



The University of Arizona 2021 Station Report NCERA-101: Committee on Controlled Environment Technology & Use

Murat Kacira, Gene Giacomelli, Joel Cuello
Biosystems Engineering Department
Controlled Environment Agriculture Center

Reporting period March 2020-November 2021

1. New Facilities and Equipment (including sensors, instruments, and control systems purchased/installed)

- Folium wireless environmental monitoring system from Autogrow [Folium - Climate Monitoring Solution — Autogrow](#) installed within a 107 m² ETFE glazed greenhouse compartment is being evaluated in comparison to Campbell Scientific wired sensors for air temperature, PPFD, RH and leaf surface temperature in the production of truss tomato (Project PI Giacomelli).
- We received and installed 72 new LED lighting bars ([Model HelioSPEC Izar](#), with Red, Green, Blue and FR spectrum) with drivers from Heliospectra within our vertical farm facility at CEAC ([UAg Farm](#)) as part of our collaboration within USDA-SCRI funded OptimIA project. A new controller ([Hash Controller, Illuminar](#)) was installed to control light intensity, DLIs and scheduling from the new LED lighting system. Illuminar Hash wireless sensor network measuring PPFD, air temperature, RH, VPD (calculated), CO₂ was installed in our vertical farm facility to evaluate its performance and application in research activities, and as part of educational program (PI M. Kacira).
- Graduate student KC Shasteen (advisor M. Kacira) has developed and evaluated a computer vision system with predictive modeling to monitor and evaluate crop growth and yield.

2. Unique Plant Responses

3. Accomplishment Summaries

- Graduate student Joseph Alcorn (advisor, G. Giacomelli) successfully produced quality vegetable crops in high solar radiation, high air temperature (>30 °C) and modest VPD (<2.0 kPa) conditions to determine the effect on harvest quality and yield compared to standard, optimal conditions (25 °C). Tomato (truss and cherry), cantaloupe and cucumber were grown within a recirculating top-drip hydroponic nutrient delivery system. Basil and lettuce were also produced within a deep-water culture, floating raft hydroponic system. All crops and both nutrient delivery systems were within a single-bay, gutter-connected, glass-covered greenhouse compartment of 7.5 x 15.1 m. The work was supported by sub-contract to UC-Merced from an INFEWS-T2 NSF grant, whose primary goal was 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.
- 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.
 - 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) in a four-year project supported by the USDA Specialty Crops Research Initiative entitled “Improving the profitability and sustainability of indoor leafy-greens production.”
 - Kacira Lab, in collaboration with Sadler Machine Co., SynerGy LLC., Thales Alenia Space, German Space Agency, Italian National Research Council, University of Naples Federico II, continued to work on designing and evaluation of a water and nutrient delivery system for crop production in microgravity environments with project funded by NASA.
 - Chiara Amitrano, visiting PhD Student in Kacira Lab, from University of Naples Federico II, evaluated the effects of VPD and CO₂ during a short term exposures of EC (as stress treatment) on green and red-leaf ‘salanova’ lettuce grown in recirculating DWC based hydroponics system within LED lighted indoor vertical farm (UAg Farm) at the UA-CEAC. The study is evaluating the Energy Cascade Model (MEC) predictions of crop biomass and photosynthesis and to be a model as decision support system.
 - PhD student Rebekah Waller and Murat Kacira (advisor), through Binational Agriculture Research Development funds (BARD) project in collaboration with Volcani Research Center and Triangle Research Center, evaluated the effects the effects of wavelength selective organic photovoltaic film deployed as greenhouse roof covering on growth and yield of tomato crop. Results indicated that for the OPV arrays evaluated in the research decreased the shortwave radiation transmittance by approximately 40% and photosynthetically active radiation (PAR) by approximately 37% to the growing area. During the hottest months of the measurement period (May–July), the OPV shade provided a suitable climate for tomato crop production, stabilizing canopy temperature during the times of day with the highest solar radiation intensities. In doing so, the OPV performed the function of a conventional shade screen method. A much greater light utilization efficiency was determined, based on the cumulative yield obtained per cumulative PAR radiation received by the crop canopy, with crops under the OPV covering compared to those under polyethylene cover in the Control section. The overall power conversion efficiency, the ratio of energy output from the solar cell to input energy from the sun, for the OPV arrays evaluated was 1.82%, with lower PCE in the afternoon periods compared to morning and midday periods. Compared to the unshaded Control crop, the OPV-shaded plants achieved higher weekly yields during the hot and high-light periods. Comparable yields were seen between the OPV-shaded plant and the plants grown under a conventional shade net. Overall, results indicated the potential of using OPV as a shade element while also being able to generate electrical energy within the same greenhouse footprint
 - 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), Neal Barto (Engineer) and Murat Kacira 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 students 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 2021 Tribal Universities and Colleges Internship Program, and within UA-CEAC annual virtual greenhouse crop production and engineering short course and intensive workshop.
- UA-CEAC continued to provide educational opportunities on CEA for new farmers through its 19th Annual Greenhouse Engineering and Crop production Short Course (virtual program in 2021), UA-CEAC Intensive Workshops on education of growers producing tomato crop hydroponically (Dr. Stacy Tollefson, Instructor) and within aquaponic systems (Dr. Mathew “Rex” Recsetar).
- Cuello has been directing the Arizona Green Box, a modular vertical farming project using a shipping container in which students grow crops hydroponically using artificial lighting. Cuello and his students designed an original cultivation system, the V-Hive Green Box, that is intended to achieve maximum crop productivity per unit volume.

4. Impact Statements

- Gene Giacomelli, using the controlled environment changed the future procedures/practices in the development of new varieties of field corn for animal feed. The Marana, AZ 7.5 greenhouse and laboratory facility represents a highly automated greenhouse hydroponic crop production system for the continuous yearly production of seed corn for breeding new varieties. Future benefits to the farmer include new breeding lines, developed up to 3 years faster (7 rather than 10 years), that ultimately create new corn varieties with attributes farmers will need, such as drought or salt tolerance to meet the effects of climate change. Given that the Bayer (Monsanto) Company supplies 70% of the world’s feed corn production our science and engineering technology will be affecting billions of dollars of the global agricultural economy. This new system recycles all its irrigation water and nutrients for seed corn production, and it requires only 20% of the total amount that is used in field production. Furthermore, with recycling, there is no discharge to the environment of wastewater or plant nutrients. The closed environment of the greenhouse makes IPM [Integrated Pest Management] highly effective for control of pests and diseases, effectively eliminating the need for chemical pesticides. Stefanie Boe, Monsanto Company’s Community Relations/Site Enablement Lead stated that: “The UA-CEAC has been an instrumental partner (G. Giacomelli, PI) in developing the necessary technology and capacity to conceive and build our new \$100M Marana, Arizona Greenhouse Complex, creating 40 - 60 new local jobs which range from HVAC engineers to plant biologists, and access for others within the company.”
- UA-CEAC organized the 20th Greenhouse Crop Production and Engineering Design Short Course (March 2021, virtually) with ~200 participants, with technical program providing unbiased research outcomes and information. UA-CEAC Intensive workshops helped to educate about 70+ participants, mostly new/beginner CEA growers, on hydroponic tomato crop production and aquaponic systems.

- Total of 7 graduate students (2 supervised by Giacomelli and five by Kacira), and 17 undergraduate students [10 Giacomelli and 7 Kacira] were hired, educated, and advised through grant funded projects to be competent in CEA hydroponic crop production systems design and operations.
- 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.
- The outcomes and information generated by our research programs at UA-CEAC with the wavelength selective organic photovoltaics based, and quantum dots-based film technologies can lead to innovation and new frontiers for greenhouse covering material alternatives.

Published Written Works, Books and Book Chapters

Refereed Journal Articles

- C. H. Parrish II, D. Hebert, A. Jackson, K. Ramasamy, H. McDaniel, G.A. Giacomelli and M.R. Bergren, Optimizing spectral quality with quantum dots to enhance crop yield in controlled environments. *Communications Biology* (COMMSBIO-20-2162-T)
- Waller, R., M. Kacira, E. Magadley, M. Teitel, I. Yehia. 2021. Semi-Transparent Organic Photovoltaics Applied as Greenhouse Shade for Spring and Summer Tomato Production in Arid Climate. *Agronomy* ,11(6): 1152.
- Magadley, Esther, Ragheb Kabha, Mohamad Dakka, Meir Teitel, Maayan Friman-Peretz, Murat Kacira, Rebekah Waller, Ibrahim Yehia. 2021. Organic photovoltaic modules integrated inside and outside a polytunnel roof. *Renewable Energy*, 182: 163-171
- Maayan Friman-Peretz, Shay Ozer, Asher Levi, Esther Magadley, Ibrahim Yehia, Farhad Geoola, Shelly Gantz, Roman Brikman, Avi Levy, Murat Kacira, Meir Teitel. 2021. Energy partitioning and spatial variability of air temperature, VPD and radiation in a greenhouse tunnel shaded by semitransparent organic PV modules. *Solar Energy*, 220: 578-589.
- Montoya, A. P., F.A.Obando, J.A.Osorio, J.G.Morales, M. Kacira. 2020. Design and implementation of a low-cost sensor network to monitor environmental and agronomic variables in a plant factory. *Computers and Electronics in Agriculture*, 178, 105758.
- Zhang, Y., M. Kacira. 2020. Comparison of energy use efficiency of greenhouse and indoor plant factory system. *European Journal of Horticultural Science*, 85(5): 310-320

Refereed Conference Proceedings Articles

Other Creative Works

- Joseph R. Alcorn. 2021. Internship Report, Sustained Growth and Yield in Elevated Greenhouse Air Temperatures through Control of VPD, Professional Science Masters, Controlled Environment Agriculture Track, Graduate Interdisciplinary College, The University of Arizona (G. Giacomelli, advisor)
- Samuel Lawrence Farrow, 2021. Internship Report, Table Grape Production Automation in CEA. Professional Science Masters, Controlled Environment Agriculture Track, Graduate Interdisciplinary College, The University of Arizona (G. Giacomelli, advisor)
- Rebekah Waller. 2021. Explorations in the Food, Energy Nexus: Organic Photovoltaic Applications

to Greenhouse Crop Production Systems. PhD Dissertation, Biosystems Engineering Department, The University of Arizona (M. Kacira, Advisor)

- G. Giacomelli, Panel Moderator, VLAB UC-Berkeley, VLAB Indoor AgTech: Planting the Seeds of a Better Food Supply Featured Startup - Sam Bertram, One.One, Commercial Leader – Sam Schatz, AeroFarm, Adaptor/Incumbent – Marta Baptista, Driscolls, Venture Group – Michael Rose, Better Food Ventures. May 27.
- G. Giacomelli, Panel Member, Is Controlled Environment Agriculture the Future of Secure and Sustainable Food Production? Moderated by Nadia Sabeh for ASHRAE, June 29
- G. Giacomelli, Committee Member CEADS (Controlled Environment Agriculture Design Standards) development group.
- M. Kacira. Panel member. Up, Down, and All Around: Modeling Airflow in an Indoor Plant Environment. ASHRAE Annual Conference. Moderator Nadia Sabeh, June 2021.
- M. Kacira. 2021. Sensors and Environmental Control. Presented at The Limits of Food Production – Vertical Farming Symposium, Munich, September 23. (Invited Speaker)
- M. Kacira. 2021. Optimizing Resource Use Efficiency in CEA Systems. GLASE Webinar Seminar Series, July 29. (Invited Speaker)
- M. Kacira. 2021. Enhancing Resource Use Efficiency in Vertical Farming. Canadian Greenhouse Conference, October 6th. (Invited Speaker)
- Orsini, F., L. Marcellis, M. Kacira. 2021. [ISHS Talks on Vertical Farming](#): An ISHS HortiDialogues Webinar Series. June-December 2021.
- [CEAC Covering Environment Seminar/Webinar Series](#).

Website and social media

- CEAC Website: <http://ceac.arizona.edu/>
- CEAC Twitter @UA_CEAC
- CEAC LinkedIn @University of Arizona Controlled Environment Agriculture Center
- CEAC Facebook: <https://www.facebook.com/UA.CEAC>

Popular Magazine Articles

- G. Giacomelli, interviewed by Larissa Zimberoff, Business Week, How to Grow Better Lettuce In Space, [Growing Better Lettuce in Space May Improve Agriculture on Earth - Bloomberg](#)
- G. Giacomelli, interviewed by Anne Treadwell, Eating Well Magazine, How the Largest Greenhouse in the U.S. Is Using 90% Less Water to Grow Their Tomatoes. <https://www.eatingwell.com/article/7895739/appharvest-indoor-growing-innovators/>