THE UNIVERSITY OF ARIZONA.

The University of Arizona 2022 Station Report
NCERA-101: Committee on Controlled Environment Technology & Use

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Biosystems Engineering Department
Controlled Environment Agriculture Center

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

- We installed 30 new LED lighting bars (iLogic8, ILUMINAR, with Red, Green, Blue and FR spectrum) with new controllers (HASH, ILUMINAR) in a growth chamber within our vertical farm facility at CEAC (UAg Farm). The system is used in a newly designed and installed aeroponics system within the growth chamber, with a custom designed and built datalogger based control, to conduct research (Kacira, PI).
- Two variable speed HAF fans (Dramm) were installed within a 107 m2 research greenhouse compartment and analysis was completed on the improvement of uniformity of night air temperature throughout the plant production zones.

2. Unique Plant Responses

3. Accomplishment Summaries

- 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.

4. Impact Statements

- 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.

Published Written Works, Books and Book Chapters

- **G.A. Giacomelli**, Updated Foreword to "Basic Principles of Growing by Plant Empowerment" by P.A.M. Geelan, J.O. Voogt, P.A. van Weel, The Netherlands.

Refereed Journal Articles

- Waller, R., **M. Kacira**, E. Magadley, M. Teitel, I. Yehia. 2022. Evaluating the performance of flexible, semi-transparent large-area organic photovoltaic arrays deployed on a greenhouse. AgriEngineering (*Accepted*)
- van Delden., S.h., M. SharathKumar, M. Butturini, L. J. A. Graamans, E. Heuvelink, **M. Kacira**, et al.. 2022. Current status and future challenges in implementing and upscaling vertical farming systems. Nature Food, 2: 944–956.
- Zhang, Y. and **M. Kacira**. 2022. Analysis of climate uniformity in indoor plant factory system with computational fluid dynamics (CFD). Biosystems Engineering, 220: 73-86

- Blum, M.A. Blum, C.H. Parrish II, D. Hebert, D. Houck, T. Moot, N. Makarov, K. Ramasamy, H. McDaniel, **G.A. Giacomelli**, and M.R. Bergren. Enhancing Light Quality with Luminescent Films Through Tunable Quantum Dot Emission for Hydroponic Lettuce Production, (*In review*, Hort Technology)

Refereed Conference Proceedings Articles

- Alcorn, J.R. G.A. **Giacomelli** and B.T. Scott (2023). Sustained Growth and Yield in Elevated Greenhouse Air Temperatures through Control of VPD. ActaHort from IHC, Angers, France. (*In review*)
- Blum, M.A., C.H. Parrish II, D. Hebert, D. Houck, N. Makarov, K. Ramasamy, H. McDaniel, G.A. **Giacomelli** and M.R. Bergren (2023). Enhancing light use efficiency and tomato fruit yield with quantum dot films to modify the light spectrum. ActaHort for IHC, Angers, France. (*In review*)
- Shasteen, KC., J. Seong, S. Valle De Souza, C. Kubota, **M. Kacira**. 2022. Optimal Planting Density: Effects on Harvest Time, and Yield. Presented at IHC 2022, Anger, France. ActaHorticulturae (*In review*).

Other Creative Works

- Shasteen, KC. 2022. Predictive Modelling and Computer Vision Based Decision Support to Optimize Resource Use in Vertical Farms. Master Thesis, Biosystems Engineering Department, The University of Arizona. [Major Advisor: M. **Kacira**]
- **G.A. Giacomelli,** Committee Member CEADS (Controlled Environment Agriculture Design Standards) development group.
- **G.A. Giacomelli,** member, Plant Production and Resource Use Efficiency Working Group, Global CEA Consortium. Leo Marcelis and Paul Gauthier, Chairs, April-May.
- **M. Kacira,** co-chair, Workforce Development Working Group, Global CEA Consortium. Penny McBride, David Bubenheim, co-Chairs, May-September.
- **G.A. 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
- **Kacira, M., G. Giacomelli**, **J. Cuello**. 2022. NCERA 101 International Meeting on Controlled Environment Technology and Use. September 11-14 Tucson, Arizona. [with Program Coordinator J. Cadogan]
- **Kacira, M**. 2022. OptimIA Project annual Stakeholder Meeting. September 15-16, University of Arizona, Tucson. [with Program Coordinator J. Cadogan]
- **Kacira, M., G. Giacomelli**, B. Pryor, T. Hooks, E. Worth. 2022. 21st Annual Greenhouse Crop Production and Engineering Design Short Course. The University of Arizona, Controlled Environment Agriculture Center, March 2022.
- **Kacira, M and G.A. Giacomelli**. 2022. Hydroponics Intensive Workshop. The University of Arizona, Controlled Environment Agriculture Center, Jan 7, 8, 9. [with Instructor Triston Hooks, and program Coordinator Ellen Worth].
- **Kacira, M**. 2022. Innovative Technologies for Small-Scale Farmers. FAO & ISHS Joint Webinar, June 21st. (Keynote presentation)
- **Kacira, M.** 2022. Optimizing air distribution in CEA. Indoor AgScience Café, May 24th. (Invited presentation)
- **Kacira, M.** 2022. Sustaining the future with precision horticulture and engineering
- focusing on resource use efficiency. Annual South Korean Society for Bio-Environment Control, May 12. (Keynote presentation)
- **G.A. Giacomelli**, Huerta and Agritecture Workshop by Yara Nagi, Agritecture, "Session 5: Farm Overview." Online, Jan 10, 2022, 3pm - 5pm (EST).
- **Giacomelli, G**. 2022. Greenhouse Design- Structures, Glazing, & Cooling. Presented at 21st UA-CEAC Annual Greenhouse Crop Production and Engineering Design Short Course, March. The University of Arizona, Tucson, AZ.

- **Kacira, M. 2022**. Monitoring Your Greenhouse Environment: Simple Tools to Technology
- Trends, Presented at 21th UA-CEAC Annual Greenhouse Crop Production and
- Engineering Design Short Course, March. The University of Arizona, Tucson, AZ.
- **Kacira. M**. 2022.Controlled Environment Agriculture. FEW Educational Module presentation at Diné College Tribal Colleges and Universities Internship Program, May 31-June 3. Tsaile, Arizona.

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

- Runkle, E., **M. Kacira**. C. Mitchell. 2022. Indoor Farming FAQs (Part 2). OptimIA project article series., Inside Grower, 10(3):16–17.