Project or Activity Number: NCERA-101
Requested Duration: From October 1, 2021 to September 30, 2026
Project Title: Controlled Environment Technology and Use
Statement of Issue and Justification:

1. The need, as indicated by stakeholders

The use of controlled environments for research, education, and crop production continues to increase. With advances in technology and increasing complexity in the operation of controlled environments, there are needs for uniform guidelines to maintain, monitor and report environmental conditions such as light quantity and quality, air temperature, humidity, and atmospheric gas composition. Although manufacturers of new technology are open to suggestions, independent evaluation of the commercially available technologies and products are necessary to validate in order to build trust and information exchange among industrial partners, researchers and commercial producers.

There are needs for education and training opportunities in all aspects of controlled environment use from technology development to facility design, and from research to commercial production. Controlled environment facilities require careful design, management, and monitoring to ensure desired conditions for crop production so that efficient processes are developed for the operation of controlled environment facilities on sustained basis. Research is needed to optimize resource use and production approaches to meet environmental, social, and financial efficiencies.

The NCERA-101 committee has taken a leading role in the on-going establishment, development, and dissemination of reporting guidelines for environmental and other variables, appropriate recording frequencies, units of measure, and types of instrumentation for controlled environments. In addition to guidelines for growth chambers and other controlled environments, the committee has developed guidelines for tissue culture projects, greenhouse environments, the use of Light Emitting Diodes (LEDs) for plant production, and is in the process of developing standards for Heating ,Ventilation and Air Conditioning (HVAC) applications for indoor vertical farming systems, with several members of the committee involved in collaboration with professional organizations such as American Society of Agricultural and Biological Engineers (ASABE), Design Light Consortium (DLC), and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The new guidelines developed for greenhouse environments are published in national/international peer- reviewed scientific, engineering, and trade journals. Printed materials suitable for displaying at controlled environment laboratories around the country have also been developed in efforts to inform and reach new users and remind current researchers of appropriate reporting standards.

Our NCERA-101 committee has a large and diverse participation from industry, universities, international partners, state and federal research agencies (such as NASA, USDA-ARS etc.), industrial, academic and institutional members (who is who of the controlled environment industry), and graduate students who attend and continue to attend after they become faculty members to strengthen , international ties, committee longevity. Therefore, the NCERA 101 committee solicits wide range of feedback from various stakeholders who have express ed interest and the need for what the NCERA-101committee does.

The NCERA-101 committee maintains analytical instruments that are available to participating members for calibrating sensors and measuring devices needed for safe and efficient operation of controlled environments. Project leaders continue to use the calibrated instruments as standards at research, educational and commercial facilities in around the United States as well as in other countries. The collection of instruments rotates among the member s institutions and then is returned to the Utah State University for re-calibration. The features of the instrument package are demonstrated and discussed at annual meetings. In efforts to maintain the instrument package, current, upgrades and replacements are continuously evaluated and discussed with NCERA-101 committee members to ensure that commonly used instruments as well as emerging analytical capabilities are included for annual evaluations.

2. The importance of the work, and what the consequences are if it is not done

The use of controlled environment technologies in biotechnology, commercial horticultural, ornamental, pharmaceutical and crop production has been increasing steadily and is significant part of the U.S. economy. Controlled environment facilities have improved significantly over time as our collective understanding and knowledge on plant growth and development processes have increased. The technology has become more systems oriented with increasing demands for accuracy, precision, and resource savings. Ongoing dialogues among scientists, engineers, and commercial users are needed to ensure equipment and expertise are developed to accommodate evolving research and production needs. Large scale controlled environments for indoor agriculture are creating a need to use standardized instruments for environmental measurements with sensor based new technologies to increase efficiencies in production processes and quality of crops (vegetables, fruits and pharmaceutical plants) grown in greenhouses.

Agricultural production issues, impact on the environment, food security and dietary concerns are important topics in the planning, organization and governing of local, state, and national economies. Urban agriculture is part of a local food system where food is produced within an urban area and marketed to consumers locally. Urban agriculture, especially with controlled environments, can contribute to the revitalization of abandoned or underutilized urban land and facilities, social and economic benefits to urban communities, and beneficial impacts on the urban landscape. Sound scientific data are needed to develop priorities, policies and if needed, regulatory guidelines for local crop production. To obtain objective results, research activities addressing these issues in agriculture, plant physiology, genetics, ecology, environmental sciences, and engineering are often conducted in controlled environments.

Well-educated professionals are needed to design, develop, operate, manage, and advance controlled environments facilities for research, education and commercial production purposes. A shortage of trained personnel is likely to result in inefficient management procedures, less than optimal space and resource utilization and low return on investments. The NCERA-101 committee in addition to research, education and outreach activities, and information transfer in the area of controlled environments, provides significant leadership role in the dissemination of information to connect researchers, educators, professionals, students, and private industries and other groups working in the area of controlled environments in the nation and also internationally.

The NCERA-101committee efforts help in safeguarding the reliability of technical and research information, training the next generation of researchers, building an industry-wide community (including researchers and equipment suppliers), and maintaining international relationships. Furthermore, the NCERA-101 Committee efforts helps to enhance quality control for research outcomes, maintain standardization of measurement protocols, provide support for managers of large controlled environment research/production facilities, and creates synergy by bringing teams together that can compete for federal and industry funding for research.

3. The forward plan

Controlled environment facilities are used at many universities, research institutes, industry technology companies, and in large specialty crop production units. These facilities are in demand and are continually upgraded and expanded. The increased diversity and advancement in available hardware, research methods and projects can benefit from clear information transfer, guidelines, and protocols. The NCERA-101 has a long history and successful partnership with controlled environment organizations in other countries to expand the dialog and provide US leadership at an international level since technologies and practices continue to evolve worldwide. This will help north American industry to expand its overseas and help local economy in the US.

A major emphasis of the NCERA-101 committee is education, communication and coordination. The committee composition of academia, students, and industry professionals representing the various segments of controlled environment technology and practices, provides a unique opportunity to ensure a comprehensive approach to address challenges and help advancing knowledge and technology used in controlled environment. As more energy and labor efficient techniques become available, the committee is able to define guidelines for supporting the educated stewardship of available resources. The committee intends to continue fostering cooperative efforts such as technology advancement and transfer, quality control and standards, development of guidelines, instrument advancements and calibrations, information transfer in the form of national and international conferences, professional development of undergraduate and graduate students, workshops, webinars, published research and educational materials, and the development of overall efficient sustainable operational strategies.

4. The advantage of doing the work as a multi-state effort

The NCERA-101committee has strong and diverse participation with members from many states as well as industry contributing to the strong impact of our Committee. Agricultural experiment stations in nine states of the North Central Region (IA, IL, IN, KS, MI, MN, ND, OH, WI) are represented on the committee. In addition, agricultural experiment stations in 13 states outside the NC region have designated committee members (AK, AL, AZ, AR, CA, CT, GA, MD, MS, NM, NJ, NY, NC, TX, UT, WV). The USDA is represented by NIFA in Washington D.C., and the two laboratories of Sustainable Agricultural Systems, and Crop Systems and Global Change in Beltsville, MD, as well as members from USDA-ARS labs. Several representatives from the NASA facilities in Ames Research Center, Moffett Field, CA, and Kennedy Space Center, Cape

Canaveral, FL are associated with the committee.

The commercial sector is well represented through private research and engineering consultants, private companies supporting NASA (Aerospace Engineering Science, Colorado, Amentum Services Inc.-Kennedy Space Center, Florida, Sierra Nevada Corp., Nevada, SyNERGE LLC, Space Life Sciences Lab), and the major growth chamber manufacturers (BioChambers, Conviron, Environmental Growth Chambers, Percival Scientific, Hettich Benelux). In addition, lamp, sensors and environmental control manufacturers (Apogee, Argus Control Systems, Cycloptics Technologies, Heliospectra, HortAmericas, iGROW Induction Lighting, Illumitex, LiCor Biosciences, LumiGrow, Philips Lighting, GE Current, PP Systems, Valoya, Fluence by OSRAM) and agricultural and biotech companies (AeroFarms, Plenty Unlimited, Ball Horticultural Company, Dow AgroSciences, Corteva AgroSciences, Fraunhofer-Center for Molecular Biotechnology, PanAmerican Seed Company, Syngenta Biotechnology, Karma Verde Fresh-Mexico, Koidra Tech LLC, Hawthorne Gardening Company,Signify) regularly support and participate in meetings, information exchange, deliberations and the organization of the committee.

The membership is approximately one third trained agricultural engineers with expertise in controlled environment agriculture. The remainder of the membership is plant physiologists and horticulturists working in various areas of plant science, biology and crop production. The mix of "basic" and "applied" researchers strengthens the committee and allows for interests, perspectives and evaluations to spur research efforts, technological innovations, partnerships and agricultural applications.

The committee has a major objective to integrate controlled environment research into classroom teaching, graduate research, and outreach and extension educational programs. The healthy interaction of different perspectives and interests assures findings and results benefit for agricultural communities, continued research and educational efforts, technological advancements and the society in general.

NCERA-101 has taken the lead in developing information on controlled environment technology and disseminating this information to universities, commercial manufacturers, growers, and government agencies. Areas with short field seasons and low winter temperatures and light, such as the NC region, as well as other regions with dry and hot climate with limited resource availabilities, can be expected to benefit from this technology in attempts to support and increase local crop production. In addition, greenhouse vegetable, ornamental, and nursery crop production is a multi-million dollar industry that is highly dependent on the knowledge generated by this committee.

States throughout the US are represented on the committee. The annual meetings have been well attended with increased participation over the years and attract participants not just from the U.S., but also from Canada, Mexico, Australia, New Zealand, and Europe. Indeed, Canadian academic institutions and industry have been an important part of the NCERA 101 committee since its inception, making NCERA-101 essentially a North American committee in terms of its outreach and influence. NCERA-101 has developed partnerships and regularly collaborates with similar controlled environment groups in UK and Australia. Several international conferences meetings between US, Canada, UK, and Australian researchers and industry have been conducted in past 20 years in NCERA-101 history. The international conferences and annual NCERA 101 meetings were held in UK (2001 and 2012), Australia (2004 and 2016) and the US (Florida, 2008). The next international conference and annual meeting of NCERA 101 Committee is planned to be conducted at University of Arizona where 300to 400 US and international participants are likely to attend and present papers on environment control technologies.

5. What the likely impacts will be from successfully completing the work

The development of new instruments, standards and guidelines for monitoring and reporting controlled environment research conditions and protocols is essential for effective research progress and commercial implementations. Communication and coordination among researchers in various locations lead to sharing of ideas to support more innovative studies and synergistic accomplishments while reducing involuntary duplications of efforts. The NCERA-101Committee's efforts are never done because of continual technological developments and new research insights. It is critical for us to continue our work with NCERA-101Committee, as a lead US group, so we can maintain a community of experts and practitioners that can quickly respond to new challenges, opportunities, and developments.

Inconsistencies in research protocols and measuring practices among scientists can lead to difficulties comparing results and potentially erroneous or overlooked findings and conclusions. Providing access to standardized calibration instruments and well-developed reporting guidelines lead to greater accuracy in research results. Uniform reporting metrics in publications also allows for more accurate communication and interpretation of results leading to more efficient crop growth protocols and food production.

High quality education of students at various levels will meet the need of filling current and future professional and research positions. Well-educated personnel can be expected to improve the use and efficiency of funds and resources allocated to controlled environment facilities. Research findings and observations are translated into applications in support of the most resource and labor efficient production techniques and approaches of food, medicinal and ornamental crops in urban as well as rural locations. The collaborations with industry ensure research findings are in step with technological advances of controlled environment facilities and production systems.

Objectives:

The overall goal of the NCERA-101 committee is to develop or improve the theory and practice of controlled environment technology with particular reference to problems important to the North Central Region, and relevant to other regions as well. As a non-funded committee, the objectives of NCERA-101 are based on education, research, communication, and coordination. The committee will foster a range of cooperative efforts especially in the following specific areas:

(1) Technology Advancement and Transfer: Advance the technology of controlled environment

agriculture (e.g., growth chambers, indoor vertical farms, greenhouses) for agricultural research and production. Disseminate novel technologies to users including controlled environment manufacturers, managers, and commercial users; teach historical and recent controlled environment technologies to students.

(2). Standards and Guidelines: Develop quality assurance procedures for environmental control and monitoring in research and production facilities to improve reproducibility of biological results. Continue to develop and update guidelines for measuring and reporting environmental parameters for studies in controlled environments.

(3). Communication: Publish research, exchange information, prepare educational materials, organize national and international symposia and conferences, and provide consultation and expertise for both scientists and commercial users of controlled environment facilities both domestically and abroad to research and industry stakeholders. The NCERA-101 committee has a website (www.controlledenvironments.org) to facilitate outreach activities.

(4). Instrument Calibration: Maintain a calibrated set of environmental measurement instruments that are available for use by researchers and commercial members.

(5). Environmental: To promote the sustainable development and energy efficient operation of controlled environment facilities.

(6) Education and Training: Support participation of undergraduate and graduate students in the Committee through student sponsorship, research presentations, and networking among all committee members to benefit career development of future researchers, academia, and commercial scientists and help develop US human resource capacity for research and industry.

Procedures and Activities:

The objectives of the committee are accomplished through communication and coordination among committee members to address critical needs through committee assignments, inputs from members, and the election of officers to provide oversight. Annual committee meetings will be held every year at sites of the members. International conferences and symposia have been held every three to four years in collaboration with our colleagues in analogous groups in Europe (UK Controlled Environment Users' Group) and in Australia (the Australian Controlled Environment Working Group). The locations for international Conferences have historically rotated among North America, United Kingdom and Australia. Others analogous groups from Asia and Mexico have also been participating in previous meetings and can be sites for potential future international conferences/meetings/events. The 2020 international conference and annual meeting in Arizona/USA was postponed from March 2020 to another future date due to ongoing COVID-19 global pandemic.

The 2017 Annual Meeting was hosted by NASA Ames Research Center in Pacific Grove, CA. In 2018, the annual meeting was held in North Carolina to coincide with the 50-year anniversary of the phytotrons at Duke and North Carolina State universities. The 2019 annual meeting was hosted by McGill University in Montreal, Canada. After the upcoming (re-scheduled) meeting in Arizona for 2021, and the next annual meeting is scheduled to be in Michigan.

Presentations and discussions by scientists and industry partners on problems, issues, new advancements, novel applications, funding opportunities, collaborations on multi-state projects, and adaptations of controlled environments in research, teaching, outreach, industry and commercial crop production are conducted at the annual meetings. Strong collaborations and interactions among research, academic, government and industry representatives during annual meetings and ongoing discussions ensure the transfer of knowledge in areas such as advances in design, instrumentation, environmental monitoring and control techniques of controlled environments. Quality control is a central focus and continued exchange of information and ideas will serve to ensure the appropriate use of controlled environment technology. The NCERA101 committee has already developed (Both et al., 2015) and will continue to work on guidelines and standards that are relevant to research and commercial use of controlled environments.

Our members will continue to publish research outcomes, exchange information, prepare educational materials, host, and contribute to organizing and participating in national and international symposia, conferences, webinars, and provide consultation and expertise for both scientists and commercial users of controlled environment facilities both domestically and abroad to research and industry stakeholders. The committee will continue to host and maintain NCERA-101 Committee Website (www.controlledenvironments.org) to facilitate outreach activities. Efforts will be made to ensure recent publications by members of the committee, including annual meeting proceedings, are widely accessible through the internet and other publication avenues. The committee will also continue to maintain a calibrated set of environmental measurement instruments that are available for use by researchers and commercial members.

Expected Outcomes and Impacts:

(1) Implementation of new techniques, technologies, and improved operation of controlled environment facilities through information exchange, technology development and transfer.

(2) Facilitate open exchange of international developments and accelerate evaluation and adaptation for applications in the US.

(3) Collaborations and meetings with international partner groups and industry collaborators in the UK, Australia, Asia and Mexico, and other countries and regions with interested and relevant controlled environments groups, will be held in conjunction with scheduled international meetings to encourage information exchange. Conference proceedings will be published and accessible through open sources. The members will continue making recorded webinar presentations available for stakeholders on websites of collaborative multi-state projects and their respective institutions.

(4) Guidelines and standards relevant to research and commercial use of controlled environments will continue to be developed, refined, and promoted by industry, government and academic partners.

(5) Continued partnerships among manufacturers, researchers, educators and operators of controlled environments to support the advancement of new technologies and improved management practices.

(6) Committee will continue to identify areas of critical research and education issues and opportunities in controlled environments and continue educating next generation scientist and engineers who will be leaders in controlled environments.

Internal and External Linkages: *This section is generated automatically as the SAESs enter participants. Any non-SAES participants can be entered by the Administrative Advisor. Include a complete table of resources utilizing the format in Appendix E.*

> ***Rationale:*** *It is important to document the extent of participation in the proposed activity to show integration across functions, disciplines, institutions, and/or states. The names of participants, their employing institution, his or her scientific discipline, the type of appointment (research, extension, joint research and extension, etc.), and SY, PY, and TY commitments should be listed on the* "*Projected Participation Report.*"

Educational Plan:

The NCERA-101 committee has established and will continue its strong collaborations and interactions among research, academic, government, and industry representatives during annual meetings and ongoing discussions ensuring the transfer of knowledge in areas such as advances in design, instrumentation, environmental monitoring and control techniques and technologies in controlled environments.

Collaborations and meetings with international partner groups in the UK, Australasia, Asia, Mexico, with other interest groups and industrial partners, will be held in conjunction with scheduled international meetings, workshops, webinars with committee members leading and participation to encourage information exchange. Conference proceedings, outreach and extension bulletins, webinar presentations will be published and accessible through the world wide web and at NCERA-101 committee website when relevant.

Guidelines and standards for measuring and reporting controlled environment research activities and design aspects will continue to be developed, refined, and promoted by industry, government and academic partners. Partnerships among manufacturers, researchers, educators and operators of controlled environments will be encouraged to advance the development of new techniques, technologies, and improved management practices in controlled environments.

The committee will continue to engage undergraduate and graduate students, postdoc researchers and technical staff to participate in presentations, meeting organization, guidelines and standards development efforts during annual and international meetings, workshops, webinars, and other relevant scientific activities.

Governance: The committee identifies participating institutions. The approved experiment station representatives are usually active for the duration of the project. At each annual meeting, a secretary is nominated and elected. The secretary serves one year and then becomes chair-elect and chair the following two years. Neil Yorio (NKOM Scientific Corporation) is the current chair, Dr. Murat Kacira (University of Arizona) is chair-elect and will become chair during FY 2021. Marc Theroux (BioChambers) serves and the current secretary. Administrative guidance is provided by an assigned Administrative Advisor and a NIFA Representative. Currently, Dr. Ramesh Kanwar (Iowa State University) is Administrative Advisor and Dr. Stephen Thompson is NIFA representative. Mark Romer (McGill University-Phytotron) serves as Officer for Membership and Dr. Carole Saravitz (NC State University-Phytotron) leads Committee Website.

Literature Cited:

Both, A.J., L. Benjamin, J. Franklin, G. Holroyd, L.D. Incoll, M.G. Lefsrud, and G. Pitkin. 2015. Guidelines for measuring and reporting environmental parameters for experiments in greenhouses. Plant Methods 11(43). 18 pp.

 December 1, 2020

Authorization: *Electronic signature of the Administrative Advisor with the date of submission.*

APPENDIX

HIGHLIGHTS OF COMMITTEE ACTIVITIES (2016 - 2020)

1. *Cooperative Research & Publication:*

    a. *Developed Guidelines and Standards*

    Both, A.J., B. Bugbee, C. Kubota, R.G. Lopez, C. Mitchell, E.S. Runkle and C. Wallace. 2017. Proposed Label for Electric Lamps Used in the Plant Sciences, HortTechnology 27(4):544-549.

    Recent advances in light-emitting diode (LED) technology now provide the horticultural industry with multiple lighting options. However, growers are unable to compare technologies and LED options because of insufficient data on lamp performance metrics. This publication proposed a standardized product label that facilitates the comparison of lamps across manufacturers. This label includes the photosynthetically active radiation (PAR) efficacy, PAR conversion efficiency, photon flux density output in key wave bands, as well as the phytochrome photostationary state (PSS), red/far red ratio, and graphs of the normalized photon flux density across the 300–900 nm wave band and a horizontal distribution of the light output

    b. *Books and Book Chapters*

Kozai, T., K. Fujiwara, and E.S. Runkle. 2016. LED Lighting for Urban Agriculture. 54 pp. Springer, Singapore.

This book focused on light-emitting diode (LED) lighting, mainly for the commercial production of horticultural crops in plant factories and greenhouses with controlled environments, giving special attention to: 1) plant growth and development as affected by the light environment; and 2) business and technological opportunities and challenges with regard to LEDs.

Lopez, R. and E. S. Runkle. 2017. Light Management in Controlled Environments. Meister Media Worldwide, Willoughby, OH. ISBN-13:978-1544254494, ISBN-10:1544254490

This book presented the underlying biology of how light influences plant growth and development of specialty crops, especially those grown in greenhouses and controlled-environment growth rooms.

Kozai, T. 2018. Smart Plant Factory: The Next Generation Indoor Vertical Farms. Springer Singapore, ISBN: 978-981-13-1064-5

Kozai, T., G. Niu, and M. Takagaki (eds.). 2019. Plant factory: An Indoor Farming System for Efficient Quality Food Production. Academic Press, Elsevier Publisher, Second Edition, pp. 487.

These books described the concept, characteristics, methodology, design, management, business, recent advances and future technologies of plant factories with artificial lighting (PFAL) and indoor vertical farms. The book discussed the basic and advanced developments in recent PFALs and future smart PFALs that emerged in 2016.

Zhang, Y. and M. Kacira. 2018. Air Distribution and Its Uniformity. In Smart Plant Factory: The Next Generation Indoor Vertical Farms. Ed. T. Kozai, Springer Singapore, ISBN: 978-981-13-1064-5

This book chapter described how air current speed affects the photosynthesis and transpiration processes of crops, the theory of leaf boundary layer and boundary layer resistance, and with example applications of improving air movement and uniformity in indoor vertical farming systems considering localized climate control.

Kubota, C. 2019. Understanding crop responses to controlled climates in greenhouses. Chapter 7. (P.205-223) In: (L.F.M. Marcelis and E. Heuvelink eds.) Achieving sustainable greenhouse cultivation. Burleigh Dodds Science, Cambridge, UK.

This book chapter summarized current understanding of interactions of key aerial environmental factors affecting plant growth and their strategic applications to improve the productivity, profitability and sustainability of greenhouse cultivation.

Lea-Cox, J.D. 2020. Advances in Irrigation Practices and Technology in Ornamental Cultivation. Chapter 12. M. S. Reid. (Ed.) Burleigh Dodds Science Publishing, Cambridge, UK. https://shop.bdspublishing.com/store/bds/detail/product/3-190-9781786763280

This chapter addressed these systemic issues, to increase the efficiency of irrigation applications, to reduce runoff volume and limit contaminant load, and make the most effective use of any capture or remediation capacity.

c. Conference Proceedings

Currey, C.J., R.G. Lopez, E.S. Runkle. 2016. VIII International Symposium on Light in Horticulture, ISHS Acta Horticulturae 1134. ISBN: 978-94-62611-09-2

Boyaci, F., M. Kacira, S. Hemming, Y. Tuzel. 2020. III International Symposium on Innovation and New Technologies in Protected Cultivation. Acta Horticultirae 1271. ISBN: 978-94-62612-69-3

d. Publications:

Calibrated environmental measurement instruments are available to members and provide a calibration reference for cooperating laboratories. A package of instruments obtained through a grant from NSF funds has been maintained and continuously updated as new instrumentation has become available. Sensor package includes quantum sensors, air temperature and humidity sensor and spectroradiometer. The instrument package is maintained by one laboratory with regular auditing of the instruments and is forwarded to anyone requesting it for a two week period of use with payment of a fee that provides funds for instrument maintenance and purchase of new instruments that become available. For additional information please see https://www.controlledenvironments.org/instrument-package/.

The NCERA-101group reported 134 publications on their station reports in 2020. A list of these publications is provided at the end. In addition to the publications listed, the NCERA-101 members reported numerous presentations at scientific meetings, workshops, grower conferences, educational outreach, and informational public events.

2. *Annual Meetings:*

2016 5th International Controlled Environment Conference/AusPheno 2016, September 18-23, Canberra, Australia,
2017 Annual Meeting, NASA Ames Research Center, Pacific Grove, CA, USA
2018 Annual Meeting, North Caroline State University, Raleigh, NC, USA
2019 Annual Meeting, McGill University, Montreal, Canada

2020 6th International Controlled Environment Conference, March 15-18, University of Arizona, AZ, USA [postponed due to COVID-19]

3. *Collaborative International Workshops / Meetings*

VIII International Symposium on Light in Horticulture. 2016. Conveners E. Runkle and R. Lopez., Michigan State University, East Lansing, MI, USA.

This international symposium, in collaboration and under the aegis of International Society of Horticultural Sciences, brought together more than 200 participants to discuss about lighting systems and technologies, crop responses to light intensity and quality. A symposium proceeding was published, Acta Horticulturae 1134.

1st International Workshop on Vertical Farming. 2019. Conveners L. Marcelis, F. Orsini, M. Kacira. Wageningen University, The Netherlands. 2019.

This international workshop, in collaboration and under the aegis of International Society of Horticultural Sciences, brought together more than 400 participants to discuss about challenges and opportunities in indoor vertical farming with topics on crop production, LED lighting, environmental control, technology, and engineering. A thematic issue was published on Vertical Farming in European Journal of Horticultural Sciences.

NCERA-101Website

Establishment and maintenance of a comprehensive electronic mailing list and a website, listing the committee's strategic goals and areas of activity, key publications, calibration instrument package capabilities, and upcoming events. All minutes and select presentations and conference proceedings from past NCERA-101 meetings are available electronically on the website (www.controlledenvironments.org).

4. Collaborative multi-state research projects

During the annual meetings and business meetings, Administrative Advisor and NIFA representative present about potential funding opportunities relevant to the NCERA-101Committee and Committee Members also discuss about potential collaborations among academic institutions along with partnerships with the Industry Members and collaborators. Some of these discussions led to large multi-state projects with participation from NCERA-101Committee members form academic institutions, USDA ARS labs, and industry and funded by USDA-NIFA SCRI, DOE-NIFA-InFEWs, and other funding agencies. The following are among these large-scale collaborative projects (*only participating NCERA-101members listed in the projects*):

- *LAMP: Lighting Approaches to Maximize Profits.* M. van Iersel (PI, Univ. of Georgia), with Co-PIs Neil Mattson (Cornell), A. J. Both (Rutgers), B. Bugbee (Utah State Univ.), J. Boldt and K. Harbick (USDA-ARS), J. Craver (Colorado

State Univ.), and with various collaborators from NCERA-101Industry Member. Funded by USDA-SCRI.

- *OptimIA: Improving The Profitability And Sustainability Of Indoor Leafy-Greens Production.* E. Runkle (PI-Michigan State Univ.), with Co-PIs C. Kubota (Ohio State), M. Kacira (Univ. of Arizona), C. Mitchell (Purdue), R. Lopez, S. Valle de Souza (Michigan State Univ.), J. Boldt (USDA-ARS). and with various collaborators from NCERA-101Industry Member. Funded by USDA-SCRI.
- *Strategic FEW and Workforce Investments to Enhance Viability of Controlled Environment Agriculture in Metropolitan Areas.* N. Mattson (PI-Cornell), Collaborators K. Harbick (USDA-ARS), E. Mattos (GLASE). Funded by NSF InFEWs.

<u>Recent scientific publications by the NCERA-101 membership</u>

1. Asseng, S., J.R. Guarin, M. Raman, O. Monje, G. Kiss, D.D. Despommiere, F.M. Meggers, and P.P.G. Gauthier. 2020. Wheat yield potential in controlled-environment vertical farms. Proc. Natl. Acad. of Sci. www.pnas.org/cgi/doi/10.1073/pnas.2002655117.
2. Bartucca, Maria Luce and Del Buono, Daniele and Ballerini, Eleonora and Benincasa, Paolo and Falcinelli, Beatrice and Guiducci, Marcello (2020), Effect of Light Spectrum on Gas Exchange, Growth and Biochemical Characteristics of Einkorn Seedlings. Agronomy, 10(7), 1042.
3. Bayley, Daniel (2020), Controlled Environment Production of Romaine Lettuce (Lactuca sativa). Thesis; School of Environmental Sciences, The University of Guelph, Ontario, Canada. url: https://hdl.handle.net/10214/21293
4. Both, A.J., K. Demchak, E. Hanson, C. Heidenreich, G. Loeb, L. McDermott, M. Pritts, and C. Weber. 2019. High tunnel production guide for raspberries and blackberries. Available at: https://www.tunnelberries.org.
5. Burgner, S.E., K. Nemali, G.D. Massa, R.M. Wheeler, R.C. Morrow, and C.A. Mitchell. 2020. Growth and photosynthetic responses of Chinese cabbage (*Brassica rapa* L. cv. Tokyo Bekana) to continuously elevated carbon dioxide in a simulated Space Station “Veggie” crop-production environment. Life Sciences in Space Research 27: 83-88. doi.org/10.1016/j.lssr.2020.07.007
6. Burgner, S.E., C. Mitchell, G. Massa, M.W. Romeyn, R.M. Wheeler and R. Morrow. 2019. Trouble-shooting performance failures of Chinese cabbage for Veggie on the ISS. 49^{th} Int. Conf. on Environ. Systems, ICES-2019-328.
7. Callaghan, Joshua (2020), Development of Rapid Propagation Systems for Hemerocallis sp. (Daylilies). M.S. Thesis; Department of Plant Agriculture, The University of Guelph, Ontario, Canada. url: http://hdl.handle.net/10214/17751
8. Caplan, D, M Dixon, Y Zheng. 2019. Increasing inflorescence dry weight and cannabinoid content in medical cannabis using controlled drought stress. HortScience 54 (5), 964-969
9. Cheng, Y., D. He, J. He, G. Niu, and R. Gao. 2019. Effect of light/dark cycle on photosynthetic pathway switching and CO_2 absorption in two Dendrobium species.

Frontiers in Plant Science. Vol 10, article 659, doi: 10.3389/fpls.2019.00659
10. Craver, J.K., J.K. Boldt, and R.G. Lopez. 2019. Comparison of supplemental lighting provided by high-pressure sodium lamps or light-emitting diodes for the propagation and finishing of bedding plants in a commercial greenhouse. HortScience 54(1):52–59.
11. Craver, J., K. Nemali, and R. Lopez. 2019. Monitoring growth of bedding plant seedlings using images. Greenhouse Management 39(10):53−56.
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