by the industry.
* Reducing the air temperature at the end-of-production significantly increased anthocyanin content of red-leaf lettuce in comparison to moderate blue or blue + red sole-source lighting alone.
* Increasing the air and/or root-zone temperature can significantly reduce foliage purpling of unrooted cuttings under LED supplemental lighting providing red + blue light.
* Air temperature has a greater impact on the growth and development of tropical foliage plants than daily light integral (DLI) or photoperiod. However, temperatures above 28 °C can be detrimental.
* We characterized two recent specialty cut flower introductions as day-neutral for flower induction.
* Providing vernalization treatments and photoperiodic lighting can hasten ranunculus cut flower production.
* Lettuce growth increases as red or green light are replaced by far-red light. However, when red light is mostly or fully replaced by far-red light, increases in growth do not continue. In addition, lettuce-leaf color and overall quality decrease as the far-red light percentage increases.

**Publications**

Ajagekar, A., Mattson, N.S. and You, F., 2023. Energy-efficient AI-based Control of Semi-closed Greenhouses Leveraging Robust Optimization in Deep Reinforcement Learning. Advances in Applied Energy, 9, p.100119.

Appel EY, Meng Q. 2022. Increasing nutrient solution electrical conductivity in Kratky-style hydroponics increases lettuce growth following the law of diminishing returns (abstr). HortScience. 57(9S):S52.

Ashenafi, E.L., Nyman, M.C., Holley, J.M. and Mattson, N.S., 2023. The influence of LEDs with different blue peak emission wavelengths on the biomass, morphology, and nutrient content of kale cultivars. Scientia Horticulturae, 317, p.111992.

Ashenafi, E.L., Nyman, M.C., Holley, J.M., Mattson, N.S. and Rangarajan, A., 2022. Phenotypic plasticity and nutritional quality of three kale cultivars (Brassica oleracea L. var. acephala) under field, greenhouse, and growth chamber environments. Environmental and Experimental Botany, p.104895.

Ashenafi, E.L., Nyman, M.C., Shelley, J.T. and Mattson, N.S., 2023. Spectral properties and stability of selected carotenoid and chlorophyll compounds in different solvent systems. Food Chemistry Advances, 2, p.100178.

Birtell EM, Meng Q. 2022. Blue light increases hot pepper seedling compactness and determines the influence of light intensity (abstr). HortScience. 57(9S):S63.

Both, A.J. 2022. Environmental sensors 101. Indoor Ag Science Café (USDA-SCRI project OptimIA). Columbus, OH. November 15. (webinar)

Both, A.J. 2022. Greenhouse energy efficiency and management, Chapter 11. In Regional Perspectives on Farm Energy (D. Ciolkosz, Ed.). Springer, Switzerland. pp. 85-93. https://link.springer.com/book/10.1007/978-3-030-90831-7

Both, A.J. 2022. On-farm energy production – Solar, wind, geothermal, Chapter 12. In Regional Perspectives on Farm Energy (D. Ciolkosz, Ed.). Springer, Switzerland. pp. 95-105. <https://link.springer.com/book/10.1007/978-3-030-90831-7>

Both, A.J. 2022. Strategies to reduce greenhouse energy costs. GLASE Summit. Ithaca, NY. November 8.

Both, A.J. 2023. Different controlled environment crop production systems. Annie Goes Online: Risk Management on Your Kitchen Table. Annie’s Project of New Jersey. February 22. (webinar)

Both, A.J. 2023. Energy efficiency in greenhouse operations. Greenhouse Grower School, Cornell Cooperative Extension of Orange County. January 18. (webinar)

Both, A.J. 2023. High tunnel construction. 68th New Jersey Agricultural Convention and Trade Show. February 7.

Both, A.J. 2023. High tunnel control with sensors. 68th New Jersey Agricultural Convention and Trade Show. February 7.

Both, A.J. 2023. How can you reduce your greenhouse energy bill? Long Island Greenhouse and Floriculture Conference. Riverhead, Long Island. January 17.

Both, A.J. 2023. Humidity control. GLASE Short Course on Climate Control. February 2. (webinar)

Both, A.J. 2023. Overview of agrivoltaics. Webinar series: Planning with Agrivoltaics in Mind. Hosted by Penn State University, Cornell Cooperative Extension, and the Farm Bureaus of PA and NY. January 19. (webinar)

Brumfield, R.G., M. Flahive Di Nardo, A.J. Both, J. Heckman, A. Rowe, R. VanVranken and M. Bravo. 20xx. Online workshop empowers women farmers to manage business risk during the pandemic. Accepted for publication in Acta Horticulturae.

Chen, W.H., Mattson, N.S. and You, F., 2022. Intelligent control and energy optimization in controlled environment agriculture via nonlinear model predictive control of semi-closed greenhouse. Applied Energy, 320, p.119334.

Dsouza, A., Kiselchuk, C., Lawson, J. A., Price, G. W., Dixon, M., & Graham, T. 2022. Development of an automated, multi-vessel respirometric system to evaluate decomposition of composting feedstocks. Biosystems Engineering, 224, 283–300. https://doi.org/10.1016/J.BIOSYSTEMSENG.2022.10.014

Eaton, M., Shelford, T., Cole, M. and Mattson, N., 2023. Modeling resource consumption and carbon emissions associated with lettuce production in plant factories. Journal of Cleaner Production, 384, p.135569.

Gu L., Grodzinski, B., Han, J., Marie, T.R.J.G., Zhang Y-J., Song, Y.C., and Sun, Y. 2023. An exploratory steady-state redox model of photosynthetic linear electron transport for use in complete modelling of photosynthesis for broad applications. Plant Cell and Environment. Pre-published-online. https://doi.org/10.1111/pce.14563

Gu L., Grodzinski, B., Han, J., Marie, T.R.J.G., Zhang Y-J., Song, Y.C., and Sun, Y. 2022. Granal thylakoid structure and function: explaining an enduring mystery of higher plants. New Phytologist 236: 319-329. https://doi.org/10.1111/nph.18371

Harbick, K. and Mattson, N.S. 2022. Optimization of spatial lighting uniformity using non-planar arrays and intensity modulation. ISHS LightSym2021. 9th International Symposium on Light in Horticultural Systems. Acta Horticulturae. 1337: 101-106.

Haveman, N., Settles, A. M., Zupanska, A., Graham, T., Link, B., Califar, B., Callaham, J., Jha, D., Massa, G., Mcdaniel, S., Parmar, C., Tucker, R., & Wheeler, R. (n.d.). Elevating the Use of Genetic Engineering to Support Sustainable Plant Agriculture for Human Space Exploration A Topical White Paper for Submission to the Primarily Authored By Co-Authors (listed alphabetically). Biological and Physical Sciences in Space Decadal Survey, 2023–2032.

Hitti, Y., S. MacPherson, M. Lefsrud. 2023. Separate Effects of Sodium on Germination in Saline-Sodic and Alkaline form at Different Concentrations. Plants 12(1234):1-13.

Holley, J., Mattson, N., Ashenafi, E. and Nyman, M., 2022. The Impact of CO2 Enrichment on Biomass, Carotenoids, Xanthophyll, and Mineral Content of Lettuce (Lactuca sativa L.). Horticulturae, 8(9), p.820.

Hooks, T., J. Masabni, L. Sun, G. Niu. 2022. Effects of organic fertilizer with or without a microbial inoculant on the growth and quality of lettuce in an NFT hydroponic system. Technology in Horticulture 2, 1 doi: 10.48130/TIH-2022-0001.

Hooks, T., L. Sun, Y. Kong, J. Masabni, and G. Niu. 2022. Effect of nutrient solution cooling in summer and heating in winter on the performance of baby leafy vegetables in deep-water hydroponic systems. Horticulturae 2022, 8, 749. https://doi.org/10.3390/horticulturae8080749.

Hooks, T., L. Sun, Y. Kong, J. Masabni, and G. Niu. 2022. Short-term pre-harvest supplemental lighting with different light emitting diodes improves greenhouse lettuce quality. Horticulturae 8, 435. Doi.org/10.3390/horticulturae8050435.

Hooks, T.; Sun, L.; Kong, Y.; Masabni, J.; Niu, G. Adding UVA and Far-Red Light to White LED Affects Growth, Morphology, and Phytochemicals of Indoor-Grown Microgreens. Sustainability 2022, 14, 8552. https://doi.org/10.3390/su14148552.

Jeong, S., G. Niu, and S. Zhen. 2022. The involvement of light intensity effects between far-red and temperature on plant growth and morphology. International Meeting on Controlled Environment Technology and Use, Arizona, Sept 11-14.

Jeong, S., G. Niu, and S. Zhen. Light intensity regulates interactive effects between far-red light and temperature on plant growth and morphology in lettuce and basil. Southern Region ASHS, Feb. 03-05, 2023, Oklahoma City, OK.

Jeong, S., G. Niu, S. Zhen. The interactive effects between far-red and temperature on plant growth and morphology: dependency of the predictive power of phytochrome photoequilibrium on temperature. Annual Conference of ASHS, Chicago, July 31 to Aug 3.

Kennebeck EJ, Meng Q. 2022. Mustard ‘Amara’ seedlings benefit from superelevated co2, but not far-red light (abstr). HortScience. 57(9S):S25.

Kobayashi, K.D. and B. Nelson. 2023. LED and fluorescent lighting effects on hydroponically grown ‘UH Manoa’ lettuce and ‘Hirayama’ kai choy. To be presented at the 2023 ASHS Conference, Orlando, FL. July 31-August 4, 2023.

Kohler AE, Birtell EM, Runkle ES, Meng Q. 2023. Day-extension blue light inhibits flowering of chrysanthemum when the short main photoperiod includes far-red light. J. Amer. Soc. Hort. Sci. 148(2):89–98.

Kohler, A.E., E.M. Birtell, E.S. Runkle, and Q. Meng. 2023. Day-extension blue light inhibits flowering of chrysanthemum when the short main photoperiod includes far-red light. J. Amer. Soc. Hort. Sci. 148:89-98.

Kong Y. and Zheng Y. 2022. Low-activity cryptochrome 1 plays a role in promoting stem elongation and flower initiation of mature Arabidopsis under blue light associated with low phytochrome activity. Canadian Journal of Plant Science. https://doi.org/10.1139/CJPS-2021-0122.

Kong Y. and Zheng Y. 2022. Phytochrome contributes to blue-light-mediated stem elongation and flower initiation in mature Arabidopsis thaliana plants. Canadian Journal of Plant Science. 102(2). https://doi.org/10.1139/cjps-2021-0018.

Kong, Y., J. Masabni, and G. Niu. 2023. Temperature and light spectrum affect lettuce and pak choy growth and morphology. Lone Star Hort Forum, College Station, Jan 9-11.

Kubota, C., E. Runkle, C. Mitchell, and R. Lopez. 2022. Answering key questions about indoor crops. Inside Grower Nov.:14-15.

Lemay J, Zheng Y, and Scott-Dupree C. 2022. Factors influencing the efficacy of biological control agents used to manage insect pests in indoor Cannabis (Cannabis sativa) cultivation. Front. Agron. 4:795989. doi: 10.3389/fagro.2022.795989

Lévesque, S., Graham, T., Bejan, D. & Dixon, M. 2022. Comparative analysis of conventional and novel water treatment technologies for growing ornamental crops with recirculating hydroponics. Agricultural water management, 269:107673. https://doi.org/10.1016/j.agwat.2022.107673

Lévesque, S., Graham, T., Bejan, D., Lawson, J., & Dixon, M. (2023). Prevention of Phytotoxic Effects of Regenerative In Situ Electrochemical Hypochlorination in Recirculating Hydroponic Systems. HortScience, 58(1), 107–113. https://doi.org/10.21273/HORTSCI16734-22

Lewus, D. 2023. Can we improve high tunnel ventilation? 68th New Jersey Agricultural Convention and Trade Show. February 7.

Lewus, D.C. 2023. Simulation of high tunnel ventilation using computational fluid dynamics. Ph.D. Dissertation. Rutgers University Libraries. 189 pp.

Lewus, D.C. and A.J. Both. 2022. Using computational fluid dynamics to evaluate high tunnel roof vent designs. AgriEngineering 4(3), 719-734; https://doi.org/10.3390/agriengineering4030046

Llewellyn D, Golem S, Jones M and Zheng. 2023. Foliar symptomology, nutrient content, yield, and secondary metabolite variability of cannabis grown hydroponically with different single-element nutrient deficiencies. Plants 12 (3), https://doi.org/10.3390/plants12030422

Llewellyn D,. Shelford T, Zheng Y and Both A.J. 2022. Measuring and reporting lighting characteristics important for controlled environment plant production. Acta Horticulturae. 1337: 255-264. DOI 10.17660/ActaHortic.2022.1337.34

Llewellyn, D, Golem, S, Foley, E, Dinka, S, Jones, AMP and Zheng Y. 2022. Indoor grown cannabis yield increased proportionally with light intensity, but ultraviolet radiation did not affect yield or cannabinoid content. Frontiers in Plant Science 13:974018. https://doi.org/10.3389/fpls.2022.974018

Llewellyn, D., T.J. Shelford, Y. Zheng, and A.J. Both. 2022. Measuring and reporting lighting characteristics important for controlled environment plant production. Acta Horticulturae 1337:255-264. https://doi.org/10.17660/ActaHortic.2022.1337.34

Lopez, R.G. and A. Soster. 2022. Producing succulents with the speed of light. Greenhouse Management 42(11):28−30.

Lopez, R.G. and A. Soster. 2022. Superior succulents: Is the paradigm that indicates all succulents require high temperatures and DLI true? Greenhouse Management 42(12):50−52.

Lopez, R.G. and N. Durussel. 2022. Avoiding caladium conundrums, Part 2. GrowerTalks 86(7):62–65.

Lopez, R.G., C. Spall, and N. Durussel. 2022. Avoiding caladium conundrums. GrowerTalks 86(6):66–67.

Lubna, F.A., D.C. Lewus, T.J. Shelford, and A.J. Both. 2022. What you may not realize about vertical farming. Horticulturae 8(4), 322. <https://doi.org/10.3390/horticulturae8040322>

Marie, T.R.J.G., Leonardos, E.D., Lanoue, J., Hao, X., Micallef, B.J. and Grodzinski, B., 2022. A Perspective Emphasizing Circadian Rhythm Entrainment to Ensure Sustainable Crop Production in Controlled Environment Agriculture: Dynamic Use of LED Cues. Front. Sustain. Food Syst. 6: 856162. https://doi: 10.3389/fsufs.

Mattson, N.S., Allred, J.A., de Villiers, D., Shelford, T.J. and K. Harbick 2022. Response of hydroponic baby leaf greens to LED and HPS supplemental lighting. ISHS LightSym2021. 9th International Symposium on Light in Horticultural Systems. Acta Horticulturae. 1337:395-402.

Meng Q, Runkle ES. 2023. Blue photons from broad-spectrum LEDs control growth, morphology, and coloration of indoor hydroponic red-leaf lettuce. Plants 12(5):1127.

Meng, Q. and E.S. Runkle. 2023. Blue photons from broad-spectrum LEDs control growth, morphology, and coloration of indoor hydroponic red-leaf lettuce. Plants 12(5):1127.

Moher M, Llewellyn D, Golem S, Foley E, Dinka S, Jones M and Zheng Y. 2023. Light spectra have minimal effects on rooting and vegetative growth responses of clonal cannabis cuttings. HortScience. 58 (2). https://doi.org/10.21273/HORTSCI16752-22.

Moher M, Llewellyn D, Jones M, and Zheng Y. 2022. Light intensity can be used to modify the growth and morphological characteristics of cannabis during the vegetative stage of indoor production. Industrial Crops and Products. 183. https://doi.org/10.1016/j.indcrop.2022.114909.

Morrow, R., J. Wetzel, S. Moffatt, and M. Blair. 2022. The role of plants in a commercial space station. ASGSR Investigators Poster

Nelson, B. 2023. Farming on the final frontier: Space farming with Martian soil simulants. Horizons (in press).

Ojo, M. O., and Zahid, A. 2022. Deep learning in controlled environment agriculture: A review of recent advancements, challenges, and prospects, Sensors 2022, 22(20), 7965.

Ojo, M. O., and Zahid, A. 2023. Improving deep learning classifiers performance via preprocessing and class imbalance approaches in a plant disease detection pipeline. Agronomy, 13, 887.

Ojo, M., Zahid, A. 2022. Automatic crop disease scouting system based on deep neural networks model. In 2022 ASABE Annual International Meeting (Presentation)

Park, Y. and E.S. Runkle. 2023. Spectral-conversion film potential for greenhouses: Utility of green-to-red photons conversion and far-red filtration for plant growth. PLoS ONE 18(2):e0281996.

Pepe, M., Leonardos, E.D., Marie, T.R.J.G.\*, Kyne, S.T., Hesami, M., Jones, A.M.P., and Grodzinski, B. 2022. A non-invasive gas exchange method to test and model photosynthetic proficiency and growth rates of in vitro plant cultures: Preliminary implication for Cannabis sativa L. Biology. 11(5), 729. https://doi: 10.3390/biology11050729.

Pepe, M., Marie, T.R.J.G., Leonardos, E.D., Hesami, M., Rana, N., Jones, A.M.P., and Grodzinski, B. 2022. Tissue culture coupled with a gas exchange system offers new perspectives on phenotyping the developmental biology of Solanum lycopersicum L. cv. 'Microtom'. Frontiers in Plant Science, Sec. Plant Physiology, Published 10 Nov. https://doi.org/10.3389/fpls.2022.1025477

Plotnik, L., Gibbs, G., Graham, T., 2022. Psilocybin Conspectus: Status, Production Methods and Considerations. Int. J. Med. Mushrooms 24, 1–11.

Rodgers, D., Won, E., Timmons, M.B. and Mattson, N., 2022. Complementary nutrients in decoupled aquaponics enhance basil performance. Horticulturae, 8(2), p.111.

Runkle, E. 2022. Far-red light in greenhouse and indoor farming. Greenhouse Product News 32(10):50.

Runkle, E. 2022. Getting started with supplemental greenhouse LED lighting. Greenhouse Product News 32(11):42.

Runkle, E. 2022. The pros and cons of cool nights. Greenhouse Product news 32(9):42.

Runkle, E. 2023. Advancements in horticultural lighting. Greenhouse Product News 33(3):10.

Runkle, E. 2023. Several consequences of growing too cool. Greenhouse Product news 33(1):12.

Runkle, E., J. Shin, and N. Kelly. A closer look at the effect of white LEDs on plant performance. Greenhouse Grower 41(1):26-28.

Shelford, T. and A.J. Both. 2023. Lighting: The design phase. Consider six vital factors when designing sole-source or traditional greenhouse lighting. Produce Grower, April issue.

Shelford, T., Both, A.J. and Mattson, N.S. 2022. A greenhouse daily light integral control algorithm that takes advantage of day ahead market electricity pricing. ISHS LightSym2021. 9th International Symposium on Light in Horticultural Systems. Acta Horticulturae. 1337:277-282.

Spall, C. and R.G. Lopez. 2022. Emerging specialty cut flowers: A study of flower induction in marigold and witchgrass. GrowerTalks 86(3):76–82.

Spall. C.S. and R.G. Lopez. 2022. Daily light integral and/or photoperiod during the young plant and finishing stages influence floral initiation and quality of witchgrass and marigold cut flowers. Front. Plant Sci. https://doi.org/10.3389/fpls.2022.956157

Spall. C.S. and R.G. Lopez. 2023. Supplemental lighting quality influences time to flower and finished quality of three long-day specialty cut flowers. Horticulturae 9(1):73.

Stallknecht, E.J., C.K. Herrera C. Yang, I. King, T.D. Sharkey, R.R. Lunt, and E.S. Runkle. 2023. Designing plant-transparent agrivoltaics. Sci. Rep. 13:1903.

Stasiak M. and Dixon M. 2022. Growing Facilities and Environmental Control. In Zheng Y. (Ed.) Handbook of Cannabis Production in Controlled Environments. Boca Raton: CRC Press/Taylor & Francis.

Stoochnoff, J., Johnston, M., Hoogenboom, J., Graham, T., & Dixon, M. A. 2022. Intracanopy lighting strategies to improve green bush bean (Phaseolus vulgaris) compatibility with vertical farming. Frontiers in Agronomy, 73.

Stutte, G., Yorio, N., Edney, S., Richards, J., Hummerick, M., Stasiak, M., and Dixon, M. 2022. Effect of Reduced Atmospheric Pressure on Yield and Quality of Two Lettuce Cultivars. Life Science in Space Research. 34, 37-44. <https://doi.org/10.1016/j.lssr.2022.06.001>

Tarr, S. and R.G. Lopez. 2023. Influence of day and night temperature and radiation intensity on growth, quality, and economics of indoor green butterhead and red oakleaf lettuce production. Sustainability 15(1):829.

Vaštakaitė-Kairienė, V., A. Brazaitytė, J. Miliauskienė, and E.S. Runkle. 2022. Red to blue light ratio and iron nutrition influence growth, metabolic response, and mineral nutrients of spinach grown indoors. Sustainability 14:12564.

Walters, K.J. and R.G. Lopez. 2022. Basil seedling production environment influences subsequent yield and flavor compound concentration during greenhouse production. PLoS ONE https://doi.org/10.1371/journal.pone.0273562

Warner, R., B.-S. Wu, S. MacPherson, M. Lefsrud. 2023. How the distribution of photon delivery impacts crops in indoor plant environments: a review. Sustainability-2165879.

Wetzel, J., R. Morrow, G. Tellez, D. Wyman, and M. DeMars. 2022. XROOTS aeroponics and hydroponics nutrient delivery in microgravity. ASGSR Oral Presentation

Xia, J. and Mattson, N., 2022. Response of common ice plant (*Mesembryanthemum crystallinum* L.) to photoperiod/daily light integral in vertical hydroponic production. Horticulturae, 8(7), p.653.

Xia, J. and Mattson, N., 2022. Response of common ice plant (*Mesembryanthemum crystallinum* L.) to sodium chloride concentration in hydroponic nutrient solution. HortScience, 57(7), pp.750-756.

Xia, J., Mattson, N., Stelick, A. and Dando, R., 2022. Sensory Evaluation of Common Ice Plant (*Mesembryanthemum crystallinum* L.) in Response to Sodium Chloride Concentration in Hydroponic Nutrient Solution. Foods, 11(18), p.2790.

Yamori, N., Levine, C.P., Mattson, N.S. and Yamori, W., 2022. Optimum root zone temperature of photosynthesis and plant growth depends on air temperature in lettuce plants. Plant Molecular Biology, pp.1-11.

Zhang, Q., J. Masabni, and G. Niu. 2023. Organic fertilizer type and rate affect watermelon seedling production. Southern Region ASHS, Feb. 03-05, 2023, Oklahoma City, OK

Zhang, Q., J. Masabni, and G. Niu. 2023. Organic fertilizer type and rate affect watermelon seedling production. Lone Star Hort Forum, January 9, 2023, College Station, TX

Zheng Y. 2022. Rootzone management in cannabis cultivation. In Handbook of Cannabis Production in Controlled Environments, ed. Y. Zheng. Boca Raton and London: CRC Press, Taylor & Francis.

Zheng Y. and Llewellyn D. 2022. Lighting and CO2 in cannabis cultivation. In Handbook of Cannabis Production in Controlled Environments, ed. Y. Zheng. Boca Raton and London: CRC Press, Taylor & Francis.