2022 Annual Report
NCERA-101 Controlled Environment Technology and Use

Project Number: NCERA-101
Project Title: Controlled Environment Technology and Use
Period Covered: 11-2021 to 11-2022
Date of This Report: November 2022
Annual Meeting Date: September 11 to 14, 2022

2022 NCERA-101 Annual Meeting
September 11 to 14, 2022
Hosted by:
Murat Kacira, Gene Giacomelli, Joel Cuello,
Organizing Committee, Controlled Environment Agriculture Center, The University of Arizona

Participant

NCERA-101 Participants List 2022 International meeting

Shamim	Ahamed	UC Davis	Ricardo	Hernandez	North Carolina State University
Jasper	Alpuerto	Bayer Crop Science	Chris	Higgins	Hort Americas
Stephen	Andrews	University of Cambridge	Triston	Hooks	University of Arizona - CEAC
Sarah	Armstrong	University of Queensland	Nick	Horsley	Hettich Instruments
Mark	Baker	Hettich Instruments	Jason	Hupp	LI-COR Environmental
Samantha	Baldwin	NZ Inst Plant & Food Research	Henry	Imberti	Percival-Scientific, Inc.
Kyle	Barnett	Cultivatd Inc.	David	Imberti	Percival-Scientific, Inc.
Jim	Berger	Applied Invention	Sharon	Inch	Elo Life Systems
Samuel	Bertram	OnePointOne	Niels	Jacobs	Light4Food
Mark	Blonquist	Apogee Instruments, Inc.	Merle	Jensen	University of Arizona - CEAC
Jennifer	Boldt	USDA-ARS	Fei	Jia	Heliospectra
James	Borden	Env Growth Chambers	Christina	Johnson	NASA Postdoctoral Program
A.J.	Both	Rutgers University	Murat	Kacira	University of Arizona - CEAC
Douglas	Brinkman	University of Minnesota	Rameshwar	Kanwar	Iowa State University
David	Bubenheim	NASA-AMES	Meriam	Karlsson	University of Alaska Fairbanks
Bruce	Bugbee	Utah State university	Rob	Kerslake	Kerslake & Associates
John	Bushoven	California State University	Kent	Kobayashi	University of Hawaii at Manoa
Jaclyn	Cadogan	Arizona State University	Mary Jo	Kopf	LI-COR Environmental
Ken	Campbell	PathoSans Technologies	Mark	Kroggel	The Ohio State University
Cesar	Cappa	GoodLeaf Community Farms	Claudia	Kuniyoshi	BrightFarms
Henry	Carcamo	Syngenta	Robert	LaDue	Bright Farms
Jason	Daff	University of York	Ryan	Lefers	Red Sea Farms
Alexis	DeFord	Ceres Greenhouse Solutions	Mark	Lefsrud	McGill University
Darren	Drewry	Ohio State University	Piotr	Legowski	Astro Space
Allison	Driskill	Signify	Peter	Ling	The Ohio State University
Rob	Eddy	Resource Innovation Institute	Matt	Lingard	BrightFarms
Gerardo Jose	Escudero Samara	FUNDAAC	Jun	Liu	Utah State University
Kitt	Farrell-Poe	University of Arizona	Mohit	Lokane	mintropy
James	Faust	Clemson University	Roberto	Lopez	Horticulture
Rhuanito	Ferrarezi	University of Georgia	Marissa	Lubarski	Bayer Crop Science
Aaron	Fields	Eden Green Technology	Jennifer	Lytle	BIOS Lighting
Paul	Fisher	University of Florida	Tilak	Mahato	University of Arizona - CEAC
Gary	Fitzgerald	Meister Media Worldwide	Brian	Mamrocha	Conviron/Argus
Efren	Fitz-Rodriguez	Univ Autonoma Chapingo, MX	Leo	Marcelis	Wageningen University
Nick	Flax	Ball Horticultural	Aaron	Martin	PathoSans Technologies
Julian	Franklin	Rothamsted Research	Gioia	Massa	NASA-KSC
Patrick	Friesen	Bio Chambers Incorporated	Neil	Mattson	Cornell University
Jenn	Frymark	Gotham Greens	Penny	McBride	UC ANR
Karla	Garcia	Hort Americas	Will	McCollum	Valoya Inc.
Gary	Gardner	University of Minnesota	Marisa	McKay	Applied Invention
Lauren	Gardner	Endurant Energy	Madeline	Melichar	Syngenta
Gene	Giacomelli	University of Arizona - CEAC	Qingwu	Meng	University of Delaware
Daryan	Godfrey	Bayer Crop Science	Harvey	Millar	University of Western Australia
Celina	Gomez	Purdue University	Sarah	Mills	Oishii
David	Goodrich	Nutrien Solutions	Cary	Mitchell	Purdue University
Adam	Greenberg	IUNU	Bryan	Mitchell	Western Dakota Technical College
Doan	Ha	Koidra Inc.	Robert	Morrow	Sierra Space
Kevin	Hainline	University of Arizona	Alexis	Moschopoulos	Grobotic Systems Limited
Ahmed	Hammad	Conviron/Argus	Kelsey	Murray	Western Dakota Technical College
Jennifer	Hanks	Corteva Agriscience	Dave	Napier	Conviron/Argus
Sara	Hassan	Farmshelf	Kris	Nightengale	AdeptAg
David	Hawley	Fluence	Genhua	Niu	Texas A&M AgriLife Research
Royal	Heins	Michigan State University	Jim	Pantaleo	UC Davis

Yujin	Park	Arizona State University	Calder	Bethke	University of Arizona-CEAC
Charles	Parrish	UbiQD, Inc.	Kishan	Biradar	University of Delaware
Robert	Pauls	Bio Chambers Incorporated	Eva	Birtell	University of Delaware
Karen	Perkins	University of Arizona	Bryan	Blue	University of Arizona-CEAC
Brandon	Phinizy	Bayer Crop Science	Michael	Blum	University of Arizona-CEAC
Stephen	Poe	University of Arizona	Alex	Cantor	University of Arizona-CEAC
Richard	Poire	Australian Plant Phenomics Fac	Cristian	Collado	North Carolina State University
William	Probasco	Astro Space	Donald	Coon	University of Florida
Barry	Pryor	University of Arizona - CEAC	Ethan	Darby	University of Tennessee
Ketut	Putra	Koidra Inc.	Laurent Amos	Dyanko	University of Bologna
Kevin	Quinlan	mintropy	Erick	Dzeketey	University of Arizona-CEAC
Matthew "Rex	Recsetar	University of Arizona - CEAC	Michael	Eaton	Cornell University
Sharon	Reid	Conviron/Argus	John	Ertle	Ohio State University
Mark	Romer	NCERA-101-McGill University	Brendan	Fatzinger	Utah State University
Pieter	Rooijakkers	Light4Food	Tamara	Friedman	University of Arizona-CEAC
Martin	Ruebelt	NatureSweet Brands	Adam	Gelman	University of Arizona-CEAC
Erik	Runkle	Michigan State University	Spencer	Givens	University of Tennessee
Nadia	Sabeh	Dr. Greenhouse, Inc.	Samson	Humphrey	North Carolina State University
Carole	Saravitz	North Carolina State University	Mark	Iradukunda	University of Georgia
Greg	Schlick	NASA/Ames Research Center	Bouche	Jacques-Joseph	The University of Auckland, NZ
Timothy	Shelford	Cornell/Rutgers University	TC	Jayalath	University of Georgia
Gregg	Short	Greenhouse Design LLC	Sangjun	Jeong	Texas A&M university
Bryan	Shubert	Hettich Instruments	Samuel	Jesse	University of Arizona-CEAC
Graeme	Smith	Graeme Smith Consulting	Megan	Kane	University of Arizona-CEAC
Soojung	Smith	Koidra Inc.	Seonghwan	Kang	Texas A&M university
Kelly	Soanes	National Research Council	Chris	Kaufman	University of Arizona-CEAC
Hans	Spalholz	Current Lighting	Nathan	Kelly	Michigan State University
Nathaniel	Storey	Plenty	Emily	Kennebeck	University of Delaware
Gary	Stutte	SyNRGE, LLC	Changhyeon	Kim	University of Georgia
Wei	Sun	BIOS	Annika	Kohler	Michigan State University
Marc	Theroux	Bio Chambers Incorporated	Noah	Langenfeld	Utah State University
Simone	Valle de Souza	Michigan State University	Lauren	Lindow	University of Florida
Marc	Van Iersel	University of Georgia	Telesphore	Marie	University of Guelph
Ashley	Veach	Fluence	Maxwell	Martin	University of Arizona-CEAC
Kellie	Walters	University of Tennessee	Morgan	Mattingly	University of Arizona-CEAC
Jennifer	Weisman	Bill & Melinda Gates Foundation	Nicklas	McClintic	Arizona State University
Kevin	Wells	Radiance Factory llc	Atila	Meszaros	University of Arizona-CEAC
zachary	Wenrick	Harvest Today	Suyun	Nam	University of Georgia
Jan	Westra	Priva	Yufei	Qian	University of California
Raymond	Wheeler	NASA-KSC	Eshwar	Ravishankar	North Carolina State University
Dave	Wilson	NASA-AMES (retired)	Jonathan	Ries	Arizona State University
Rachelle	Winningham	Signify	Hailey	Schleining	University of Arizona-CEAC
Rustin	Wright	Biora by MineARC Systems	Joseph	Seong	Michigan State University
Jia-Long	Yao	NZ Inst Plant & Food Research	KC	Shasteen	University of Arizona-CEAC
Melanie	Yelton	Plenty	Fatemeh	Sheibani	Purdue University
Neil	Yorio	Maui Greens Inc.	Jiyong	Shin	Michigan State University
Ying	Zhang	University of Florida	Maxwell	Smith	University of Arizona-CEAC
Shuyang	Zhen	Texas A&M University	Eric	Stallknecht	Michigan State University
Paul	Zykan	Bayer	Bret	Timmonds	Cornell University
Al	Zylstra	Dramm Corporation	Jose Olaf	Valencia Islas	University of Arizona-CEAC
			Kahlin	Wacker	University of Georgia
Student Participants			Mitchell	Westmoreland	Utah State University
			Chrisa	Whitmore	University of Arizona-CEAC
Trey	Ansani	University of Arizona-CEAC	Yilin	Zhu	Texas A&M University

Brief summary of minutes of annual meeting

NCERA-101 Business Meeting Summary
Meeting started at 7:18 pm, September 12th, 2022
Introduction and Welcoming Remarks from meeting host Dr. Murat Kacira

Introduction of the NCERA-101 Executive Officers by Dr. Murat Kacira
Chair: Dr. Murat Kacira (University of Arizona)
Chair Elect: Marc Theroux (BioChambers)
Secretary: Dr. Ricardo Hernandez (North Carolina State University)

Recognition of Industry Sponsors by Dr. Murat Kacira (University of Arizona)
The following sponsors were acknowledged:

CONVIRON	DRAMM
ARGUS	BAYER
IUNU	RED SEA FARMS
Inside GROWER	KOIDRA
CURRENT	BIORA
PERCIVAL	HORTAMERICAS
CANDIDUS	FLUENCE
BRIGHT FARMS	ENV. GROWTH CHAMBERS
NATURE SWEET TOMATOES	LI-COR
APOGEE	BIOCHAMBERS
HETTICH	LIGHT4FOOD
CORTEVA	ASTROSPACE
VALOYA	

Approval of Minutes from 2021 by Dr. Ricardo Hernandez (North Carolina State University)

Approval was requested at 7:20 pm, motion to approve the minutes by Dr. Bruce Bugbee (Utah State University). Motion Seconded by Dr. Marc van Iersel (University of Georgia), Minutes approved unanimously.

Announcements of Other Relevant Conferences (All)

- 2023 Greensys- Cancun MX, October 22-27 (http://www.greensys2021.org/)
- 2023 ASHS – Orlando FL, 31-July to 4-August (https://ashs.org/)
- 2023 International workshop on VF- China
- 2024 X International Symposium on Light in Horticulture, Seoul Korea, May 19-22 (https://www.ishs.org/symposium/716)

Additional meetings suggested by attendees:

Resilience harvest conference, ARI institute long beach CA - Suggested by Dr. Mark Lefsrud (McGill University)
ASBE Omaha Nebraska- Suggested by Dr. Mark Lefsrud

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

- Congratulations t**o** Dr. Murat Kacira (University of Arizona) and his team for organizing this International Conference and this year's annual meeting of the NCERA 101 Committee in Tucson. Great reception and Tour programs.

- It is good to know that some of you are having NIFA CIG grants to conduct your research. These activities, you can highlight in your annual reports.
- Annual report of today's committee report will be due within 60 days of this meeting – by November 11, 2022. Newer annual reporting guidelines described under #7 are here: https://www.ncra-saes.org/multistate-handbook.
- NCERA 101 Committee's mid-term review will take place in 2023, Dr. Kanwar will take care of it.
- The NCRA had announced the release of RFA *on Climate Change last year*, designed to enhance our NC multistate research program. This year's deadlines have already passed but we could keep an eye on the future. Please reach out to either your AES director or Chris and Jeff in the NCRA office with any questions (christina.hamilton@wisc.edu and jjacobsn@msu.edu).
- Consider resubmitting the nomination for the NCEREA 101 Committee for the **Excellence in Multistate Research Award**. Here are the instructions from the 2022 award: http://escop.info/wp-content/uploads/2017/04/ESCOP_RESEARCH_AWARD_2022.pdf. 2023 call hasn't been formally released yet.

To proceed with efforts for the Excellence in Multistate Research Award a committee will be established led by Dr. AJ Both (Rutgers University). Dr. Murat Kacira (University of Arizona) and Marc Theroux (BioChambers) offered to be part of the committee.

Membership Report was presented by Mark Romer (McGill University Phytotron)

- 47th anniversary of this group, several international members attended the meeting.
- Regretting to report the passing of Dr. Lou Albright and Dr. Judy Thomas,
- To become a member contact Marc Romer (mark.romer@mcgill.ca) requirements include participating, sponsorship and attending at least one meeting.

Membership Number .....March 2021 173
March 2022 173

- Additions 8
- Deletions.....8
- Net Gain(Loss) 0

Membership Composition	Institutions	Members
• Phytotrons & Controlled Environment Facilities	7	9
• University Departments, Agr. Exp. Stations	67	86
• Government Organizations & Contractors	12	
• Industry Representatives	56	66
Total Number of Institutions / Members	**142**	**173**
Total Number of Countries	9	
Total Number of US States	33	

New Institutions: Dept of Environmental Horticulture (York College of Pennsylvania); Dept of Biological & Agricultural Engineering (Texas A&M University); Tropical Plant & Soil Sciences Dept (University of Hawaii); Biora by MineARC Systems; Orbital Farm; Holistic Industries; Maui Greens Inc.

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

Website Summary, November 2021 to September 2022,https://www.controlledenvironments.org/

Website location	Page views	% page-views
Landing page	3404	25.15 %
Meetings	3145	23.24 %
Growth-chamber-handbook	1101	8.14 %
Members	598	4.42 %
Activities	366	2.70 %
Officers	264	1.95 %
Station reports	261	1.93 %
Past-meetings	255	1.88 %
Reporting guidelines	251	1.85 %
Lighting	185	1.37 %

- Any website comments, questions, suggestions, send them to Dr. Saravitz's (NCSU) email (carole@ncsu.edu)
- Dr. Saravitz suggested to send any new published articles to add to the website "publication"

Student Grant/support Update (Dr. Ricardo Hernandez, North Carolina State University)

- Twenty travel grants of $ 450 each awarded to participating students
- Poster competition support (in meeting competition) with 3 cash prices of $750, $500, $250 for 1st, 2nd and 3rd, .
  For a total of $10,000 dollars investment to the future scientists in CE, this is in large thanks to our industry supporters.
- Poster winners
  - Third place, Nick McClintic, Arizona State University, Investigating application frequencies of plant growth promoting microorganisms' effect on lettuce (Lactuca sativa) seedlings, Poster 109
  - Second Place, John Ertle, The Ohio State University, Nighttime Dim Lighting Enhances Lettuce Leaf Conductance but Does Not Reduce Tipburn Under Tipburn-inducing Indoor Farm Conditions, Poster 211
  - First place, Sangjun Jeong, Texas A&M,The Involvement of Light Intensity in Interactive Effects between Far-red and Temperature on Plant Growth and Morphology, Poster 101

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

- $35,000 travel grant money in the account, pay out $10,000 this year for students.
- Comments on quantum sensor calibration: Dr. Bugbee has sent quantum calibration sensors to several colleagues, other instruments have not been rented. The instrument package has not been used.

- New development: Quantum sensors drifting a lot (5% at year), not a clear reason and results could not be reproduced. Dr. Erik Runkle (Michigan State University) mentioned that new sensors do not show the drift if purchased on or after 2016.
- A recommendation is to make sure you have newer sensors (not older than 10 years) and continue to calibrate sensors often.
- Clear sky calculator is often under used; from this calculator you can use it to tell if your sensor has a problem.
- Dr. AJ Both (Rutgers University) asked Dr. Bugbee what actions were taken to reduce the drift of quantum sensors. Dr. Bugbee uses different materials for the sensors to make sensor better sealed to prevent moisture.
- Dr. Marc van Iersel (University of Georgia) commented that he had issues with old LI-COR sensors, they were having issues on a day to day basis.
- Please email Dr. Bruce Bugbee (bruce.bugbee@usu.edu) if you have questions about quantum calibration.
- ePAR sensors are also included in the instrument package, Apogee has agreed to donate some for the package

Reporting Guidelines

- ASABE Standards efforts, Dr. Mark Lefsrud (McGill University)
    - PAFS – 30 - S653 Heating, Ventilating and Air Conditioning (HVAC) for Indoor Plant Growth without sunlight. *Published ANSI/ASABE/ASHRAE EP 653. October 2021*. This received a special recognition (Dr. Ed Harwood, rest-in-peace)
    - ES-311 - S642 - Recommended Methods of Measurements and Testing for LED Radiation Products for Plant Growth and Development. *Published*. Dr. AJ Both (Rutgers University) mentioned that they are working on the revision and the revision should be out soon.
    - ES-311 - S640 - Definition of Metrics of Radiation for Plant Growth (Controlled Environment Horticulture) Applications. Renewed. New committee created to modify and include ePAR.
    - ES-311 - X644 Performance Criteria for Optical Radiation Devices and Systems Installed for Plant Growth and Development. On hold (covid and other issues) and anticipated to published in 2024 (TBD). A new committee will be formed and they are looking for new members, Rachelle Winningham (rachelle.nono@signify.com) asked for a leader for this standards, if interested please email Rachelle
- Controlled environment research data sharing task force, Dr. N. Mattson (Cornell University), Dr. Erico Mattos (Candidus) gave the update.
    - https://ceaod.github.io
    - Controlled Environment Agriculture Open Data Project (CEAOD)
    - Task force members: Dr. Kubota (Ohio State University), Dr. Mattos (Candidus), Dr. Harbick (USDA-ARS), Mr. Tran (Koidra), Dr, Yang (Purdue University), Dr. Yelton (Plenty)
    - Why submit your data?: Comprehensive, public data in the field of Controlled Environment Agriculture (CEA) is scarce. Increased access to public CEA data has the potential to lead to new machine learning (ML)

and data analytics tools that can propel the CEA industry forward. Public dissemination of data is an important component of many scientific journals and federal grants (i.e. data management plan).

- Dr. Erik Runkle (Michigan State University) asked if light quality was one of the variables to input, Dr. Erico Mattos (Candidus) didn't know.

Future Meetings:

- 2023- UC Davis hosted by Dr. Shamim Ahamed (UC Davis)
  Current Date: April 19-21, 2023
  Location: UC Davis Conference center
  Accommodation: Hyatt Place at the University
  Tour: UC Davis CEA Facilities and working with the local industry
  The meeting will follow the regular annual meeting format (station reports)
  Dr. Carole Saravitz (NCSU) requested pictures and date for the website
- 2024- Iowa State University, Dr. Chris Curry
- 2025- Karma Verde, Mexico, Leo Lobato
- 2026- University of Georgia, Dr. Rhuanito Ferrarezi and Dr. Marc van Iersel

Election of New Secretary

- Incoming secretary 2023 nominations
  Marc Theroux (Biochambers) asked to nominate Dr. Neil Mattson (Cornell University), Mark Romer (McGill University) seconded the nomination. Vote to elect Dr. Neil Mattson, unanimous to elect Neil Mattson.

NCERA-101 Award Discussion

- Mark Romer (McGill University) suggested to again offer an award to celebrate facilities, intuitions, industries. This was delayed from 2018 due to pandemic. He requested volunteers to develop an award plaque. Also, an interesting background photo for the plaque. He also requested for volunteers for a committee to do the work (concise wording of the award and concise presentation of the granted awardee).
  Title: Award for significant organization contributions for CE sciences
  Mark Romer asked for volunteers to contact him via email (mark.romer@mcgill.ca).
  Dr. Erik Runkle suggested to have a process, with a nomination, then based on submissions, the committee will review the nominations to select the winner.
  Dr. Gary Gardner (University of Minnesota) seconded Erik's suggestion and asked the executive committee to find an award committee of 3 people.
- <u>The motion to empower the executive committee to form a sub-committee to determine the nature of the award and determine the criteria and provide a recommendation</u>. Seconded by Dr. Ray Wheeler (NASA), motion was approved unanimously.

New Business open discussion

- Dr. AJ Both (Rutgers University) mentioned that Kenneth Tran (Koidra) will develop a data driven grower book that is to be posted online. This will be

launched soon, and he has asked to encourage critics of the first draft of the book to improve it.

- Dr. Ramesh Kanwar (Iowa State University) mentioned that the Department of State, NIFA, Dutch investment, and FFAR are potential opportunities for CEA research funding. Dr. Kanwar will reconnect, and the Executive Committee will follow up.

Passing of the Gavel to Marc Theroux (Biochambers) new Chair

Recognition comments from Marc Theroux to Murat Kacira's contribution to renewing the group.

ADJOURN

Accomplishments

Rutgers University

We continue 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. We are continuing to work on a comprehensive evaluation of ventilation strategies for high tunnel crop production (David Lewus). We are continuing our work using life cycle assessment tools to assess the environmental impacts of switching from high-pressure sodium lighting to LED lighting (Farzana Afrose Lubna).

Michigan State University

We coordinated several outreach programs that delivered unbiased, research-based information on producing plants in controlled environments, including the Michigan Greenhouse Growers Expo and the Floriculture Research Alliance annual meeting.

In collaboration with colleagues at Arizona, Michigan State, Purdue, Ohio State, and the USDA-ARS, we completed the second year of our research and outreach project entitled "Improving the profitability and sustainability of indoor leafy-greens production".

Ph.D. student Hyeonjeong Kang and Roberto Lopez investigated the influence of the photosynthetic daily light integral and root-zone temperature on rooting of tropical foliage plants during propagation. A daily light integral between 6 to 10 mol·m–2·d–1 is recommended because further increases have minimal impact on root growth or quality. The greatest root dry mass was recorded when cuttings were rooted at a root-zone temperature of 25 °C.

Ph.D. student Nathan Kelly and Erik Runkle studied the effects of dynamic UV-A or blue light on red-leaf lettuce growth and quality attributes. We grew lettuce under white plus red LEDs and delivered additional UV-A or blue light during one of three eight-day phases, or continuously. UV-A or blue light applied during the final phase of production or continuously equally increased secondary metabolite concentrations and leaf coloration, but growth was inhibited under continuous supplemental blue light.

Nathan Kelly and Erik Runkle studied lettuce grown indoors to determine how background lighting (various combinations of blue, green, and red light) influences the effectiveness of far-red light at increasing biomass accumulation. Preliminary results indicate lettuce biomass was the lowest when either no far-red light was present or when far-red light was delivered at its maximum intensity, as long as green light was included in the photon spectrum.

Ph.D. student Eric Stallknecht and Erik Runkle investigated the mechanism by which an experimental red-fluorescent greenhouse cover increases the biomass accumulation of floriculture, leafy green, and fruiting crops. In part, red-fluorescent materials increased biomass accumulation by increasing leaf area, which was correlated with a decrease in the transmission of blue light. However, the blue light fraction did not completely explain plant growth responses, suggesting effects of the green- and red-light fractions.

Eric Stallknecht and Erik Runkle investigated how experimental photovoltaic greenhouse glazing materials influenced the morphology and yield of greenhouse crops. Preliminary results indicate some crops can tolerate minimal to moderate shading caused by photovoltaic panels without decreasing yield, whereas other crops could not. These findings reiterate the necessity of carefully designing combined agricultural and photovoltaic systems considering the crop type, photovoltaic panel type, location, and time of year.

Ph.D. student Jiyong Shin and Erik Runkle studied the interaction between air temperature and photon spectra on the growth of lettuce and basil grown indoors. Preliminary research indicates that air temperature and photon spectra interacted in determining the growth and morphology of the leafy green species. This suggests that air temperature and photon spectra need to be simultaneously considered when developing indoor plant production protocols.

Research technician Annika Kohler and Erik Runkle examined the influence of light intensity and spectrum on the morphology and shelf stability of frill-leaf lettuce grown indoors. Under a relatively high ratio of blue to red light, both lettuce cultivars were compact, had less fresh mass, and greater chlorophyll content than plants grown under a lower light ratio. After 9 days of refrigeration, one cultivar grown under high light with the highest ratio of blue to red light decayed quicker than the other lighting treatments.

Former M.S. student Sean Tarr and Roberto Lopez performed experiments and established the base and optimum temperatures for fresh accumulation of arugula, kale, red oakleaf lettuce, and green butterhead lettuce.

Sean Tarr and Roberto Lopez modeled how the photosynthetic photon flux density and CO2 concentration interact with mean daily temperature to influence the growth, yield, and quality of hydroponically grown green butterhead and red oakleaf lettuce. Dry mass of both cultivars was influenced by the interaction of CO2 and temperature; biomass accumulation was greatest at 800 µmol·mol–1 CO2 at temperatures of 73 or 79 °F (23 or 26 °C).

Sean Tarr and Roberto Lopez investigated how the day length provided to marigold ‘Xochi’ young plants influenced subsequent flowering and cut flower quality. Regardless of the photoperiod provided, time to visible bud and open flower were similar across the young-plant photoperiods tested. Stem length at harvest was greatest when seedlings were grown under photoperiods of 13 to 16 hours.

M.S. student Devin Brewer and Roberto Lopez quantified the influence of blue or blue + red end-of-production (EOP) sole-source lighting on red-leaf lettuce. Results indicate that light intensity was more effective at increasing anthocyanin content than light quality alone. However, 100% blue light at the end of production increased mineral nutrient content beyond levels quantified in plants not receiving additional lighting.

M.S. student Caleb Spall and Roberto Lopez investigated the influence of supplemental light quality on time to harvest and finished quality of several specialty cut flowers. Time to harvest of cut flowers with a long-day flowering response was hastened when grown under blue, red, and far-red light combined, or 100% blue light, compared to cut flowers grown under 100% red light. Stem lengths were greatest under 100% red light.

NASA Ames Research Center, Moffett Field, CA

NCERA-101 project areas addressed: Covid and NASA Ames Research Center closure severely restricted Controlled Environment Laboratory access. As a result, accomplishments focused on utilization of initial Controlled Environment results enabling completion of phase one decision support and related vegetation assessment objectives.

Completed Phase One Objectives for NASA Ames Research Center / State of California Space Act Agreement - Utilizing Adaptive Management Methods for Invasive Aquatic Plant Management: Phase one objectives include 1) remote sensing method development for mapping and vegetation assessment, 2) testing of Unmanned Aircraft Systems (UAS), 3) decision support methods, and 4) daily environmental input sources for vegetation model. Field study area is the California Delta – an intricate network of waterways, canals, and sloughs connecting Sierra Nevada watersheds (San Joaquin and Sacramento with San Francisco Bay) carrying more than 90% of the state's precipitation and supplying California agriculture and communities.

Satellite-based, Remote Sensing Tool for Vegetation Mapping and Canopy Characterization: Completed development of a remote sensing method, utilizing European Space Agency (ESA) Sentinel satellite series, for mapping and characterizing vegetation community structure for Floating Aquatic Vegetation (FAV). Remote sensing tool is in beta testing by the State of California, Division of Boating and Waterways for directing allocation of FAV management resources (personnel and treatment methods) and assessment of management effectiveness.

Unmanned Aircraft System (UAS) Evaluation Test Completed: Completed first field test using UAS (drone and autonomous control) for treatment and assessment of vegetation communities in difficult to access landscapes. Addressed both operational demands and treatment effectiveness.

Decision Support - Linking Landscape-Scale Remote Sensing Assessment and Natural Resources Management: Initial decision support tool combines weekly satellite-based vegetation mapping and canopy assessments with weekly field management practices to assess effectiveness of management practices locally and landscape scales.

Return to the Lab - FAV Evapotranspiration and Water Use : The measured return to the Controlled Environment Lab is focused on resumption of remote identification of FAV and Submerged Aquatic Vegetation (SAV) and plans to use CE chambers gas exchange and on-water (field) validation measurements to add ET monitoring and modeling to the landscape-scale assessment.

Awards: NASA Spotlight Award – Recognizing significant achievement in Technology Transfer and Interagency Collaboration.

Purdue University

For the far-red x CO2 study of young leaf-lettuce growth response, early baby-stage red oakleaf lettuce responded positively to 1200 µmol/mol CO2 and/or 20-40 µmol/m2/s FR light, but differently to other FR/CO2 combinations. At mid-baby-stage, lettuce grew best at 20 µmol/m2/s FR and 1200 µmol/mol CO2, and at teen-stage, biomass went up with each increase in FR and CO2, but leaf area went down or stayed the same.

For the close-canopy-lighting study, energy-utilization efficiency expressed as kWh of electrical energy used for lighting / g biomass produced (FW or DW) doubled for both scenarios of CCL tested.

University of Arizona

Graduate student of Gene Giacomelli, Max Smith completed progress producing tomato (truss and cherry), cantaloupe and cucumber within a recirculating top-drip hydroponic nutrient delivery system. All crops are within a single-bay, gutter-connected, glass-covered greenhouse 7.5 x 15.1 m. Crops are produced in high solar radiation, high air temperature and modest VPD conditions to determine the effect on harvest quality and yield compared to standard, optimal conditions. This is continuing work supported by sub-contract to UC-Merced from an INFEWS-T2 NSF grant, whose primary goal is to develop a solar-energized greenhouse for the purification of the salt-laden drainage water from field production agriculture in the Central Valley of California. It will further produce edible vegetable crops while operating at its excessive air temperatures required for desalinization.

Wavelength altering properties of quantum dots in plastic film for the improvement of tomato and lettuce plant production was continued within a single-bay, gutter-connected, ETFE film-covered greenhouse 7.5 x 15.1 m, by Michael Blum and Morgan Mattingly, graduate students of Gene Giacomelli, in collaboration and support of Matt Bergren, UbiQD company .Graduate student, Michael Blum (advisor, G. Giacomelli) has outfitted a recirculating top-drip nutrient delivery system within a single-bay, gutter-connected, ETFE-covered greenhouse compartment of 7.5 x 15.1 m for evaluating the wavelength altering properties of quantum dots in plastic films for the improvement of tomato plant production supported by a NASA-STTR grant with UbiQD company, Los Alamos, NM, and collaborators Matt Bergren and Charles Parrish.

Gene Giacomelli has hired, trained, educated and/or advised 19 undergraduates working on grant supported research projects, and 7 graduate students (3 as my graduate student supported by grant funds, and 4 as committee member) to be competent in CEA hydroponic crop production systems design and operations.

Gene Giacomelli, collaborator, SAM2 (Space Analog for Moon & Mars) at Biosphere 2, Kai Staats, Director Sam2. Prepared hydroponic lettuce production system for Analog Astronaut Conference May 6 – 8, 2022.

Chris Beytes, Grower Talks trade magazine participation in NGMA meeting at UA-CEAC and visit to UA-CEAC facilities and presentation with student networking. [facilitated by Gene Giacomelli]

KC Shasteen, graduate student of Murat Kacira, developed a machine vision application and implemented a predictive modeling-based system monitoring crop growth and yield, planting density optimization and yield predictions, that can be used in a DFW or NFT based production system.

Kacira Lab, through collaboration and support of Red Sea Farms company, are evaluating the effect of wavelength selective greenhouse covering materials to reduce energy demands for cooling and on varieties of tomato crop growth and yield. The outcomes of the project are also directed towards evaluating humidity controls, wireless monitoring technology, and company's patented technology which combines thermal energy storage and saltwater evaporative cooling to both actively and passively maintain an ideal greenhouse temperature.

Kacira is co-PI (UArizona), with Runkle (PI, Michigan State University), Lopez and Valde de Souza (co-PI, Michigan State), Kubota (Ohio State), and Mitchell (Purdue), and Boldt (USDA-ARS) continued collaborations in a project supported by the USDA-SCRI program entitled "Improving the profitability and sustainability of indoor leafy-greens production."

Kacira Lab, in collaboration with Sadler Machine Co., SynerGy LLC., Thales Alenia Spacein Italy, German Space Agency, Italian National Research Council, University of Naples Federico II, completed a Phase A project funded by NASA that designed and evaluated the performance of a water and nutrient delivery system for crop production in microgravity environment.

Michele Ciriello, visiting PhD Student in Kacira Lab, from University of Naples Federico II, evaluated the effects of DLI and number of cutting/harvest on yield and quality attributes of basil crop grown in recirculating DWC based hydroponics system within LED lighted indoor vertical farm (UAg Farm) at the UA-CEAC.

Graduate student KC Shasteen (advisor Murat Kacira) developed and evaluated a computer vision system to monitor crop health and growth in a vertical farm setting. The research evaluated computer vision-based crop monitoring and modeling-based crop fresh and dry biomass prediction approach (speaking plant-based approach) to be used for decision making and environmental control application in vertical farming system and evaluated various what-if scenarios for co- optimization of environmental variables (air temperature, humidity, DLI, CO2) leading to resource savings. Furthermore, the model developed was used to identify and evaluate most optimal planting densities for the maximum crop yield outcome under specific environmental conditions.

Tilak Mahato (hydroponic specialist) and Murat Kacira (PI) continued to provide technical support for crop production and greenhouse systems controls and collaborations with Todd Millay (Director of UArizona Student Union Affairs) for the rooftop greenhouse facility which provides education and training for students, community outreach, and fresh produce access for food challenged students through campus pantry.

Kacira (co-PI), in collaboration with K. Chief (PI) et al., within NSF-NRT funded project titled “Indigenous Food, Energy, and Water Security and Sovereignty” continued to educate a cohort graduate student on novel and sustainable off-grid production of safe drinking water, brine management operations, and controlled environment agriculture systems to provide technical solutions for communities, currently with Navajo Nation, challenged to have access to fresh produce and safe drinking water. The project collaboration included educational and training programs for technical staff members and intern students, on controlled environment agriculture (CEA) systems, hydroponic crop production, sensors and controls in CEA, offered during May 31st-June 3rd 2022 Tribal Universities and Colleges Internship Program.

UA-CEAC continued to provide educational opportunities on CEA for new farmers through its 21th Annual Greenhouse Engineering and Crop production Short Course (March 7-8-9) (Giacomelli, Kacira, Cadogan, organizers), UA- CEAC Intensive Workshops on education of growers producing tomato crop hydroponically (Dr. Triston Hooks, Instructor).

Kacira, Giacomelli, Cuello (co-conveners), with program coordinator Jaclyn Cadogan and support from industry sponsors, organized and hosted the 2022 NCERA 101 International Meeting on Controlled Environment Technology and Use, September 11-14 at the University of Arizona campus. The conference brought together 200+ participants from academia and industry, and included 6 technical sessions with 20 invited speakers, 3 panels with 9 panelists, and technical tours.

The Ohio State University

The Ohio Controlled Environment Agriculture Center (OHCEAC) with 21 academic members launched research consortium with seven inaugural members supporting to advance

CEA through various researches covering Horticulture, Engineering, Plant Pathology, Microbiology, Entomology, Workforce training, and Food Safety.

The first annual conference of OHCEAC was held on July 20th with with a total of 169 participants. This year's focus was 'Advancement of Microbial Technologies in Controlled Environment Agriculture'.

McGill University

The Biomass Production Laboratory at Macdonald Campus of McGill University is investigating the relationship between pigment absorbance and supplemental lighting for crop production. We have been doing studies on the impact with low pressure sodium lamps (LPS) and have been collecting data that LPS lamps are equivalent to other amber light systems for plant growth.

University of Delaware

Undergraduate student, Evyn Appel, and Qingwu Meng explored programming of Raspberry Pi and installing imaging devices to track and monitor plant growth. With overhead infrared images, we quantified the progressive growth of the plant canopy.

Qingwu Meng created and taught a new graduate-level course, Controlled Environment Crop Physiology and Technology, with 10 students enrolled. This course allowed students to gain insights on principle concepts and familiarity with practical tools in controlled environment agriculture.

University of Hawaii

Different LED lighting (red, blue, 50% red:50% blue) could be used to supply artificial lighting for 'UH Manoa' lettuce plants.

Additional nutrients through a pellet fertilizer or nutrient solution are necessary for proper plant development when using the Martian soil simulants.

Arizona State University

ASU Indoor Farming Certificate Program: ASU is offering a new ASU certificate program 'Indoor Farming Certificate' from the 2022 Fall semester.

Indoor Vertical Farming Workshops in Phoenix: Yujin Park, Zhihao Chen, and the City of Phoenix are developing 3-day workshops on indoor vertical farming, targeting a wide range of potential stakeholders in Phoenix.

Collaboration with the Zimin Institute for Smart and Sustainable Cities at ASU: Yujin Park and Zhihao Chen are working together with the Zimin Institute to create a closed-loop urban food production system that uses food waste as a primary nutrient source in indoor vertical farming settings.

UC Davis University

CEE lab at UC Davis developed autonomous microclimate and nutrient monitoring systems using Raspberry PI and Aurdino for two small-scale indoor farming systems for conducting energy efficiency and automation research activities for indoor farming.

Dr. Ahamed worked with a group of experts in the Global CEA consortium (GCEAC) with a mission of partnering globally to accelerate profitable indoor horticulture through rapidly collaborative innovation. The group worked with various aspects, including the technology

roadmap, demonstration facilities, strong partnership networks, collaborative innovation projects, improved sustainability, workforce development, and market development.

CEE lab (Dr. Ahamed) published a comprehensive literature review on fodder production's current status and challenges in controlled environments. This study provides a comprehensive literature review on techniques and control strategies for indoor environments and watering that are currently used and could be adopted in the future to achieve the economic and environmental sustainability of controlled environment fodder production (CEFP).

A new graduate-level course, "Energy Sytems Modeling," for CEA facilities has been developed and will be offered (Dr. Ahamed) in fall 2022 at UC Davis.

UC Davis team led by Dr. Ahamed and Dr. Lieth participated in urban greenhouse challenge 3, organized by the University of Wageningen from the Netherlands. UC Davis team placed 5th over 30 teams with over 260 students and professionals from 20 countries.

LI-COR Environmental

LI-6800 Portable Photosynthesis System: The LI-6800, equipped with the 6800-01A Fluorometer, is the only instrument capable of the Dynamic Assimilation Technique. It allows you to collect data for full response curves in a fraction of the time required by steady state measurements. In contrast with the RACiR method, the Dynamic Assimilation Technique does not depend on empirical corrections and is traceable to first principles of gas exchange measurements.

LI-600 Porometer/Fluorometer: The LI-600 accelerometer/magnetometer measures three variables–heading, pitch, and roll–and the GPS receiver records leaf location and solar position. The LI-600 software uses these data to calculate the angle of incidence (its orientation to the sun at a given time and place) for each leaf measurement, allowing researchers to evaluate a plant’s environmental status more thoroughly. A new barcode generator in the desktop software allows for creating custom barcode labels that can then be scanned by the LI-600 for sample information.

Plenty Inc.

In 2022, Plenty earned a spot on Forward Fooding’s FoodTech 500 list, was named one of South San Francisco’s Best Tech Startups, and received an AgTech Breakthrough award.

Thirty-percent of the workforce in Compton, CA is local to the area, and Plenty has collaborated with Compton’s mayor to support the greater community.

Plenty has identified a site for a campus of several farms growing different crops on the East Coast of the United States.

Plenty consistently supplies nutritious food to consumers through seasonal and climatic variations, pandemic disruptions, and supply chain limitations.

Sierra Space/ORBITEC, Madison WI

Microgravity Plant Growth: The Veggie units fabricated by Sierra Space were delivered to the ISS in 2014 and 2017 and continue to be actively used to support plant research and crop production tests. Sierra Space also continues to support the Advanced Plant Habitat Unit on ISS. The APH was delivered to orbit in 2017 and is also being regularly used to support plant research. Our XROOTS Aeroponics/Hydroponics Technology Demonstration is currently operating on the ISS. It is using one of our Veggie plant growth systems to provide lighting.

Aerospace Environmental Control & Life Support Systems: Sierra Space is collaborating with Blue Origin to develop a commercial space station called Orbital Reef. Part of the station core will be comprised of Sierra Space's Large Inflatable Fabric Environment (LIFE) habitat modules. The LIFE habitat will incorporate 2-3 Astro Garden modules. The Orbital Reef will be serviced in part by Sierra Space Dream Chaser vehicles.

Koidra Inc

Autonomous greenhouse challenge: Koidra led Koala team, in collaboration with Neil Mattson at Cornell University and A.J.Both at Rutgers University, won the autonomous greenhouse challenge at the Netherlands' Wageningen University & Research repeatedly in 2021 and 2022. For the online challenge in 2021, Koala team outperformed 46 teams from 24 countries in growing virtual lettuce using AI and computer vision modeling.

In the 2022 challenge, 5 teams out of 46 teams above competed to autonomously grow a lettuce crop using an artificial intelligence algorithm. During the challenge, the Koidra team used its Ai algorithm to remotely adjust greenhouse parameters such as lighting, ventilation, heating, irrigation, fogging and blackout screens. Various monitors provided feedback on the greenhouse conditions. RGB (red, green, blue) images of the lettuce gave insights into its weight and growth in real time, while thermal images revealed the veggies' rate of water loss through transpiration. Koala team won the challenge and has become the only AI team to outperform the Dutch reference growers by 27.8% in net improvement.

Autonomous growing pilot in commercial greenhouse: We partnered with Great Lakes Greenhouse, in collaboration with Harrow Research and Development center to receive 2 grants the Greenhouse Competitiveness and Innovation Initiative grant and the Independent Electricity System Operator for developing and piloting AI-based autonomous growing technology to remotely grow eggplants and cucumbers in a commercial greenhouse. Our trial has been started for several months.

Percival-Scientific

Percival-Scientific has developed new LED platforms to optimize spectral uniformity weighted to photosynthetic, Circadian, and insect responses. This optimization of spectral performance to use-case dependent spectral load demands led to very specific choices in LEDs for their spectral and intensity qualities. The LED selection involved solving the corresponding combinatorial problem of which LEDs to select for which defined purpose. This led us into the development of three platforms:

A general purpose 8-color system to simultaneously hit 420nm, 450nm, 530nm, 630nm, 660nm, 730nm spectral points (chosen for UV response, Chlorophyll A/B efficiency optimization, shade avoidance, and flowering response), as well as points between by choosing whites with large color temperature differences.

Broader, simplified dual-channel tiles. Including extended-white 3000-6000K CCT controllable white LED boards, as well as white interspaced with red to permit more efficient Circadian response regime adjustment.

Effective linear LED patterns for incubator and insect spectral demands.

HortAmericas

Brillo Demonstration Greenhouse project had as objective to establish an automated, profitable and reproducible operation of a small-scale local greenhouse operation for young/new

producers. It encompassed all phases, from the construction to the produce sale in grocery stores. This project proved high yield is possible in a low-tech greenhouse in harsh climate when using the right technology. For this project light was optimized to provide the maximum daily PAR while maintaining plant balance.

The Intracanopy lighting trial done with large Ohio greenhouse tomato grower demonstrated intracanopy light fixtures can help to maintain a higher plant density and fruit load which resulted in larger average fruit size and greater yields compared to the control group. Using Intracanopy Light (ICL) fixtures enabled the research area to maintain a higher plant density and fruit load which resulted in larger average fruit size and greater yields compared to the control group.

Over the 31 week comparison time period, the research areas' average fruit size was 162.61 grams, across all shoots, or 8.63% larger than the control group's 149.69 grams.

Total yield was 69,594.72 kg, or 14.61% more than the control group's 60,720.96 kg.

Trials will continue throughout the 2022 and 2023 season.

Hort Americas created a new educational service to provide high quality short courses for young and experienced growers. In total 10 short courses were developed in the past year. All these courses are teached in live sessions and recordings are also available.

In our commitment to education we have created around 40 new videos in our new section on YouTube called "Mastering Controlled Environment Agriculture" these videos are videos are open to the public.

Hort Americas created seven new and free guides for growers. These guides are available on our website and free to the public.

Impact statements

Rutgers University:

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. Crop lighting presentations and 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%.

Michigan State University:

The Michigan Greenhouse Growers Expo, Electronic Grower Resources Online, and The Floriculture Research Alliance meetings delivered unbiased, research-based information to over 3,000 greenhouse growers, plus additional growers and marketers of vegetable and fruit crops.

Unlike annual bedding plants, daily light integral has minimal impact on root dry mass of foliage crops during propagation. Root-zone and air temperature have a greater impact on root and shoot growth during propagation and production.

We learned that end-of-production UV-A or blue light can be equally effective at increasing the concentrations of some secondary metabolites, as well as leaf coloration, as

continuous lighting. However, supplemental blue light inhibited biomass accumulation of lettuce, while end-of-production blue light did not.

We generated models that predict the base, optimum, and maximum temperatures of leafy greens that will help growers determine production temperature setpoints and conduct cost-benefit analyses.

We learned that moderate intensity end-of-production lighting may significantly affect phytochemical, nutrient, and morphological features of leafy greens.

Red-fluorescent shading materials can increase the biomass accumulation of floriculture, leafy green, and fruiting crops compared to materials that do not change the light spectrum. Commercial implementation will depend in part on the product cost and longevity, crops grown, greenhouse location, and time of year.

The implementation of photovoltaics into agricultural systems requires the proper validation of crop type, geographical location, and photovoltaic cover type. Trade-offs that exist between energy generation and plant growth will need to be evaluated for each growing situation.

Purdue University:

For the Minitron III development project, the technology created, which is a combination of a small-scale controlled-environment crop-growth facility, a recirculating hydroponics system, an adjustable LED lighting system, and a crop gas-exchange cuvette system, has the potential to read real-time crop response to a given set of environmental parameters (light intensity, spectrum, photoperiod, temperature, CO2 concentration, and temperature) at any time during its cropping cycle. Gas exchange is the main crop-response parameter, which can be measured in response to dose-response profiles, as a real-time response to current environmental manipulations, or as an indirect metric of growth in response to a given growth environment.

For the far-red x CO2 study of young leaf-lettuce growth response, the message to indoor farmers is that there is a lot to be gained by tailoring the environment to the crop rather than grow different salad crops in a constant compromise environment from start to finish of their production cycle. Different environmental combination optima for different species and cultivars, and at different stages of crop development, will cause growers to reconsider where and when specific environments will be used, and whether different growth compartments can or should be created within open warehouse space.

For the close-canopy-lighting study, growers and manufacturers of indoor lighting infrastructure should re-evaluate how lamp-crop separation distances can be varied throughout crop production, including how close separation distances also can accommodate delivery of fresh CO2 , removal of transpiration water vapor, while maintaining desired temperature setpoints.

University of Arizona:

UA-CEAC organized the 21st Greenhouse Crop Production and Engineering Design Short Course (March 7-8-9, 2022) with 110+ participants to help educate and inform those on fundamentals of growing crops in CEA systems, technologies, innovations. UA-CEAC intensive workshop helped to educated about 50 participants, mostly new/beginner CEA growers, on hydroponic crop production and CEA systems.

Total of 12 graduate students (3 supervised by Giacomelli and 9 by Kacira), and 23 undergraduate students [19 Giacomelli and 6 Kacira] were educated on hydroponics crop

production, greenhouse, and indoor vertical farming-based systems at UA-CEAC. Most continue within the commercial, production or academic aspects of CEA having significant impact within this area.

UA-CEAC (with undergraduate student greenhouse helpers, research associate-Tilak Mahato, engineering support and supervisor-Murat Kacira) in collaboration with Todd Millay of UArizona Student Union Affairs, supported operations of UArizona's Roof Top Greenhouse facility at the Student Union, and provided 3000+ lbs of fresh produce to Campus Pantry for students to help alleviating food insecurity challenges on the university campus. In our research at experimental scale, consideration of various DLI and CO2 concentration injection combinations evaluated, and strategies developed, can help achieving energy savings, and the computer vision and models developed to evaluate various what-if scenarios for co-optimization of environmental variables in indoor vertical farming systems can help improving resource consumption leading to improved resource use efficiencies.

The outcomes and information generated by our research programs at UA-CEAC with the wavelength selective organic photovoltaics based, NIR reflecting greenhouse cover, and quantum dots-based film technologies can lead to innovation and new frontiers for greenhouse covering material alternatives.

In our research with experiments and modeling based, consideration of various DLI and CO2 concentration injection combinations evaluated, co-optimization of variables evaluated, and strategies developed, can help achieving energy savings, and the CFD models developed in our research can help improving environmental uniformity with alternative air distribution system hardware and designs and environmental control strategies in indoor vertical farm-based operations.

Gene Giacomelli with efforts of Masters students Sam Farrow and Max Martin and private company grant support has determine most of the management practices for automating continuous, year-round table grape production in the greenhouse.

The Ohio State University:

We continue offering an online monthly forum 'Indoor Ag Science Café' to serve as a non-competitive communications platform for indoor farmers and relevant stakeholders. The listserv currently has a wide range of stakeholder members, serving as a very effective engagement method with industry stakeholders. During the reporting period, the forums reached a total of 1,373 stakeholders. Cumulative number of views (YouTube) of recorded presentations was 2,278 for the reporting period and 27,969 for the period since August 2018.

McGill University:

Low pressure sodium lamps have the capacity to grow plants at an equal level as other lighting fixtures. Supplementing with blue light improves the growth but only small amounts of blue light is required to maximize growth.

University of Delaware:

Our hydroponic leafy green research revealed species-dependent responses to far-red light under ambient-Earth and superelevated carbon dioxide concentrations, providing data to facilitate spectral customization in space crop production.

We have gained experience with indoor hydroponic cultivation of hot peppers under different spectral conditions, fertilizer strengths, and nutrient management methods. This

knowledge will advise future research on environmental and cultural optimization to improve pepper yield and quality.

Qingwu Meng published two articles with Erik Runkle (Michigan State University) in the Produce Grower magazine. These articles summarized their latest research on LED lighting in indoor hydroponic lettuce production for professionals in the controlled-environment agriculture industry.

University of Hawaii:

'UH Manoa' lettuce, commonly grown in the field or in greenhouses, could be grown indoors under LED lighting.

Martian soil simulants can grow several vegetable crops, but supplemental fertilization is required.

Arizona State University:

In collaboration with strategic partners, ASU Indoor Farming research and educational programs plays an important role in enhancing understanding of indoor vertical farming crop production and management and connecting stakeholders to advance the implementation of indoor vertical farming for more accessible fresh healthy food for Phoenix residents who are located in food deserts.

While rapidly rising fertilizer prices, unstable supplies, global phosphorus shortage, and greenhouse gas emissions and high energy demands associated with chemical fertilizer production are recognized as severe threats to sustainable crop production, our research results show a great potential of using food waste fertilizer as a sustainable alternative to chemical fertilizer.

We learned more about the plant growth, flowering, and fruit development responses of ever-bearing strawberries in response to sole-source lighting control. Our finding will contribute to improve the productivity of indoor strawberry production via precise lighting control.

UC Davis University:

Taylor's lab studied the potential of growing watercress on an indoor vertical farm and their potential health benefits. This work demonstrates the great potential of watercress in a new era of controlled environment agriculture to deliver improved health benefits to customers.

Three undergraduate student works with Dr. Ahamed as part of a senior year design project for designing autonomous indoor aquaponic systems. Also, three undergraduate interns (one form the University of Illinois Urbana-Champaign, one electrical and one mechanical engineer from UC Davis) work on developing indoor farming systems with potential opportunities for increasing lighting energy efficiency using the light guide.

Gross's lab at UC Davis produced an extension video for promoting the research finding for broader communities (https://www.youtube.com/watch?v=7qSiNjSicjA), "Is Fish Farming Factory Farming? Animal Welfare in Aquaculture"

LI-COR:

LI-6800 Portable Photosynthesis System: The Dynamic Assimilation Technique is based on a reformulation of the steady-state equation that enables you to measure assimilation curves. Dynamic assimilation data are comparable in uncertainty to traditional survey data. The increase in variability is typically offset by higher data density.

LI-600 Porometer/Fluorometer: Measuring the angle of incidence of a leaf is a useful variable for understanding a plant's architecture and its physiological responses to the environment. A leaf's angle of incidence may change, for example, to maximize light intensity for photosynthesis, minimize light intensity to conserve water, or allow light through a canopy to lower leaves. Knowing the angle of incidence of a leaf can lead to insights into how light intensity drives photosynthesis, and into the differences in measurements taken on the same plant.

Sierra Space/ORBITEC:

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

Sierra Space is advancing the technology of controlled environment systems to meet the performance and quality needs of long duration space applications. Some of this technology may be transferable and scalable to terrestrial protected agriculture systems.

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 space biology-controlled environment and human life support work in our outreach efforts to spark interest in high school and college students toward STEM fields.

HortAmericas:

From 2021 to the present date Hort Americas has teached educational short courses to more than 400 people including hobby growers, students, small and big growers and researchers.

Brillo Greenhouse project is working on being a demonstration greenhouse where information will be open to the public. This will help growers in harsh climates to understand the benefits and costs of the use of high technology to optimize crop production.

Hort Americas continues its partnership with Arize from Current to keep providing the most advanced technology of controlled environments and greenhouses for agricultural lighting.

Koidra:

Due to the ever-growing world population, the demand for fresh and healthy vegetables is increasing. Autonomous greenhouses can ensure that more people are fed with nutritious products. In addition, these techniques contribute to increasing food safety and a higher production volume of healthy vegetables, using fewer resources such as energy. The Koidra's win at the autonomous greenhouse challenge again has provided concrete proof of concept on leveraging AI in automate climate controls inside greenhouse.

The concept of using AI to automate the climate control in a greenhouse is relatively new. Koidra has organized workshops and provides public talk to educate people about data-driven growing for better yield and resource efficiency

Koidra has been working with strategic partners from both private sectors and researchers from academics (e.g., Cornell University, Rutgers University, Ohio State University) to trial and democratize autonomous growing on different crops in different types of commercial greenhouses.

Percival:

Developments in lighting architecture at Percival have enabled us to expand our spectral capabilities. We can reach extended doses of intensity from UVC, UVB, UVA, particular chlorophyll peaks, particular insect response, shade response, flowering response, down to infrared regimes for bacteriochlorophyll, and are able to resolve the combinatorial issues to solve some of these spectral demands simultaneously.

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