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SEPTEMBER 2019

CONFERENCE REPORT

CONTROLLED ENVIRONMENT INDOOR AND VERTICAL FOOD PRODUCTION COORDINATED RESEARCH CONFERENCE

A Conference to Plan an Interdisciplinary Controlled Environment Indoor Agriculture R&D Roadmap and Coordinated Research Plan

AFRI Foundation Program Priority A1102: “Foundational Knowledge of Agricultural Production Systems”

EXECUTIVE SUMMARY

The University of Arizona hosted a two-day Arizona CEA Conference sponsored by the U.S. Department of Agriculture that took place at the Biosphere 2 in Tucson, Arizona on September 9-11, 2019. A diverse group of stakeholders from industry, academia, government sectors gathered to engage with the critical issues, both current and future, facing vertical and indoor food production systems. Discussions revolved around seven major thematic areas, established from the preceding workshop "Research and Development Potentials in Indoor Agriculture and Sustainable Urban Ecosystems" co-hosted by the USDA and U.S. Department of Energy (DOE) in June 2018: Economics, Production Systems, Engineering, Plant Breeding, Food Nutrition and Safety, Industrial Ecology in Closed Systems, and Pest Disease and Management.

A CRITICAL JUNCTURE FOR INDOOR AND VERTICAL FOOD PRODUCTION

Developing sustainable and strategic plans to feed the future in the face of growing global challenges will require interdisciplinary vision and innovation on a grand scale. These growing global challenges include climate change, continued and increasing water scarcity in agriculture, insufficient agricultural land to meet growing global food demands and soaring global populations that are becoming increasingly urbanized. Addressing these grand challenges to feed the future will require innovative, integrative and interdisciplinary solutions that draw on both historical and current approaches such as traditional plant breeding and modern gene editing technologies, or developing strategies to reduce global food waste, as well as forward thinking and out-of-the-box innovation.

Controlled environment agriculture (CEA) implemented as indoor agricultural food production systems may offer innovative technological solutions to solve such problems. CEA systems range from basic high tunnel systems, and advanced hydroponic greenhouses using sunlight, to fully insulated indoor operations that produce crops on multiple levels (i.e. vertical farming, VF) solely using electrical lighting. Indoor agriculture, such as VF, is a nascent and rapidly growing CEA system with the potential to help mitigate many of the environmental and social challenges at the food-energy-water nexus. CEA operations are advertised as solutions to many environmental

issues in food production because they are protected from the vagaries of the outside environment, and can be constructed in even the most extreme environments.

Despite these advantages, CEA greenhouse indoor and vertical farming systems are technology intensive, require large capital investment and energy inputs, and they demand higher level worker skill and knowledge for effective operation. Although CEA systems can manage light, water, temperature, nutrient elements and CO2, these conditions, especially with new cultivars, different species and innovative production systems now in development, have not been optimized. Furthermore, there are unknowns about business economics, long-term sustainability, and consumer trends, adding more challenges to overcome within the complex CEA production systems.

The promise of CEA indoor and vertical food production depends on optimizing these unknowns. Thus, these unknowns deserve an integrated, cross-disciplinary, systems-based approach that integrates stakeholder needs and feedback to address challenges and identify opportunities to grow this industry sustainably and contribute to the U.S. agricultural economy.

SUMMARY OUTCOMES

The discussions and ideas exchanged at the Arizona CEA Conference had several important outcomes:

- A final workshop report (80+ page) and a report summary (this document) synthesizing outcomes from presentations and discussions at the conference for the CEA indoor food production industry in North America.
- A coordinated agricultural project (CAP) grant proposal addressing the thematic areas discussed in the CEA conference (not funded). This proposal was authored by conference organizers in collaboration with conference participants, with preparations for the submission begun during the final day of the conference.
- A working group focused on the development of a comprehensive framework for best practices in design and operation for CEA enterprises was formed by conference participants: the Controlled Environment Agriculture Design Standards (CEADS). The CEADS project incorporated in February 2021 and has distributed the debut CEADS standards for peer review, with publication of CEADS v1.0 scheduled for May 2021.
- Seven topic areas, each with ‘Challenges’ and ‘Opportunities’, were the focus of the Conference study. These represent the fundamental concepts for successful CEA operations, and are documented here.

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ECONOMICS

The Economics discussion focused on strategies to enhance the role of indoor crop production within urban areas, in order to establish CEA as an industry leader of the global agricultural market. People are increasingly looking towards controlled environment systems to improve the environmental and social sustainability of agriculture, while also addressing increased consumer demands for fresh, local, and high-quality produce. Despite this clear role for indoor crop production, there are many economic questions that need to be addressed regarding the scalability and long-term sustainability of these systems. Discussions within this thematic area focused on the following topics: (1) identification of the metrics of success in CEA systems from both an industry and community perspective; (2) the development of a pipeline to quantify environmental and social benefits of CEA in a Benefit-Cost Analysis framework; and (3) the scalability of CEA and IA systems. Additional points of consideration included increasing productivity of CEA systems, promoting rural prosperity, and maintaining environmental health.

CHALLENGES

- The relationship between capital expenditures and operational expenditures will change as automation within CEA facilities increases.
- The carbon costs associated with CEA must be considered.
- Energy, labor, and rent are the highest associated costs within CEA facilities.
- Consumer thoughts on CEA produce should be better understood by the industry.
- Grocery stores often lack well-qualified produce managers that can appropriately handle inventory.
- Automation and robotics is an expensive start-up cost, and therefore a luxury of larger companies.

OPPORTUNITIES

- Facilities should implement on-site water treatment systems where possible.
- Facilities should utilize nutrient water and condensate recycling systems where possible.
- Siting should be considered as a critical factor prior to constructing a CEA facility to minimize utility costs.
- The energy sources available within each state should be considered.
- The near term solutions that can be provided by utilizing blockchain technology should be considered.
- Facilities should consider how state-grown programs can be implemented to offer premium market prices.

PRODUCTION SYSTEMS

The Production Systems discussion centered on the effective utilization of hand labor and automation in CEA production processes, in addition to the implementation of innovative technological solutions that can solve industry-related challenges. CEA production systems range from basic high tunnel systems to fully insulated indoor operations that can produce crops on multiple levels by using electrical lighting; each type of production system has differing needs to be fulfilled to allow for maximum optimization of production. Discussions within this thematic area focused on the following topics: (1) canopy management strategies that can enhance productivity and reduce waste; (2) attention to workflow logistics that can increase labor efficiency; and (3) the implementation of integrated environmental controls, precision nutrient delivery, and automation to CEA production systems. Additional topics of consideration included the need for CEA professional certification programs that can benefit the industry and strategies to promote financial sustainability in indoor crop production systems.

CHALLENGES

- The industry must determine whether LED lighting systems are the answer, or just a trend.
- The gap between industry and academia within the CEA field must be bridged.
- New tools for nutrient management in production systems are needed.
- Protocols that identify optimal light spectrums for horticultural LED lighting systems are lacking.
- Assessment procedures that provide accurate interpretations of production system performance are needed.
- Industry standards that are more proactive for the environmental impacts of wastewater are lacking.

OPPORTUNITIES

- An organization should be identified that can create and regulate industry best practices, standards, and protocols
- Research priorities should be identified to aid in the development of new solutions and technologies.
- Real time nutrient evaluations that are reliable and consistent should be utilized.
- A bank of modern nutrient standards should be created.
- Events that foster collaboration between industry and academia should occur more frequently.
- Economic thresholds should be evaluated on an individual facility basis.
- Ratooning strategies for increased yields and waste reduction should be explored.

ENGINEERING

The Engineering discussion focused on the integration of robotics and automated systems within CEA facilities to improve overall production. CEA facilities utilize technical expertise and extensive knowledge of both engineering and horticulture to allow for efficient year-round production of quality crops within a range of climates. Discussions within this thematic area focused on the following topics: (1) strategies to increase lighting efficacy and light use efficiency while reducing costs; and (2) the integration of innovative automation and robotic systems that minimize need for labor inputs; and (3) the improvement of water use efficiency and cycling in growing systems within CEA facilities. Additional points of consideration included general discussions on lighting, wastewater management, carbon dioxide regulations, and nutrient cycling.

CHALLENGES

- The installation and degradation of LEDs presents a number of engineering and design challenges.
- The deployment of artificial intelligence in the industry is not currently cost effective with the data collection capabilities of existing technologies.
- Further research is needed on how plants respond to differing levels of light and water.
- LED lighting systems experience increased degradation in greenhouse environments due to solar radiation, salts, etc..
- Engineering solutions for the development and implementation of smart sensors in CEA facilities is lacking.
- Smaller CEA operations cannot utilize smart sensor and control technologies due to prohibitive costs.

OPPORTUNITIES

- Further research related to LED thermal load issues should be implemented.
- Significant parameters for CEA production should be researched and, based on the collected data, low-cost, easy-to-use sensors can be designed for growers.
- The industry should demonstrate need and raise investment for the creation of a national CEA database.
- Benchmarks and standards for lighting and resource use should be developed.
- Climate controls can be used to reduce the operational costs of greenhouses by making real time adjustments of climate factors like lighting and CO2 levels.
- A list of critical sensors needed by the horticulture industry should be compiled.
- Modeling work related to the early detection of plant abnormalities should be developed.

PLANT BREEDING

The Plant Breeding discussion focused on the application of effective breeding practices to increase yield, transportability, and pest resistance of CEA crop cultivars. CEA production can mitigate crop damage caused by pests and allow for shorter transportation distances; these potential benefits provide breeding programs with the opportunity to prioritize other traits in cultivars that will both appeal to consumers and be compatible with, or even enhance, flavor and nutritional contents of CEA products. Discussions within this thematic area focused on the following topics: (1) the identification of plant traits that should be privileged in breeding programs for indoor farming; (2) the consideration of how CEA production systems can alter the structure of microbial communities associated with plants and growing media; and (3) the identification of a set of factors that make a cultivar or crop a good fit for indoor farming. Additional points of consideration included how supplemental lighting, temperature, and nutrient conditions can be optimized for plants within CEA facilities.

CHALLENGES

- There is a need to separate greenhouses from other forms of indoor production facilities in the context of plant breeding.
- The time frames for desired crop traits within indoor crop production settings are not clearly defined.
- The competition in plant breeding efforts between indoor and field production interests can slow progress.

OPPORTUNITIES

- Careful consideration can be given to the unique breeding needs of each crop cultivar for CEA production systems.
- Prioritization should be given to the desired architectural traits of crops to achieve high yield and optimal harvest index.
- Partnerships between plant breeding facilities and large-scale indoor growers should be explored to implement large-scale screening and validation of crop cultivars.
- Varieties that are developed for CEA production may not need extensive disease resistance traits (relative to those for field production), but seed-borne and mechanically-transmitted diseases should be addressed in breeding programs.
- Application of speed-breeding technology to fast-track cultivar development that is suitable for CEA crop growing and production systems should be explored.

FOOD NUTRITION AND SAFETY

The Food Nutrition and Safety discussion focused on the effective utilization of food safety protocols and increasing the nutritional quality of crops. Both consumers and the agricultural industry are placing greater emphasis on the importance of food safety, transparency, and post-harvest practices to deliver a crop that consumers can trust. Additionally, the industry is continuously working to research and identify methods that can be utilized to improve the nutritional content, quality, and flavor of CEA-grown produce. Discussions within this thematic area focused on the following topics: (1) the ways in which indoor growing conditions alter the microbial communities of plants and impact product quality and shelf life; and (2) the impacts of altered growing media and environmental conditions to the quality, flavor, and nutritional content of the crop. Additional points of consideration included the relationship between aromatics, flavor, and nutritional properties of CEA crops, and the need for standardization of food safety protocols in CEA facilities.

CHALLENGES

- CEA facilities are challenged with sourcing clean seeds and plants.
- There are differing protocols required for greenhouses as compared to fully indoor systems.
- There is a lack of understanding and consensus on post-harvest handling practices of CEA produce.
- CEA grown crops, specifically tomatoes, are reputationally lacking in quality and flavor.
- The effect of light qualities and quantities on the nutritional quality of crops is not well enough understood.

OPPORTUNITIES

- Seed sanitization methods should be identified on an individual facility basis.
- End-point standards that all systems are required to meet should be created.
- Standardized and accessible educational opportunities and training programs for CEA food safety should be created and implemented.
- Design parameters and baseline criteria for facilities to utilize on food safety and production practices should be created.
- The industry should consider how microbial communities can be used to indicate the safety of produce.
- Industry standards and best practices for food safety through coalition building, such as the nascent CEA - FOOD SAFETY COALITION (ceafoodsafety.org), should be developed.

INDUSTRIAL ECOLOGY OF CLOSED SYSTEMS

The Industrial Ecology of Closed Systems discussion centered on promoting the environmental sustainability of production systems through improved facility management and disposal practices. CEA facilities are challenged in the ability to balance necessary industrial processes with environmentally sustainable practices. To mitigate these challenges, industrial ecology seeks to develop processes that will reduce the amount of pollutants and material wastes generated. Discussions within this thematic area focused on the following topics: (1) the production of CEA products that are widely economically accessible; (2) the function of CEA systems in urban and rural food sheds in terms of supply chain and job creation; and (3) the implications of systems for natural resource stewardship and climate. Additional points of consideration included proper facility disposal practices and utilization of efficient waste stream systems.

CHALLENGES

- Improper facility disposal practices can lead to salt buildups in oceans.
- Inedible crop waste disposal practices result in carbon dioxide and methane emissions.
- Electricity limits are being imposed on facilities to promote energy efficiency.
- The cannabis industry may cause blanket regulations for other types of CEA production.
- HVAC regulations in California require by law for systems to vent air outdoors when conditions are favorable to conserve energy; this can be problematic for indoor farms seeking closure and recycled atmospheres.

OPPORTUNITIES

- Community engagement, environmental stewardship, and consumer health should be promoted by the CEA industry.
- Production and capture of bio-gas for fuel and biochar fertilizer from production facilities should be implemented.
- Renewable and alternative energy sources should be utilized by CEA facilities.
- Thermal energy storage and off-peak power usage should be encouraged.
- Policies related to regulating CEA production efficiency should be based in terms of Watts per kilogram of produce rather than per unit area.

PEST AND DISEASE MANAGEMENT

The Pest and Disease Management discussion focused on the importance of effective and efficient management practices within controlled environment facilities. Although proper building designs and implementation of sterile protocols are important, they do not protect fully indoor growing systems from pests and diseases. Major outbreaks of pests or diseases pose a serious threat to indoor CEA operations. Discussions within this thematic area focused on the following topics: (1) the identification of major viral, fungal, and insect pathogens of indoor production systems and strategies for their mitigation and management; (2) the integration of Integrated Pest Management (IPM) practices in indoor production to reduce chemical control; and (3) the balance between effective pest and disease management without harming beneficial insects and pollinators. Additional points of consideration included the importance of proper personnel training, implementation of biosafety protocols, and the utilization of targeted pest management strategies.

CHALLENGES

- Growers often fail to address disease issues within their facilities when yields are remaining sufficient, with consequences down the road.
- The identification of the source of infection for diseases is challenging.
- Determining when proactive and preventative treatment methods are needed is difficult for growers.
- Facilities are challenged in maintaining cleanliness and sanitization.
- The IR-4 herbicide label expansion to biological controls must be evaluated for CEA facilities.

OPPORTUNITIES

- More efficient methods for on-site monitoring and pest and disease detection should be developed.
- Beneficial organisms should be utilized as a form of biocontrol.
- The industry needs to search for new, non-chemical methods of plant protection.
- The incorporation of pesticidal ultraviolet (UV) lights should be investigated.
- The utilization of drones to release beneficial insects in CEA facilities should be considered.
- The academy and industry should provide IPM related technology and information to growers.
- Gene editing technology can be utilized to guide plant breeding for increased resistance to pests and diseases.

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The primary authors of this report were

Rebekah Waller (University of Arizona)
Victoria Ramsay (University of Arizona)

The primary editors of this report were

Dr. Gene Giacomelli (University of Arizona)
Dr. Murat Kacira (University of Arizona)

With editorial input from

Dr. Paul Zankowski (USDA-OSEC)
Dr. Kai Ling (USDA-ARS)
Dr. Sarah Federman (Plenty Unlimited)

The organizing committee and Key Collaborators for the conference consisted of

Dr. Steven Newman (Colorado State University)
Dr. Kai Ling (USDA-ARS)
Dr. Paul Zankowski (USDA-SEC)
Dr. Sarah Federman
Dr. John Adams (University of Arizona - Biosphere 2)
Dr. Kevin Bonine (University of Arizona - Biosphere 2)
Dr. Murat Kacira (Univeresity of Arizona)
Dr. Joaquin Ruiz (University of Arizona - Biosphere 2)
Dr. Gene Giacomelli (University of Arizona)

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Dr. Gene Giacomelli
Dr. Murat Kacira
Dr. Joaquin Ruiz

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