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/)
- 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)

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

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

Membership Composition	Institutions	Members
• Phytotrons & Controlled Environment Facilities	8	10
• University Departments, Agr. Exp. Stations	67	87
• Government Organizations & Contractors	12	12
• 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 CO_2 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.

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