(사)한국생물환경조절학회
The Korean Society for Bio-Environment Control

THE UNIVERSITY OF ARIZONA

2022 KSBEC Annual Conference
May 12, 2022

# Sustaining the future with precision horticulture and engineering

## *focusing on resource use efficiency*


**Murat Kacira, PhD**
Director, Controlled Environment Agriculture Center
Biosystems Engineering Department


Controlled Environment Agriculture Center

THE UNIVERSITY OF ARIZONA

# Grand challenges

## Integrated, Complementary, Smarter Production Agriculture Systems

## What is Controlled Environment Agriculture (CEA)

An innovative method of growing plants with integration of engineering and plant sciences, and environmental controls that creates optimized aerial and root zone environments, focusing on production benefits such as:

- *predictable crop timing and yield,*
- *consistently available produce with high quantity and quality,*
- *high resource use efficiency,*
- *no pesticide use*
- *and, minimum environmental impact*

# Technology Levels for Controlled Environment Agriculture



Wholesum Harvest, Amado, Arizona


Urban Ag,


Gotham Greens, NY


AeroFarms, Newark, NJ

## Greenhouse technologies and industry are mature and advancing.


**Wholesum, AZ**


**Gotham Greens, CA/NY/IL/CO**


**AppHarvest, KY**


**Tanimura & Antle, TN**


**Winset Farms, CA**


**Bright Farms, PA/OH/NC/VA/IL**

# Vertical Farming is fast evolving.


AeroFarms, NY, USA


Plenty, San Francisco & Los Angeles, CA, USA


Bowery, NY, USA

Greensense Farms, IN, USA

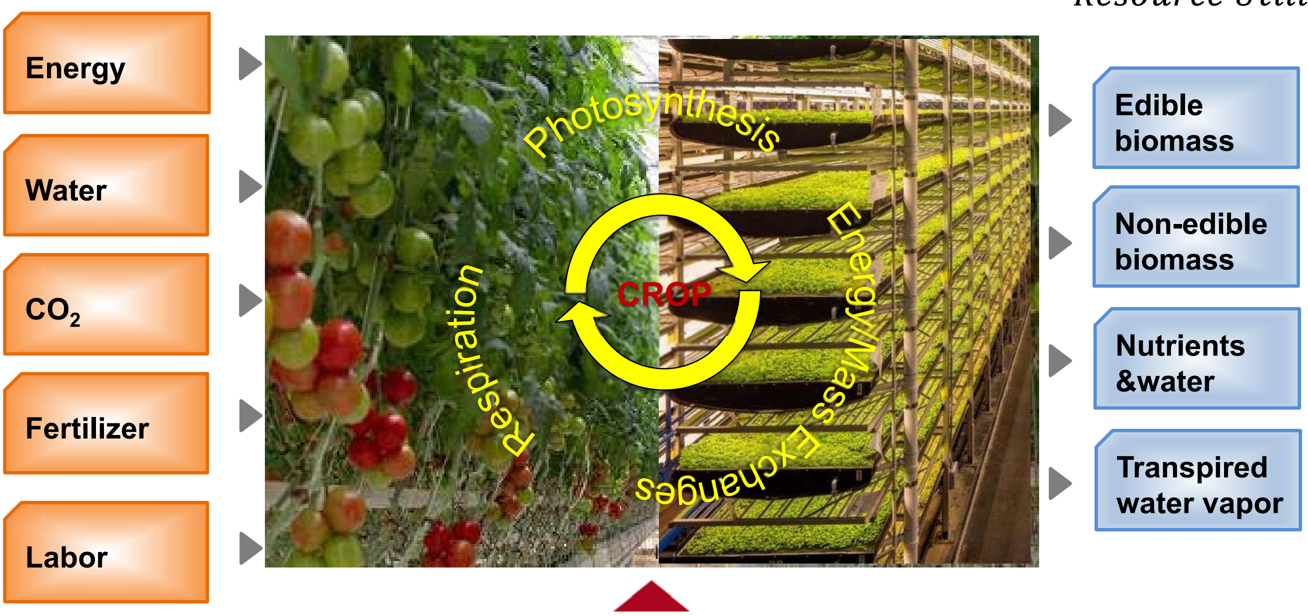
Shenandoah Growers, VA, USA

80 Acres Farm, OH, USA

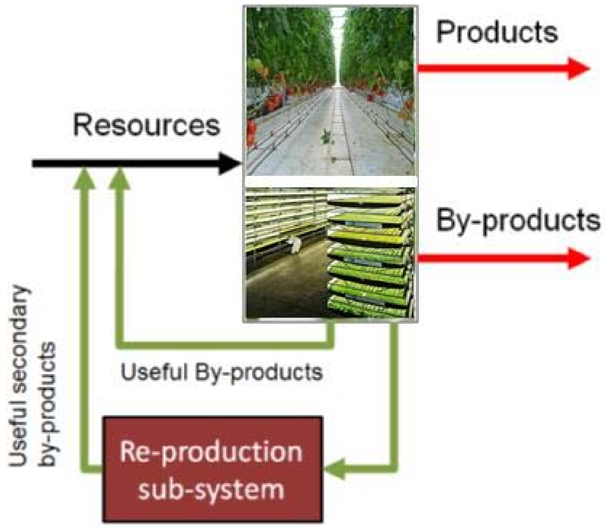
# Bottom Line! Maximize outputs while minimizing inputs *Resource use efficiency* (RUE)

*"Maximize the plant growth with the minimum resource inputs, help contributing to minimum emission of environmental pollutants and minimum costs for the resources used"*

$$RUE = \frac{CropOutput\ (Yield)}{Resource\ Utilization}$$



# Fundamental difference between CEA and field agriculture


Complete control on both demand and supply

## Plant and Data Centric Environmental Controls!

Sensing/understanding plant/microclimate interactions to develop energy efficient, resource conserving control/management strategies in CEA systems

**Resource savings and production quality**

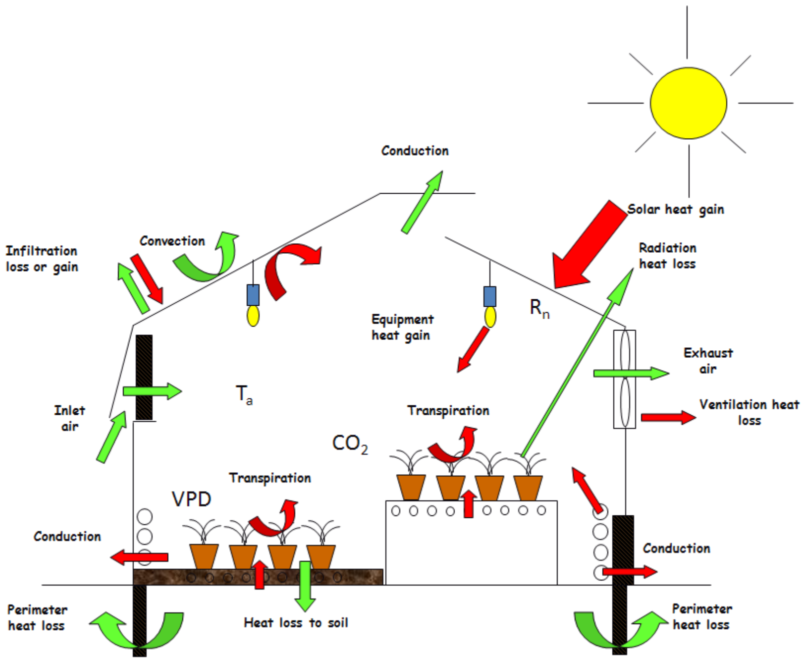
↓

**Combining greenhouse physics with crop physiological information**

↓

**Plant Response Based Control**
- Plants as "Sensors"

**Big Data**
- Greenhouse status
- Crop diagnostics
- Decision support
- Control actions

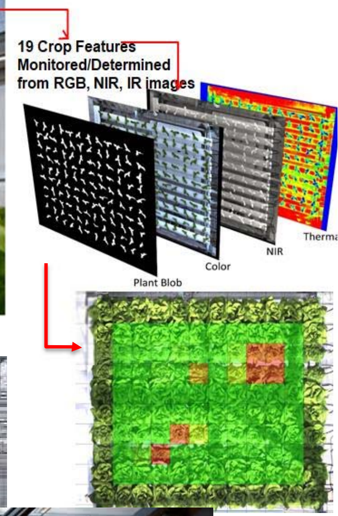


# Emerging Automation Technology

**Automated Crop diagnostics and Decision Support Systems (DSS)**


(PlantEye)

(TopCrop Monitor, Priva)

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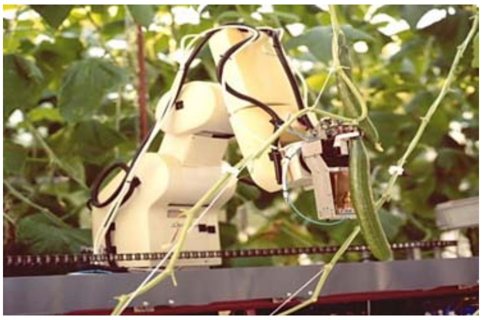
# Emerging Automation Technology - Robotics



www.wageningenur.nl

P. Ling, Ohio State Univ..

Iron-Ox

www.naro.affrc.go.jp

www.wageningenur.nl

## Warehouse Based Vertical Farms

**AeroFarms, New Jersey, USA**

**Plenty, San Francisco, CA, USA**

**Bowery, NJ, USA**

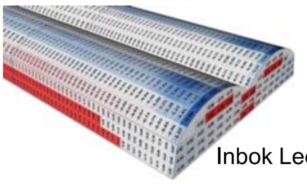
**JPFA, Chiba, Japan**

**Shenandoah Growers, VA, USA**

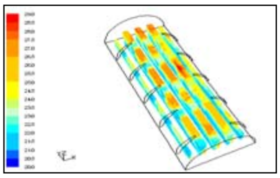
**Farminova, Antalya, Turkey**

## Advances in modelling greenhouse systems using CFD

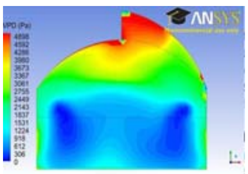
- Natural ventilation
- Fan ventilation
- Insect screens
- Crop transpiration
- Heating systems
- Solar radiation
- Spore transfer
- Cooling systems (Fog, Pad & fan)
- Pesticides distribution / emission
- Humidity control and condensation
- CO2 distribution / Photosynthesis
- Alternative energy integrated GH systems



Inbok Lee et al.

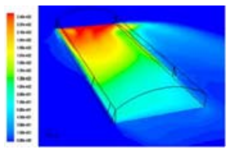


Nebbali et al.

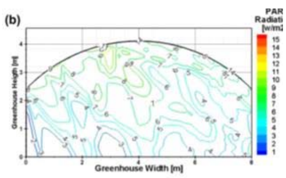


Tamimi et al.

Fatnassi et al.



Bartzanas et al.



Fidaros et al.

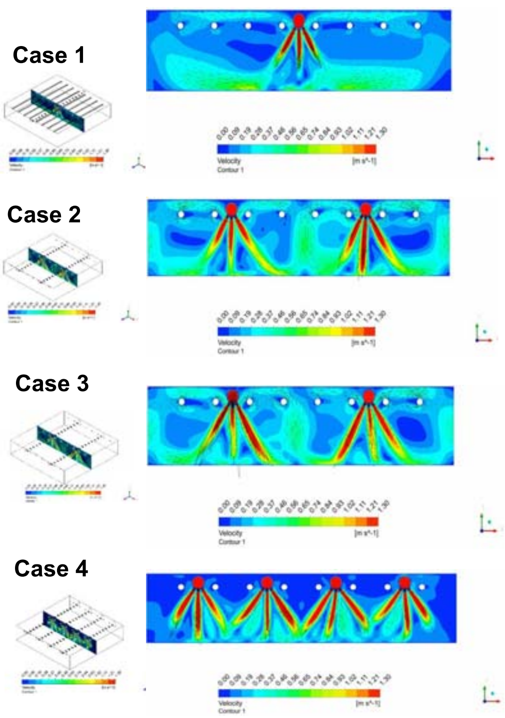
Roy et al.

## Computational Aerodynamics for Improved Air Conditioning & Distribution Systems

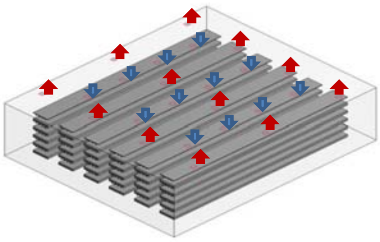
**(Y. Zhang, 2019-)**

Controlled Environment Agriculture Center

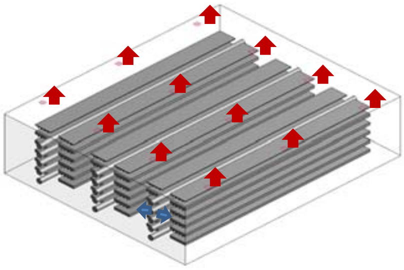
**Air Velocity**



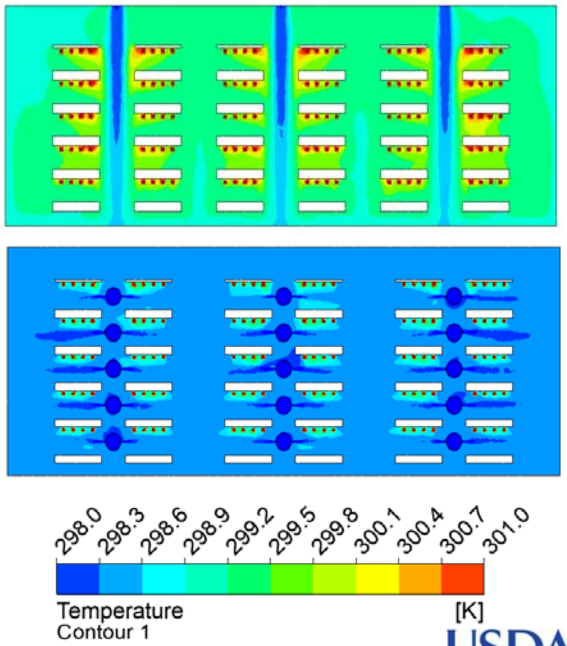

**Design I**



**Design B**



**Air Temperature**




USDA

## Optimizing DLI and CO2 for Lettuce Grown in Vertical Farm

**(B. Caplan, 2019)**

Controlled Environment Agriculture Center

| DLI (mol $m^{-2}$ $d^{-1}$) | Total Usage (kWh) | Avg. Fresh Weight (g/head) | EUE (kg/kWh) |
|---|---|---|---|
| 9 | 3,251 | 130 | .058 |
| 11 | 3,532 | 153 | .062 |
| 13 | 3,813 | 164 | .062 |
| 15 | 4,094 | 177 | .062 |
| 17 | 4,375 | 180 | .059 |
| 19 | 4,656 | 200 | .062 |

- Higher light intensity → compact, heavier
- Lower light intensity → large, lighter
- Market expectations?
- Loss in fresh/dry weight vs savings in electrical energy?

Grodan

ENZA ZADEN

**DLI:**

17 mol $m^{-2}$ $d^{-1}$

13 mol $m^{-2}$ $d^{-1}$

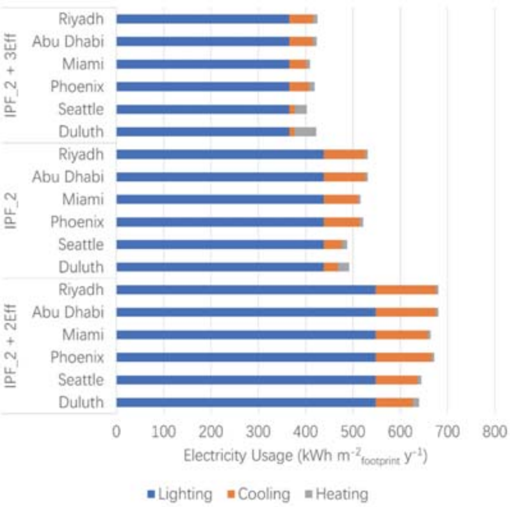
9 mol $m^{-2}$ $d^{-1}$

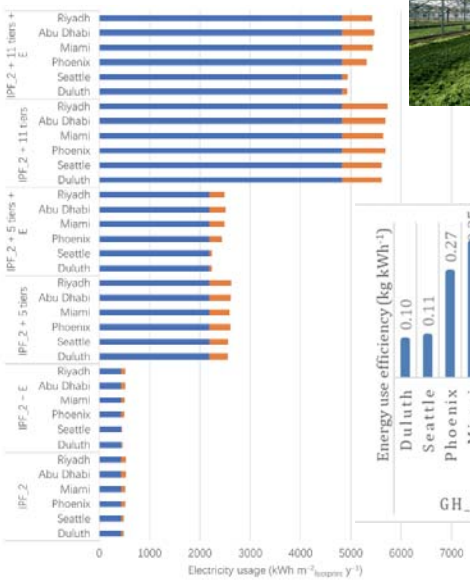
Eur. J. Hortic. Sci. 85(5), 310–320 | ISSN 1611-4426 print, 1611-4434 online | https://doi.org/10.17660/eJHS.2020/85.5.2 | © ISHS 2020

Original article

Comparison of energy use efficiency of greenhouse and indoor plant factory system

Ying Zhang and M. Kacira
Department of Biosystems Engineering, The University of Arizona, Tucson, USA



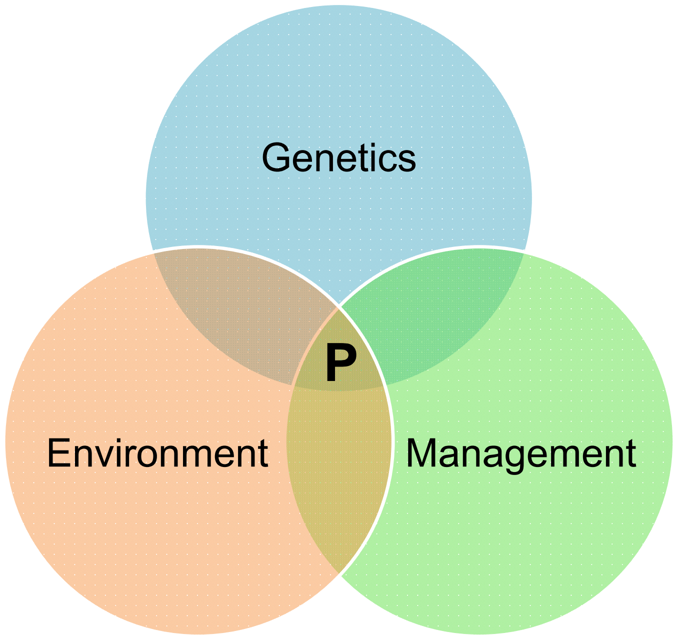





## Phenotype = Genetic x Environment x Management

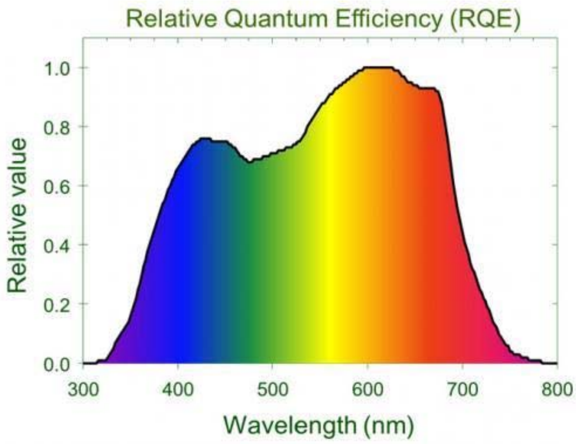
## Critical indicators characterizing crop growth and quality

Leaf fresh weight,
Leaf dry weight,
Crop height
Leaf area and canopy closure
Relative growth rate
Crop/Produce quality (e.g. color, texture, flavor, phytochemicals, ….)



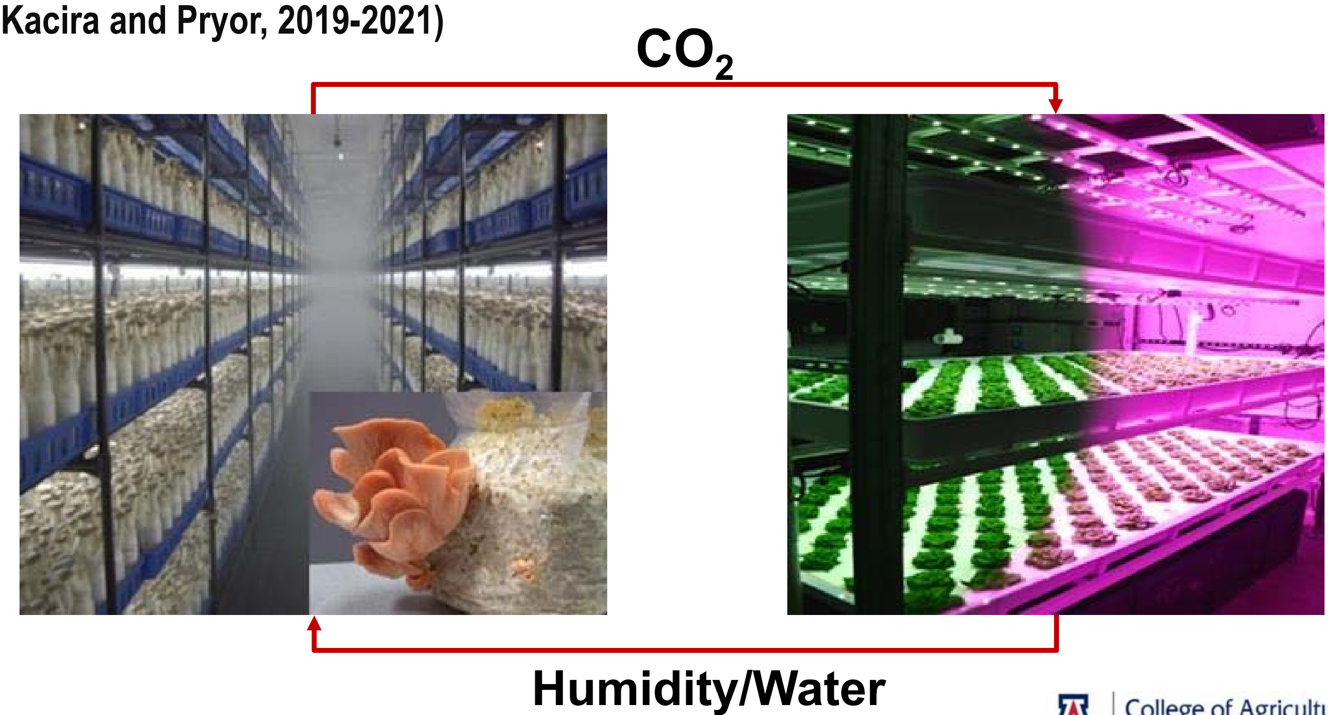
# LED lighting for Horticulture

- Efficacy and controllability
- Research capabilities vs practical/commercial applications
- How to define wavelengths/need standardization
- What spectrums to design and manufacture for growers
  - General (easy/lower cost) vs boarder spectrum
  - Cap-Ex and Op-Ex
- ROI for LEDs for growers
- Fixture designs and deployments for improved Light Use Efficiency (LUE)
- Breeding to enhance LUE




# Integrated Vertica Farming-CEA Systems for Optimized Resource Use

**(Kacira and Pryor, 2019-2021)**

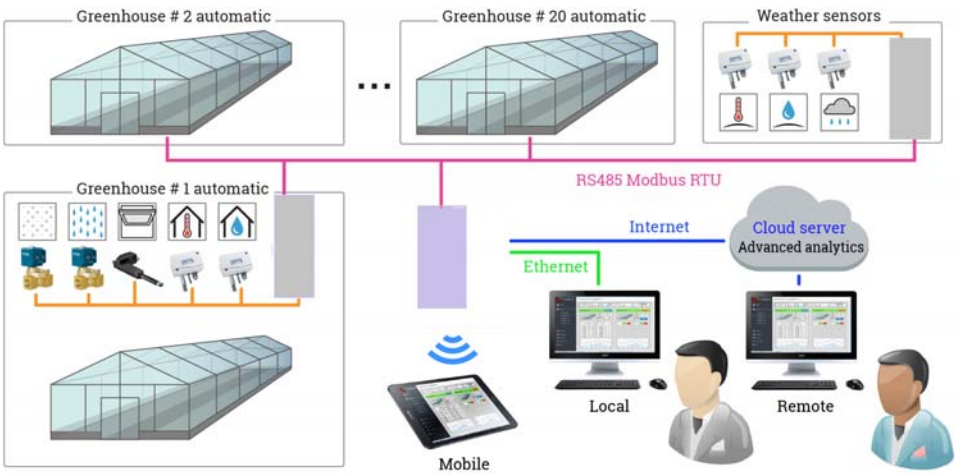


## Automation/Robotic in Vertical Farms



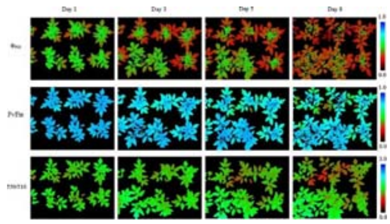

## Emerging Automation Technology -

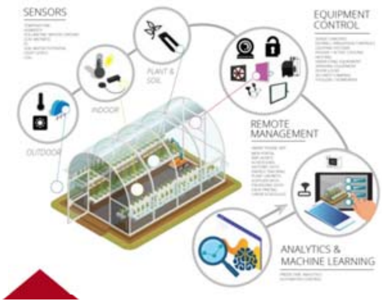
**Internet of Things (IoT) and Cloud Based Service for Data Access/Management**



## Trends in Environmental Controls in CEA

- Need for plant centric environmental controls
- Need for timely detection for plant health and growth
- Need for remote access and control capabilities, ICT integration
- Need for decision support systems
- Need for autonomous control



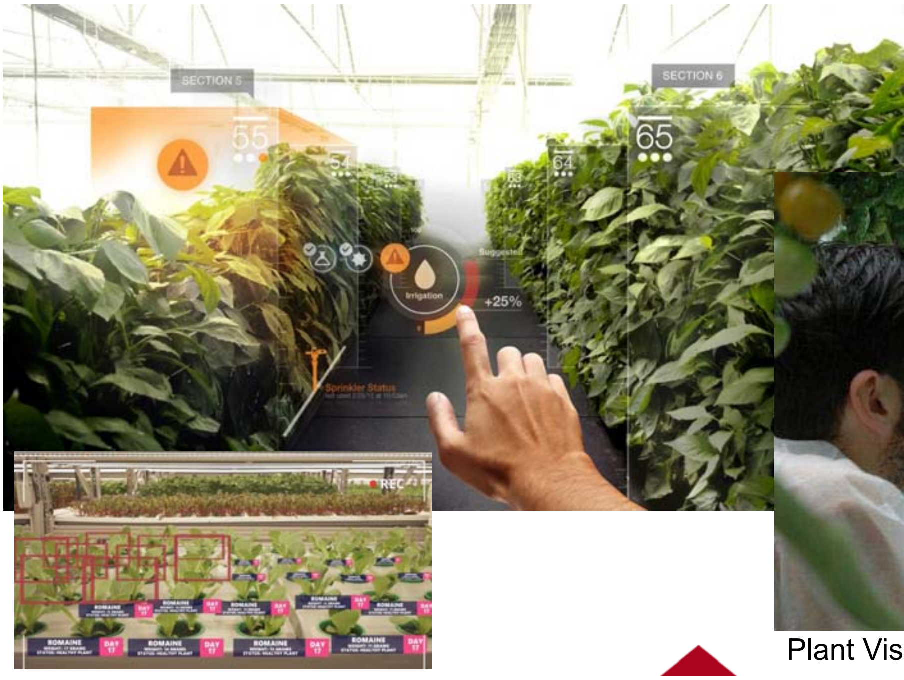



## Speaking Plant Approach: Challenges and opportunities Research questions

- Diverse set of sensors exists. What crop related information we want to know?
- Interpreting the sensor readings/signals. What are the metrics to consider for crop health, growth, and environmental controls?
- Frequency of measurements
- Spatial and temporal variability
- Sensor accuracies
- Environmental disturbance and how to overcome effects on sensor readings/signal interpretation
- Sensor fusion, modeling, expert inputs
  - Sensor signals and correlation to environmental data, historical data, predictive models, domain expert inputs

## Emerging Automation Technology -

Augmented and Virtual Reality integrated CEA Systems




Plant Vision

## Can Artificial Intelligence do as well as farmers in the future?

**VS**

*"AI teams were even more efficient and more productive and realized a 17% higher net profit than the grower reference group."*

*Autonomous Greenhouse Challenge, WUR 2018*

## Energy Producing Greenhouse Systems

**(Kacira et al., 2012-present)**

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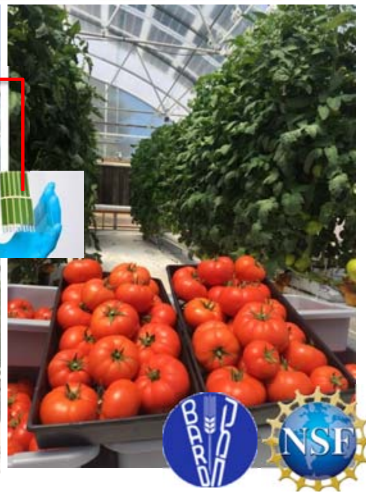
Biosystems Engineering

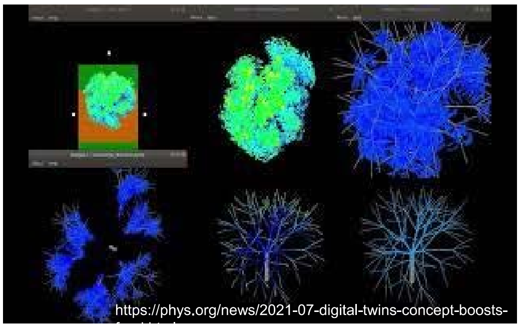





USDA
Green Fund
ROUGH GREENHOUSES
ABENGOA SOLAR
SNAP-FAN
WADSWORTH Control Systems

## Emerging Automation Technology - Field/Outdoor Precision Horticulture



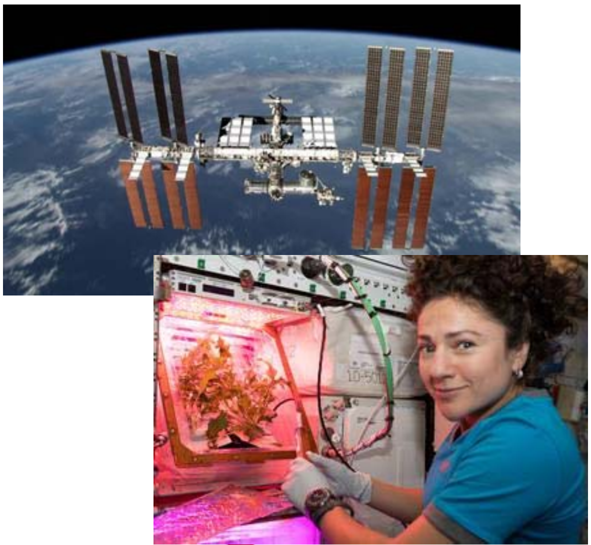

## Sustaining Astronauts in Space: NASA Selects Five Research Projects Designed to Improve Crop Habitats.

**(M. Kacira, P. Sadler, R. Furfaro, M. Kim, K. Farrell-Poe, J. Adams, 2020-2021)**

**Partners: Thales Alenia Space-Italy, German Space Agency, Univ. of Naples Federico II-Italy, Italian National Research Council, SyNRGE LLC.**

### University of Arizona:

"Microgravity crop production: Meeting the challenges of water/nutrient delivery, volume management, and providing diet diversity for the International Space Station"




15 16 17 18 19 — **S6** INNOVATIVE TECHNOLOGIES AND PRODUCTION STRATEGIES FOR SUSTAINABLE CONTROLLED ENVIRONMENT HORTICULTURE

18 19 — **S8** ADVANCES IN VERTICAL FARMING

17 18 19 — **S18** III INTERNATIONAL SYMPOSIUM ON MECHANIZATION, PRECISION HORTICULTURE, AND ROBOTICS : PRECISION AND DIGITAL HORTICULTURE IN FIELD ENVIRONMENTS

## Educating Future Farmers, Engineers, and Leaders of Precision Horticulture