CIDA Hackathon: Theme 2

Controlled Environment Agriculture

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Keywords	Controlled environment agriculture, resource use efficiency, energy, nutrient, water
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The Issue

Controlled-Environment Agriculture (CEA) is a technology-based approach towards year-round production of high nutrient, perishable fruits and vegetables as well as animal proteins, providing additional benefits to the affordability and resilience of current agrifood supply chain. Challenges remain in the cost and resource use efficiency to provide desired return over investment values.

Challenge 1: How might we improve resource-use efficiency in controlled environment agriculture (CEA) by using waste/by-products, or more efficiently controlling the environment based on smart control algorithms?

Details

CEA is a technology-based approach toward food production. CEA is most often used to produce high nutrient density perishable fruits and vegetables, as well as animal protein (fish/insects). The aim of CEA is to provide protection and maintain optimal growing conditions throughout the development of the crop. Year-round plant crop production takes place within an enclosed, regulated growing structure such as a greenhouse or building. Hydroponics (growing plants in amended water rather than soil) is a highly efficient method for producing crops in environmentally controlled structures. Aquaculture (raising fish in indoor tanks) is another form of CEA. In aquaponics, the combination of aquaculture and hydroponics, fish and plants are produced together in one integrated system.

The costs and benefits of CEA can depend on a variety of factors, including resource availability (e.g. water, daylight, infrastructure), crop choices (ease of production vs. value), and markets (geographic proximity of production to points of consumption; demand for products), to name a few. Globally, production value of these sectors is dramatically increasing (10% annual growth rate for hydroponics) due to increased consumer demand for fresh local products and environmental factors, such as lack of irrigation water or decreasing availability of wild-capture fish. Production near urban centers can reduce CO2 emissions for transportation; however, this may be offset by other costs, such as higher energy inputs. In many climates, high-tech approaches may not be necessary. Growing in a high tunnel (simple plastic covered greenhouse) or net house in soil, raised beds, or recirculating hydroponic systems to save water may offer enough protection from the elements.

Strategies for Efficient Water and Nutrient Use in Hydroponic Production

In hydroponic plant production, maintaining a balanced nutrient recipe is crucial for healthy growth. Nutrient demand changes as plants selectively transport ions into their tissues at different life stages, and in response to variation in environmental parameters. Overtime, certain ions--like iron and calcium--tend to accumulate in solution, while others--like nitrogen and potassium that plants readily uptake--will deplete. For this reason, growers reset the nutrient solution by draining to the sewer as it moves farther and farther from the original nutrient recipe’s concentrations and ratios. This practice threatens one of the primary benefits of hydroponics: to reduce water consumption compared to field-grown crops. Equalizing nutrient mass inputs from the solution and outputs in plant tissue will prevent this recipe drift and eliminate water and nutrient waste. The challenge: use tissue and fertigation nutrient analyses to calculate starting and refill nutrient recipes that would continually maintain a balanced recipe.

Considerations

— Intensive Resource Use — High-tech production systems can be very resource intensive. Examples of this in CEA are like greenhouses with supplemental light, indoor farms, or recirculating aquaculture systems that can require extensive heating/cooling, light, water, nutrients, oxygen (aquaculture) and carbon dioxide (greenhouse).

— Problematic Systems or Climate Conflicts — Controlled environment production requires technological approaches to regulate environmental conditions (light, temperature, relative humidity, dissolved oxygen, etc.). Simple environmental control may use thermostats (typically with on/off control based on a temperature set point) with no underlying logic which can result in wasted energy (for example, heating and venting may be on different thermostats set to conflicting settings so one might be heating a greenhouse at the same time one is venting it). Similarly, dispensing feed to fish on a set schedule might not coincide with appetite and consumption, such that costly feed is wasted, and growth is not optimized.

— Cost of Regulating Systems — Sophisticated environmental control systems cost tens of thousands of dollars, but are often required to address the above problems, and have the capacity to integrate several factors — like available solar radiation or supplemental lighting might decrease the need for heating, or venting that can both cool and dehumidify.

Constraints

- Integrate Byproduct/Waste as Resource: A constraint is to explore using waste or side-stream byproducts from other industries to mitigate intensive resource use. For example, heat or CO2 from power plants or small co-generation facilities, processed animal waste for plant crop nutrient inputs (e.g. fertilizer from aquaculture effluent), or industrial/agricultural waste streams for animal crop nutrient inputs (e.g. dietary protein directly from food/animal processing byproducts; protein from insects grown indirectly on organic waste).
- Lower Cost + Increase Control: Can you use low-cost sensors, microprocessors, and smart algorithms? How might you create energy saving, automated control systems to improve overall efficiency and reduce overhead costs

Recommended Resources

Research Journal Articles

- Nicholson, C.F., K. Harbick, M.I. Gómez and N.S. Mattson. 2020. An economic and environmental comparison of conventional and controlled environment agriculture (CEA) supply chains for leaf lettuce to US cities", in Food Supply Chains in Cities, (E. Aktas and M. Bourlakis, eds.), Palgrave Macmillan.
- Pinstrup-Andersen, P., 2018. Is it time to take vertical indoor farming seriously?. Global food security, 17, pp.233-235.
- Graamans, L., Baeza, E., Van Den Dobbelsteen, A., Tsafaras, I. and Stanghellini, C., 2018. Plant factories versus greenhouses: Comparison of resource use efficiency. Agricultural Systems, 160, pp.31-43.
- Rouphael, Y., Kyriacou, M.C., Petropoulos, S.A., De Pascale, S. and Colla, G., 2018. Improving vegetable quality in controlled environments. Scientia Horticulturae, 234, pp.275-289.
- M.Badiola, O.C.Basurko, R.Piedrahita, P.Hundley, D.Mendiola, 2018. Energy use in Recirculating Aquaculture Systems (RAS): A review. Aquacultural Engineering 81, pp. 57-70.
- James M. Ebeling, Michael B. Timmons. Recirculating Aquaculture, Ch 11: Recirculating Aquaculture Systems. 2012 (Also aquaponics chapter?)
- F.I. Hai, C. Visvanathan, R. Boopathy. Sustainable Aquaculture. 2018. (Ch. 4-6 Aquaponics – pdf available through library)

White Papers

- AgFunder AgriFood Tech Investing Report 2019
  https://agfunder.com/research/agfunder-agrifood-tech-investing-report-2019/
- Artemis State of Indoor Farming Report 2017
- Indoor Crop Production: Feeding the Future 2nd Edition, May 2017
- The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States, Buzby 2014, USDA report
- FAO 2018 The State of World Fisheries and Aquaculture
- FAO Fish to 2030
- FAO (171) Edible insects: future prospects for food and feed security. Chapters 7-9.

Videos

- Horticultural Engineering Technology (dozens of lectures by CEA academics)
  https://www.youtube.com/channel/UCsD2oKzVv1B_GtumyKKE8LA
- Series of CEA Plant Physiology lectures by professor Chieri Kubota
  https://www.youtube.com/playlist?list=PL7fPr3CuAdvv4ZPJKPvi4U7VblxKJnegD

Cost Accounting Spreadsheet:

- http://cea.cals.cornell.edu/research/marketing.html
  *Password to edit cells is 1234

Datasets

- Typical Meteorological Year Data, hourly representative climate across a year for 1,000 locations in the U.S. Useful for citing a production operation based on environmental conditions or in modeling energy use or climate control
- NOAA Fisheries landings database (by state, species, etc.)
- Data collection tools/monitoring systems: Microsoft FarmBeats, Cargill iQuatic

CASE STUDIES / CEA RESEARCH EXAMPLES:

Case Studies

- Use of artificial intelligence to operate a greenhouse, Microsoft wins a competition at Wageningen University:
  https://www.microsoft.com/en-us/research/blog/competition-win-a-steppingstone-in-the-greater-journey-to-create-sustainable-farming/
- Innovative Greenhouses Help Farmers Adapt to Climate Change
  https://www.nationalgeographic.com/environment/future-of-food/telangana-india-agriculture-greenhouses/
- AeroFarms (aeroponic vertical farm) - https://aerofarms.com
- Infarm (living hydroponic plants grown in supermarkets) - https://www.infarm.com/en
- Ynsect (insect protein/frass used for animal feed, plant fertilizers) - http://www.ynsect.com/en/
- rootAI (robotic harvesting of fruiting crops) - https://root-ai.com/

Current Research Topics Worldwide

- (*Automation*) Robotic management of labor intensive processes used in CEA production systems. “Smart” controls that accommodate systems’ needs on a real-time or predictive basis (e.g. watering, feeding).
- (*Data*) Optimization of crop production environments using big-data predictive informatics and automation by employing rapidly deployable and infinitely scalable mesh sensor and actuator networks with centralized database, machine learning and artificial intelligence including Phyto metric diagnostic and feedback capacity.
- (*Physical*) Ergonomic improvements in CEA production systems
- (*System*) Profitable and sustainable food production systems using state-of-the art hydroponic and aquaponic CEA (fish production) system designs.
- (*Data, Ops*) Material science advancements for improved energy efficiency and light spectrum control.
- (*Bio*) Smart microorganisms that can measure things like nutrient availability and plant stress and potentially secrete fixes that allow for yield and taste to be maintained.
- (*System*) Methods for moving larger, but still specialty crops, indoors.