CEAC Today

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Tour Station 1: Moon Base Greenhouse/BLSS

The UA-CEAC/SMC Prototype Lunar Greenhouse will help to develop growing and composting systems for Bioregenerative Life Support Systems that could be used for recycling atmosphere, water, and solid materials, as well as, growing food for the future lunar and Martian bases.

Contact: Phil Sadler, Sadler Machine Co. Email: sadlermachineco@aol.com
Collaborators: Lane Patterson, MS Student, Gene Giacomelli, Ph.D.

Tour Station 2: Teaching Laboratory and Cultivar/Variety Trials

A 482m^2 sawtooth-style greenhouse used for teaching, research and outreach. Current research projects fee-for-service variety trial partially funded by Eurofresh Farms.

Contact: Pat Rorabaugh, Ph.D. Email: patrora@ag.arizona.edu

Tour Station 3: Baby Salad Leaf Production for "Food for Health"

Plants produce various phytochemicals that are of nutritional and medicinal value to humans therefore CEA produced crops can enhance the nutritional quality of the American diet.

Contact: Chieri Kubota, Ph.D. Email: ckubota@ag.arizona.edu

Tour Station 4: Automated Plant Health, Growth and Sensing System

Automated sensing system for plant health and growth monitoring for developing autonomous environment agriculture systems.

Contact: David Story, MS Student Email: dstory@email.arizona.edu
Collaborators: Murat Kacira, Ph.D., Chieri Kubota, Ph.D., and Ali Akoglu, Ph.D

Tour Station 5a & 5b: Greenhouse Natural Ventilation and Evaporative Cooling Analysis

Analysis of greenhouse natural ventilation and development and validation of control strategies for naturally ventilated greenhouses equipped with fog and cooling systems.

Contact: Murat Kacira, Ph.D. Email: mkacira@ag.arizona.edu
Collaborators: Dr. Rafael Linker, Technion, Israel, Dr. Avraham Arbel, ARO, Bet Dagan, Israel, Dr. Chieri Kubota, Plant Sciences, Dr. Gene Giacomelli, Agricultural and Biosystems Engineering, Federico Villarreal, Ph.D. Student, Post-Doctoral Researcher (position available).
Sponsor: United States-Israel Binational Agricultural and Development Fund (BARD)

Tour Station 6: Sustainable Resource Management and Year Round Production of Fresh Green Salad Crops with Automated and Remotely Monitored Controlled Environment Plant Production Systems

Sustainable resource management and economic feasibility of year-round production of leafy green crops in semi-arid region.

Contact: Myles Lewis, MS student Email: mylesd@email.arizona.edu
Collaborators: Murat Kacira, Ph.D., Gene Giacomelli, Ph.D.

Tour Station 7: Economic Development with CEA

Strategic partnership with Innovative Technologies Development Center

Contact: Ron Richman and Robert Schatz, ITDC
Email: RJRichman@inno-tech.org, rshatz@inno-tech.org
Collaborators: Chieri Kubota, Ph.D. Plant Sciences, Judith Brown, Ph.D., Plant Sciences, Gene Giacomelli, Ph.D.

Tour Station 8: South Pole Food Growth Chamber Live Webcast

Real time demonstration of telepresence for the SPFGC, an enclosed hydroponic multiple food crop production system located in Antartica.

Contact: Lane Patterson, MS Student Email: lane12345@rocketmail.com
Collaborators: Phil Sadler, Sadler Machine Co, Gene Giacomelli, Ph.D.

Tour Station 9: Biomass Production in Aquaponics

Production of tilapia and lettuce within a semi-closed organic multi-cropping system.

Contact: Jason Licamele, Ph.D. student Email: licamele@email.arizona.edu
Collaborators: Gene Giacomelli, Ph.D., Merle Jensen, Ph.D. Kevin Fitzsimmons, Ph.D.

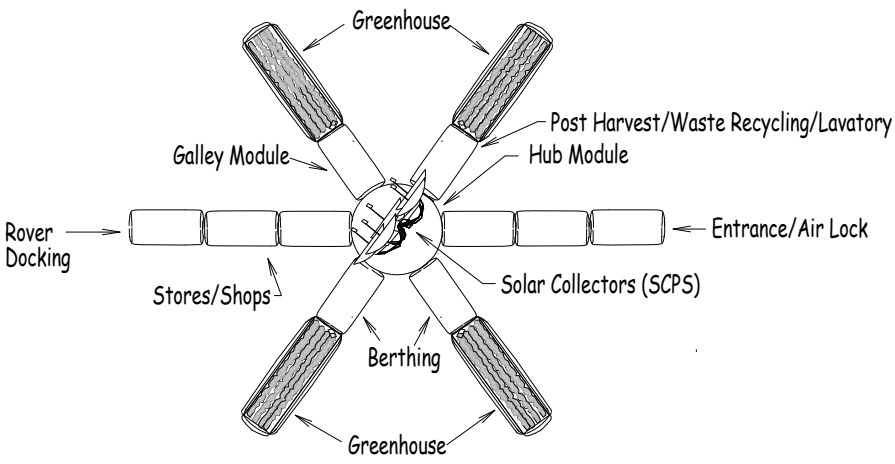
Controlled Environment Agriculture Center Tour
ISHS Workshop on Greenhouse Environmental Control and Crop Production in Semi-Arid Regions
Friday, October 24, 2008

Station # 1
Topic Title: UA-CEAC/SMC Prototype Lunar Greenhouse
Primary Contact: Phil Sadler
Contact Email: sadlermachineco@aol.com
Collaborators: Lane Patterson, MS student, Gene Giacomelli, Ph.D., Roberto Fufaro, Ph.D.

The Lunar Habitat model secured beneath the lunar surface [left], and without lunar regolith covering.

Welcome to our Prototype Lunar Greenhouse and whose purpose is to demonstrate a number of Bioregenerative Life Support System technologies that will enable astronauts to live and work at future lunar and Martian bases. This is a cooperative effort between University of Arizona Controlled Environment Agriculture Center (UA-CEAC), Aerospace-Mechanical Engineering (UA-AME), and Sadler Machine Company. Bioregenerative Life Support Systems (BLSS) is the use of plants and the microbial community to provide life support for the lunar habitat crew by recycling the atmosphere, water, organic solid waste, and producing food, similar to what occurs in the natural ecosystems on Earth. NASA estimates that by providing 50% of the caloric intake of the Lunar crew from a BLSS crop production system and with 50% supplied from Earth, that 100% of the required atmosphere and water can be continually recycled.

The results of solar and cosmic radiation, micrometeorite bombardment, the vacuum of space, and large thermal differentials (107C to -153C), necessitates that the lunar base be buried beneath a minimum of one meter of lunar regolith. Natural light is collected and delivered to the lunar greenhouse crops through fiber-optic cables, and provides electrical power for the habitat.



In addition to the folding structure, Cable Culture hydroponic crop growing systems and Sadler HPS water-jacketed lamps developed at the UA-CEAC are unique original system components. This development of new plant production, illumination, and composting components integrated into one system will allow the development of BLSS life support systems to enable a long term presence on the lunar surface.

Prototype Lunar Greenhouse collapsed (left) and extended (right).

Further information:

http://ag.arizona.edu/ceac/live/CEAC_live.htm
http://moonsociety.org/video
http://www.youtube.com/watch?v=Z-0qJ4eZhs4

Lunar greenhouse glazing provided by AGC, F-Clean (ETFE)

Station # 2

Topic Title: Teaching Laboratory and Cultivar / Variety Trials

Primary Contact: Dr. Patricia A. Rorabaugh
Contact Email: patrora@ag.arizona.edu

Collaborators: Student greenhouse manager: Casey Lohrenz, Student workers: Heidi Hawkins, Evan LaBrant, Case Giacomelli, Chris Federici, PLS 217 students, UA CEAC/Financial support: Dr. Gene Giacomelli, Fee For Service Funding: EuroFresh Farms, Willcox AZ, Entomology support: Dr. Roger Huber, Erynn Dunn, Greenhouse support: Neal Barto, Arturo Baez, Mark Carson, Todd Ruhl

The CEAC teaching laboratory is a 482 m^2 sawtooth-style polycarbonate-covered greenhouse with rack & pinion roof vents, standard pad and fan cooling and natural gas heaters and CO_2 generator. It has a fertigator with Anderson injectors that allows for irrigations to be provided on the basis of accumulated light. The nutrient solution is delivered to the plants via a top-drip irrigation system. There are 9 rows that run approximately north-south with overhead cables at a height of 3 meters. Since there can be as much as a 5 C rise in temperature from the pads to the exhaust fans, the rows have also been divided into 3 sections to allow for testing of plant growth and yield in different temperature zones. This greenhouse is used for teaching, research and outreach.

Each year, Dr. Rorabaugh teaches an introductory greenhouse hydroponic class (PLS 217) in the Fall and an advanced crop production class (PLS 394) in the Spring.

As part of these classes an experiment, relevant to the greenhouse hydroponic industry, is performed. Experiments in the past have included variety trials, tests of different types of aggregate growing materials and grafting trials.

Last year and this year EuroFresh Farms, the largest single-location greenhouse hydroponic tomato grower in the United States, has been partially funding variety trials. They also supplied grafted tomato transplants for these tests. This is advantageous for the students here at the CEAC, as they have the opportunity to participate in an actual trial of varieties that may ultimately be grown for commercial production at EuroFresh.

The students learn commercial growing techniques including proper plant cultural practices, bumble bee management, identification of pests and diseases and the use of beneficial insects and other IPM methods to control typical greenhouse problems. They learn how to manage the clusters for optimum fruit quantity, participate in taste tests and learn how to use a Brix meter to test fruit quality. They also learn about greenhouse structures and control systems as well as nutrient delivery systems, nutrient recipes and plant nutrition. Finally, they learn about the economics and marketing involved in this industry. The PLS 217 class ends with a luncheon in which the students prepare a dish to share that must include at

least one of the crops we are growing in the greenhouse. This year, tomatoes, peppers and cucumbers are being grown.

Students transplanting and maintaining their crops.

As part of this year's variety trial, students will keep records as to plant growth, fruit yield and quality, insect and disease problems and any other items that might cause a variety to be fit or unfit for commercial use.

Last year, some of the plant and fruit properties noted were:

- one of the tomato varieties was resistant to powdery mildew, a disease problem in the southwest.
- the fruit of one of the cluster varieties tended to fall off prematurely.
- the fruit of a grape variety would fall off before ripening.
- smaller fruited variety plants seemed to be more resistant to whitefly.
- smaller fruit varieties would grow much faster and could have faster sucker development, requiring more labor for pruning.
- one of the varieties was very vegetative, requiring extra leaf pruning early on.

These kinds of notations are important because they can mean the selection of a:

- pest-resistant variety that will cut down on the use and ultimate cost of beneficial insects for pest control.
- "balanced" variety that will reduce the pruning necessary.
- variety whose fruit will stay on the truss, if a TOV type, or detach from the truss when ripe, but not before, if a grape type.

The selection of the proper variety for a location and market are critical for the success of an operation. We appreciate the support of EuroFresh Farms, and the opportunity for our students to learn while participating in an actual commercial variety trial.

Station #3

Topic Title: Baby Salad Leaf Production for "Food for Health" Collaboration

Primary Contact: Chieri Kubota, Controlled Environment Plant Physiology and Technology Lab, Department of Plant Sciences
Lab website: http://cals.arizona.edu/research/kubota
Contact Email: ckubota@ag.arizona.edu
Collaborators: Cynthia Thomson, Ph.D. Nutritional Sciences

Research background: Plants produce various phytochemicals that are of nutritional and medicinal value to humans. Population studies among Americans have consistently demonstrated inadequate consumption of fruits and vegetables. Improving intake of fruits and vegetables has been a major public health effort for many years with minimal success. Given this, there is an opportunity to consider other approaches to enhance the nutritional quality of the American diet. One plausible approach is the development of fresh produce containing a greater concentration of phytochemicals known to improve health, thus while consuming fewer servings of produce, Americans would still have significant exposure to health-promoting food constituents. Controlled environments provide a unique opportunity to modify the concentrations of selected phytochemicals in fruits and vegetables, yet practical information is limited regarding methods effective in optimizing phytochemcial production. In the Controlled Environment Plant Physiology and Technology (PI: Dr. Chieri Kubota), we conduct number of applied research projects aiming to develop a useful method for improving greenhouse produce quality by increasing concentrations of flavor components (such as sugar and organic acid) and nutritional phytochemical components (lycopene, anthocyanins, phenolics, and vitamins) under controlled greenhouse conditions in semiarid areas. The main technology that we use includes manipulating electrical conductivity (EC) of the hydroponic nutrient solution and light quality through supplemental lighting. Our research demonstrated that increasing EC in greenhouse limits the water availability to the tomato plant and hence improves the sweetness, acid and lycopene concentration in tomato fruits. We have also observed significant increase in carotenoids and anthocyanins in lettuce.

Evaluation of yields and quality of baby salad leaves (lettuce and komatsuna): As part of the on-going collaboration with Dr. Cynthia Thomson at the Department of Nutritional Sciences and Arizona Cancer Center, the Kubota lab is in charge of year-round production of baby leaves (mix of two lettuces and komatsuna). A total of 45 post-menopausal over-weight women are recruited and consuming

greenhouse vegetables at three different doses (2, 5, and 10 servings a day) to examine human body response in terms of mitigating oxidative stress by consuming more vegetables. In the Kubota lab, while producing sufficient amounts of study vegetables (baby leaf mix, red pepper, and tomato), we evaluate seasonal changes in yield and the major phytochemical compounds in leaves (carotenoids, anthocyanins, phenolics, and ascorbic acid).

Other projects in Kubota lab (http://cals.arizona.edu/research/kubota)

- **Technology Development toward Introduction of Grated Vegetable Seedlings in U.S. Open-field Fresh Vegetable Production**
- **Natural Ventilation Control for Minimizing Water Use for Cooling in Semiarid Greenhouses.**
- **A Greenhouse Water Recovery System for Crop Production in Semi-Arid Climate**
- **Production of Plant Made BioPharmaceuticals under Controlled Environments**
- **Light Quality Optimization for Leafy Vegetables using LEDs**
- **Strategic Use of Far-red Lighting in Greenhouse Plant Production**

Recent publications:

Kubota, C., M.A. McClure, N. Kokalis-Burelle, M.G. Bausher, and E.N. Rosskopf. 2008. Vegetable grafting: History, use, and current technology status in North America. HortScience. 43:1664-1669.

Wu, M., and C. Kubota. 2008. Effects of high electrical conductivity of nutrient solution and its application timing on lycopene, chlorophyll and sugar concentrations of hydroponic tomatoes during ripening. Scientia Hort. 116:122–129.

Thomson C.A., N.R. Stendell-Hollis, J.L. West, E.C. Cussler, L.M. McCune, M. Kroggel, H.J. Kim, C. Kubota. 2008. High-lycopene consumption increases plasma carotenoid levels but does not have decrease levels of oxidative stress and inflammation in healthy adults. The Open Bioactive Compounds Journal. 1:7-12.

Wu, M., and C. Kubota. 2007. Effects of electrical conductivity of hydroponic nutrient solution on leaf gas exchange of five greenhouse tomato cultivars. HortTechnology 18:271-277.

Kubota, C. and M. Kroggel. 2006. Air temperature and illumination during transportation affect quality of mature tomato seedlings. HortScience 41:1640-1644.

Javanmardi, J. and C. Kubota. 2006. Variation of lycopene, antioxidant activity, total soluble solids and weight loss of tomato during postharvest storage. Postharvest Biology and Technology. 41:151-155.

Kubota, C., C.A. Thomson, M. Wu, and J. Javanmardi. 2006. Controlled environments for production of value-added food crops with high phytochemical concentrations: High lycopene tomato as an example. HortScience 41:522-525.

Station #4: **Automated sensing system for plant health and growth monitoring**

Topical Title: **A Machine Vision Guided System for Plant Health and Growth Monitoring in Controlled Environment Agriculture Production**

Primary Contact: David Story, MS student, Agricultural and Biosystems Engineering
Contact Email: dstory@email.arizona.edu
Collaborators: Dr. Murat Kacira, Ph.D., Agricultural and Biosystems Engineering
Dr. Chieri Kubota, Ph.D., Plant Sciences
Ali Akoglu, Ph.D., Electrical and Computer Engineering

In traditional greenhouse production, actual plant conditions are determined by human interactions/observations and measurements which are either destructive or invasive and may not be practical for real time monitoring and control applications. Actual greenhouse conditions are determined by human guess-work or preset environmental parameters instead of having controls focused on a plant's specific needs. At canopy and field scale, imaging techniques have the potential to identify emerging stresses and to guide sampling for identification of the stressor. These remote sensing applications are increasingly being applied in the rapidly evolving precision agriculture, which should improve crop production, while being more environmentally friendly than the 'classic' production methods.

Vision allows humans to perceive and comprehend the world around them. Machine vision can duplicate the human vision by electronically perceiving and understanding an image. Non-contact sensing and monitoring of plant growth using machine vision system has the potential to detect trend changes in plants before the actual human visual detection can be made and this may improve the level of intelligent control in greenhouse processes such as irrigation automation, climate control and ultimately efficient use of resources and energy for production. Thus, the objective of this research is to develop an autonomous machine vision guided plant health, growth and quality monitoring system and develop a sensing methodology for early plant stress detection using image processing applications (morphology and texture based).

The plant monitoring system developed in this research consists of three components (Figure 1): A precise positioning system to place a color CCD camera on designated plants or on the canopy, an image processing module and also a climate monitoring module. An 8-bit color CCD camera is positioned through a robotics system in the X-Y coordinate plane, targeting plants located underneath. The camera is automatically positioned to be in the middle of the perceived plant and an image is then acquired after the plant is tracked. This image is then analyzed for specific parameters and all data are then stored into a database in real time.

Through database manipulation, trends are determined and overall plant growth/health is identified (Figure 2). Some of the plant features extracted for plant health and growth monitoring included; top projected canopy area, canopy perimeter, and the rate of change of weighted boundary (morphological features), R-G-B values and ratios (color features), contrast, entropy and local homogeneity (textural features) (Figure 3). The system performance will be compared with contact methods (i.e. chlorophyll content and stomatal conductance measurements) to determine accuracy and feasibility of the non-contact system for timely stress detection and plant health/growth analysis.

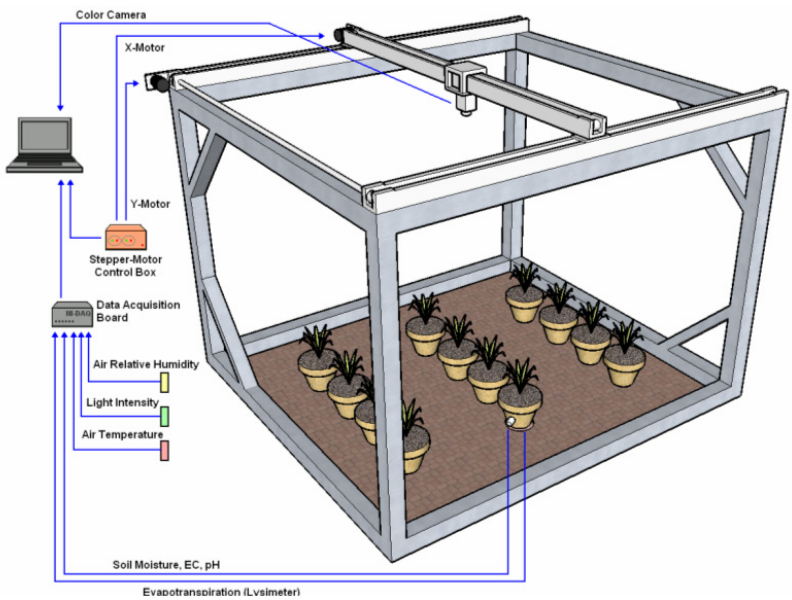


Figure 1. Schematics of overall system design

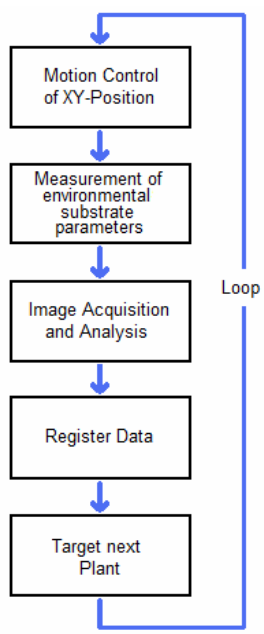
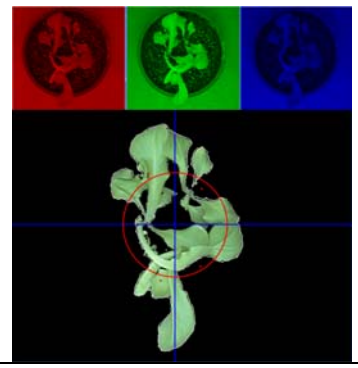


Figure 2. Flow of system operation

Parameters analyzed from the retrieved original image

From Blob Image	***From Masked Image***
	
Top Projected Canopy Area	RGB values
Blob Traced Perimeter	HSL values
Blob Weighted Radius (from center of mass)	Brightness

Textural Analysis of Masked Image			
Entropy $\sum_i \sum_j P[i,j] \log P[i,j]$	*Energy* $\sum_i \sum_j P^2[i,j]$	*Contrast* $\sum_i \sum_j (i-j)^2 P[i,j]$	*Homogeneity* $\sum_i \sum_j \frac{P[i,j]}{1+\lvert i-j \rvert}$

Figure 3. Extracted plant features for plant health and growth monitoring.

Station #5a: Greenhouse Natural Ventilation and Cooling Analysis

Topic Title: Enhanced Climate Control of Semi-arid and Arid Greenhouses Equipped with Fogging Systems

Primary Contact: Dr. Murat Kacira, Ph.D. Agricultural and Biosystems Engineering
Contact Email: mkacira@cals.arizona.edu
Collaborators: Dr. Rafael Linker, Technion, Israel, Dr. Avraham Arbel, ARO, Bed Dagan, Israel, Dr. Chieri Kubota, Plant Sciences, Dr. Gene Giacomelli, Agricultural and Biosystems Engineering, Post-Doctoral Researcher (position available)
Sponsor: United States-Israel Binational Agricultural and Development Fund (BARD)

Introduction

In the present global and highly competitive market, growers must supply high quality produce year-round in order to secure long-term markets. However, in semi-arid and arid environments, greenhouses are either not in use or generate low-quality produce during a period that extends roughly from late spring to early fall. This is due to the inability of the current climate control systems to maintain acceptable temperature and humidity at a reasonable cost during these hot months. Several recent studies have shown that fogging systems based on high-pressure nozzles could be used to achieve acceptable temperature and humidity throughout the year. However, due to the absence of efficient, proven, control strategies for such systems, these are rarely, if ever, used in commercial greenhouses. The primary objective of this project is to develop and validate high-performance control strategies for fogging systems that will enable or improve year-round cultivation in greenhouses located in arid and semi-arid regions.

The research will include two main tasks. The first task will focus on the development and validation of climate control algorithms capable of maintaining the air temperature and humidity at levels suitable for crop growth throughout the year. The experiments at the Controlled Environment Agriculture Center (CEAC) will examine natural ventilation system equipped with fogging using different approaches that take into account the capabilities and limitations of the system. The second task will investigate the influence of the system flexibility on the performance of the fogging system. Operational flexibility will be represented by the number of fogging levels achievable by separate activation of different nozzle lines and/or pressure change in the lines, and the control time-step. A systematic investigation will be conducted in order to devise guidelines for the installation of fogging systems in greenhouses.

Experiments will be conducted in mechanically-ventilated greenhouses by partners located in Israel and our experiments will be conducted in a naturally-ventilated greenhouse located at CEAC. The experiments that will be conducted during the first stage of the project will provide data for calibrating and validating models of the greenhouse climate and crop transpiration, as well as for developing control strategies. During the second stage of the project, experiments will be conducted to validate the performance of the control strategies.

Research Plan

Strategy and Methodology

Contrary to mechanically-ventilated greenhouses, the air exchange rate in naturally ventilated greenhouses can not be precisely controlled or, in most cases, even accurately estimated when compared to mechanically ventilated greenhouses. As a result, it would be unrealistic to try maintaining the air web bulb temperature and humidity at predefined setpoints in a precise fashion. Rather, we propose to develop a strategy that will determine the control actions (window openings and fogging rate) by minimizing a criterion composed of two terms (Figure 1). The first term will penalize temperature and humidity that are not within predefined bonds. The second term will represent the cost of the control actions. At any given time-step, the optimal control actions will be determined using a black-box model (neural network) of the greenhouse that will predict the temperature and humidity based on the past and current measurements and control actions. A search will be conducted to determine the optimal control actions, and these will be implemented in an open-loop fashion. The time-step of the control procedure will be determined based on the greenhouse dynamics, and is expected to be in the order of 15-25 minutes.

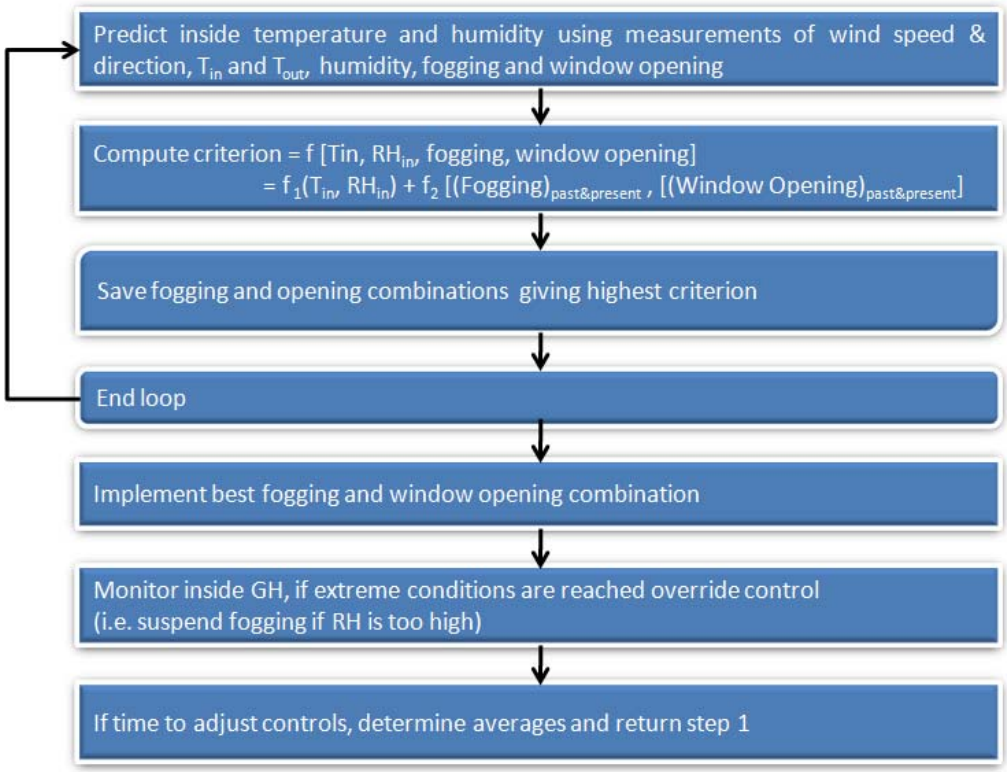


Figure 1. Flowchart of the propsed control scheme (natural ventilation).

<u>Position Availability:</u>

Position: Postdoctoral Researcher

Duration: 3 years (Start immediately)

Location: Agricultural and Biosystems Engineering, Controlled Environment Agriculture Center, University of Arizona, Tucson, AZ

Details: Information on salary & application procedures for postdoctoral positions is available at: https://www.uacareertrack.com/applicants/jsp/shared/frameset/Frameset.jsp?time=1219265031484, search for UA Job #41558.

Station #5b: Greenhouse Natural Ventilation and Fog Cooling Research
Topic Title: Determining Penman-Monteith Coefficients for Tomato Crop in a Semi-arid Greenhouse Under Three Different Greenhouse Cooling Settings

Primary Contact: Federico Villarreal Guerrero
Contact Email: toloc604@email.arizona.edu
Collaborators: Dr. Murat Kacira

Introduction

Greenhouse natural ventilation systems are generally cheaper, need less intallation investments and operational costs than mechanical ventilation systems. However, natural ventilation systems have lack of control of air flow due to a-high dependence of inside conditions on outside environmental conditions, which change continuously on a daily baisis and during a season. The development of effective control strategies for greenhouse natural ventilation is necessary to benefit from its potential advantages.

An important step in the control of natural ventilation is the accurate prediction of the real vetilation requirements in the greenhouse. Ventilation rates depend mainly on the effect of outside climate on inside climate, and on the cooling effect from the evaporative cooling settings and plants. Ventilation formulae, which include these parameters into account need values of Penman-Monteith (P-M) coefficients of the crop being grown under the current greenhouse settings for the calculation of Required Ventilation Rates.

Some P-M coefficients are available in literature for different crops mainly for Mediterranean and Mid-temperate climates. Information about P-M coefficients for a common greenhouse grown crop in semiarid climates is lacking. Therefore, the aim of this study was to determine the P-M coefficients for a tomato crop in a semiarid greenhouse and under three greenhouse cooling settings for prediction of Required Ventilation Rates. This approach is expected to produce apropriate conditions for plants inside the greenhouse when implemented as part of a control strategy.

The objectives of this study were: (i) to determine the radiation (*A*) and the aerodynamic (*B*) coefficients used in the Penman-Monteith equation, to predict the evapotranspiration of a tomato crop grown under three different cooling settings in a greenhouse located in a semiarid climate. Also (ii) to adjust the values of the generated P-M coefficients through modeling for different values of Leaf Area Index (LAI).

Materials and Methods

Data obtained from experiments with a tomato crop conducted by Ishii *et al* (2006, Unpubished) and Sabeh (2006, Unpublished), were used for the analysis. Three greenhouse settings were used: Pad and Fan (P&F), Fog with Mechanical Ventilation (Fog&Fan) and Fog with Natural Ventilation (Fog&NV). Evapotranspiration, outside and inside solar radiation, inside air temperature and relative humidity were measured during May-July. Humidity ratio deficit of inside air was determined using pychrometrics. Values of *A* and *B*, the P-M coefficients were calculated by multiple linear regression of evapotranspiration against solar radiation and humidity ratio deficit (Eq 1). Furthermore, results of P-M coefficients were adjusted for different LAI (Eq. 2) to account for the dynamic contribution of transpiration for different crop ages.

Results and Discussions

Results of the Penman-Monteith coefficients are shown in Table 1. Both, *A* and *B* were statistically significant (α= 0.01) in their corresponding models. The values of *A* were found to be similar between greenhouse settings. *A* has a direct relationship with solar radiation and given that the experiments were performed at the same location, with same outside climate (under the same solar radiation load), values of *A* were expected to be found equal.

$$\lambda ET = AS_g + B(\hat{w}_s - w_g) \quad \text{(Eq. 1)}$$

$$\frac{A}{A^*} = \frac{B}{B^*} = \frac{1-e^{-k\Lambda}}{1-e^{-k\Lambda^*}} \quad \text{(Eq. 2)}$$

λ , Latent heat of vaporization (kJ kg^{-1})

ET , Evapotranspiration (g m^{-2} s^{-1})

A , Radiation coefficient (dimensionless)

S_g , Solar radiation intercepted by the crop canopy (W m^{-2})

B , Aerodynamic coefficient (W kg m^{-2} g^{-1})

$\hat{w}_s$, Aerodynamic coefficient (W kg m^{-2} g^{-1})

w_g ,Humidity ratio (g kg^{-1})

k , Canopy light extintion coefficient (dimensionless)

Λ , LAI (dimenssionless)

*, denotes reference values

However, the values of *B* showed bigger differences between cooling settings compared to the values of *A*. Mechanical ventilation systems generally produce greater air exchanges and may create drier environments than natural ventilation systems. Also, fog systems are expected to produce more uniform and humid environments than Pad-Fan systems. These discrepancies in humidity patterns may have affected the values of *B*. Aerodynamic resistances and *B* have an inverse relationship. When mechanical ventilation is used, greater air velocities are expected around plant leafs and consequently, thinner leaf boundary layers (small aerodynamic resistances). Then, under mechanical ventilation, values of *B* will be generally larger than under natural ventilation (Table 1).

Table 1. Radiation (*A*) and Aerodynamic (*B*) coefficients for three different greenhouse settings with tomato plants.

GH Setting	CV	RMSE	R^2	A	B
P&F	17.18	24.64	0.97	0.14*	11.83*
Fog&Fan	17.44	28.49	0.97	0.13*	14.35*
Fog&NV	39.46	50.34	0.87	0.14*	9.39*

***,** Statistically significant with α=0.01, LAI = 3**.**
CV, Coefficient of variation. **RMSE,** Root Mean Square Error.

Plants transpire differently depending on their growth stage. Generally, as plants grow and their LAI is increased, transpiration is incremented and affect values of *A* and *B*. In Fig. 1 a mathematical model (Eq. 2) was used to adjust the values of *A* and *B* for different LAI (Seginer, 2002). According to the results, *A* and *B* increases as LAI increases. While *A* presented similarity in its values between greenhouse cooling settings, the values of *B* showed larger differences as LAI was increased.

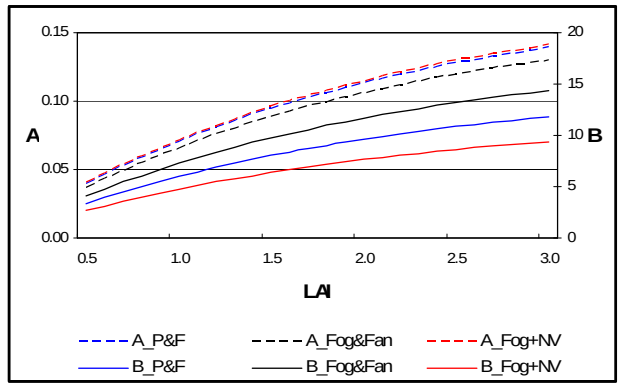


Fig. 1. Radiation (*A*) and Aerodynamic (*B*) coefficients for different values of LAI and three greenhouse cooling settings.

Conclusions

In this study, the values of the *A* (radiation coefficient), and *B* (aerodynamic coefficient), were calculated for a tomato crop grown in a semiarid climate under three different greenhouse cooling settings; Pad and Fan, Fogging with Mechanical Ventilation and Fogging with Natural Ventilation.

Adjustments on the values of *A* and *B* were performed through modeling to account for different LAI. Values of the P-M coefficients estimated under this approach might produce better estimations of real ventilation requirements in a greenhouse.

Using these results as the ventilation goal of the control system might represent a good control strategy for greenhouse natural ventilation.

Reliable assessment of P-M coefficients is required for most common crops grown in commercial greenhouses. These estimations could be achieved by analysing data by joint research conducted in different climatic regions.

Acknowledgements

Experimental data of Fog under Natural ventilation provided by Iishii, M., S. Sase and C. Kubota. 2006. Unpublished data.

Experimental data of Pad & Fan and Fog with continuous mechanical ventilation provided by Sabeh N. 2006. Unpublished data.

References

Seginer, I. 2002. The Penman-Monteith evapotranspiration equation as an element in greenhouse ventilation design. *Biosystems Engineering* **82** (4), 423-439.

Station #6: Sustainable Resource Management and Year Round Production Of Fresh Green Salad Crops With Automated And Remotely Monitored Controlled Environment Plant Production Systems

Primary Contact: Myles Lewis, Professional Science Master's Student
Contact Email: mylesd@email.arizona.edu
Collaborators: Dr. Murat Kacira, Agricultural and Biosystems Engineering, Dr. Gene Giacomelli, Agricultural and Biosystems Engineering, Dr. Mary Olsen, Plant Pathology, Dr. Merle Jensen, Emeritus Professor, Plant Sciences, and Dr. Joel Cuello, Agricultural and Biosystems Engineering.

Water usage and energy consumption as it relates to agriculture continues to be a very important topic of discussion. Water is the most vital natural resource for sustainable economic development in Arizona. Even though Arizona suffers from limited water supply and drought, the majority of people are not aware of the severity of future challenges. One of the most important components of sustainable water management is the development of mechanisms to reduce and reuse existing resources.

The Floating Hydroponic System (FHS) is a technique with plants that float on a body of water and completely cover the surface. With such a design, it is possible to limit water use to precisely the amount which is used by the plants. Along with precision control of the root and aerial environment of the plants, this alternative production system may help to make agriculture sustainable within semi-arid regions in the future.

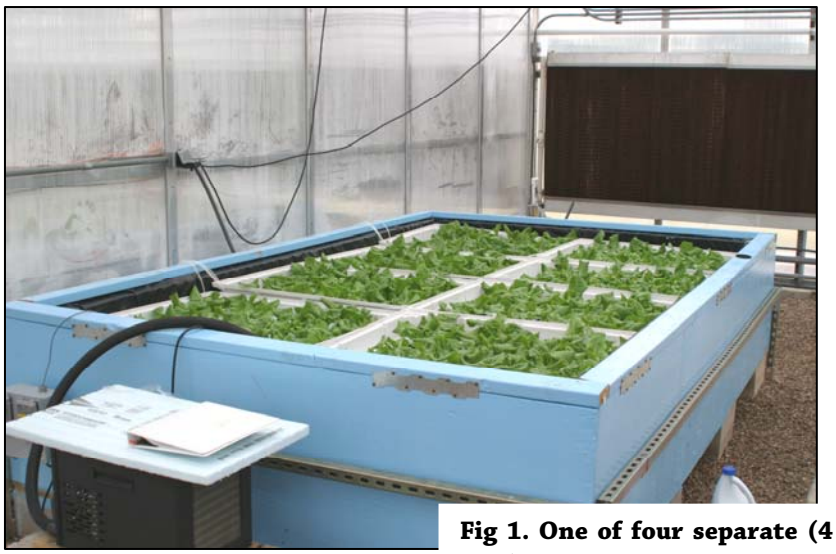


Fig 1. One of four separate (4 x 8 foot) FHS research units at CEAC used for several investigations, including: (1) Lettuce variety trials; (2) Determining the effect of a commercial product to prevent Pythium in lettuce; (3) Stimulating the production of plant phytochemicals.

As energy and fuel prices rise, fresh foods will increase in price due to their shipment from distant production locations. With concern for food safety and food for healthy lifestyle, locally grown produce is gaining popularity. In order to determine the feasibility of such a

venture in the desert southwest, preliminary research is being conducted using a scaled version of a FHS, which will provide information such as yields and operating costs for the arid southwest. This data when combined within a business and financial plan can then be used to aid new agricultural businesses in Arizona. Automated and remotely monitored, the floating hydroponic system was designed and constructed at the CEAC. A professional Science Master student Myles Lewis is working under the supervision of Dr. Gene Giacomelli and Dr. Murat Kacira (Agricultural & Biosystems Engineering) and the advising of Dr. Merle Jensen, Emeritus Professor, Plant Sciences, to determine the economic feasibility of commercial greenhouse lettuce production within a floating hydroponic system in the Southwest. We will study the potential sustainable management of water and fertilizer in hydroponic systems. In addition, we will study year-round production of high quality, nutritious fresh salad vegetables with reduced water and fertilizer applications by comparison to field production.

Fig 2. One of the FHS used in stimulating the production of plant phytochemicals with an electrical current.

In addition, Dr. Joel Cuello (Agricultural & Biosystems Engineering) in collaborative research with Dr. Murat Kacira is evaluating the effect of stimulating plants with low power levels of electrical current to induce the leafy greens and pharmaceutical crops to enhance phytochemical production. Future research will include the studies of the dynamics of the system, and the effects of electrical conductivity (EC), pH and water temperature on plant growth, quality and phytochemical yield.

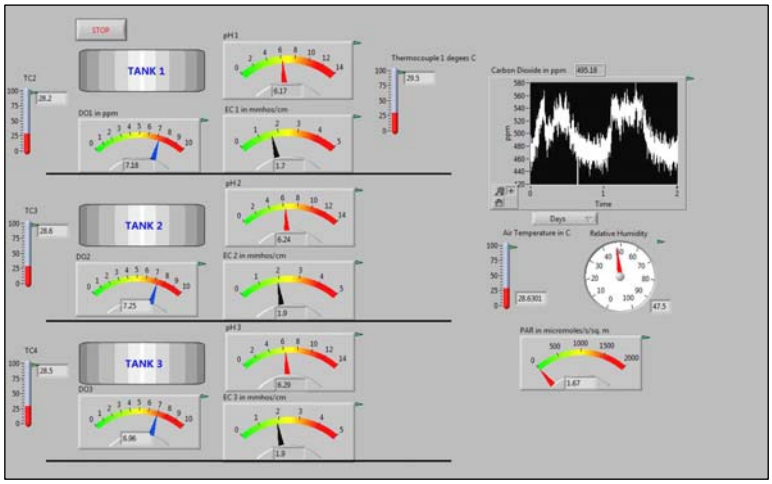
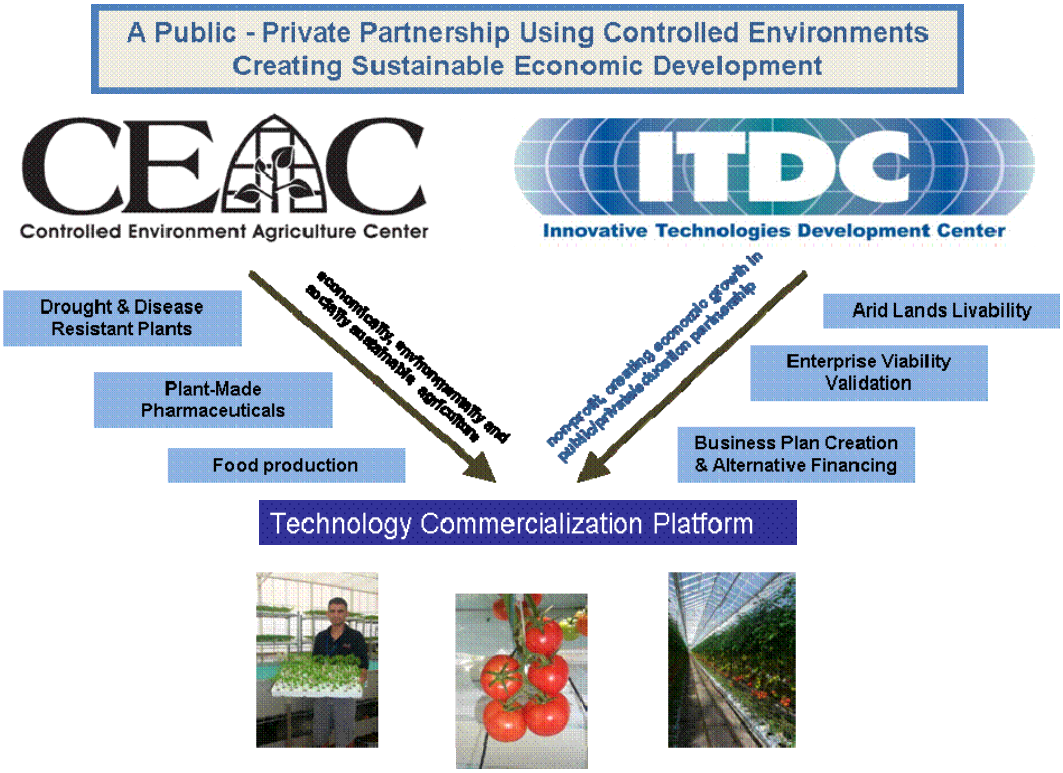
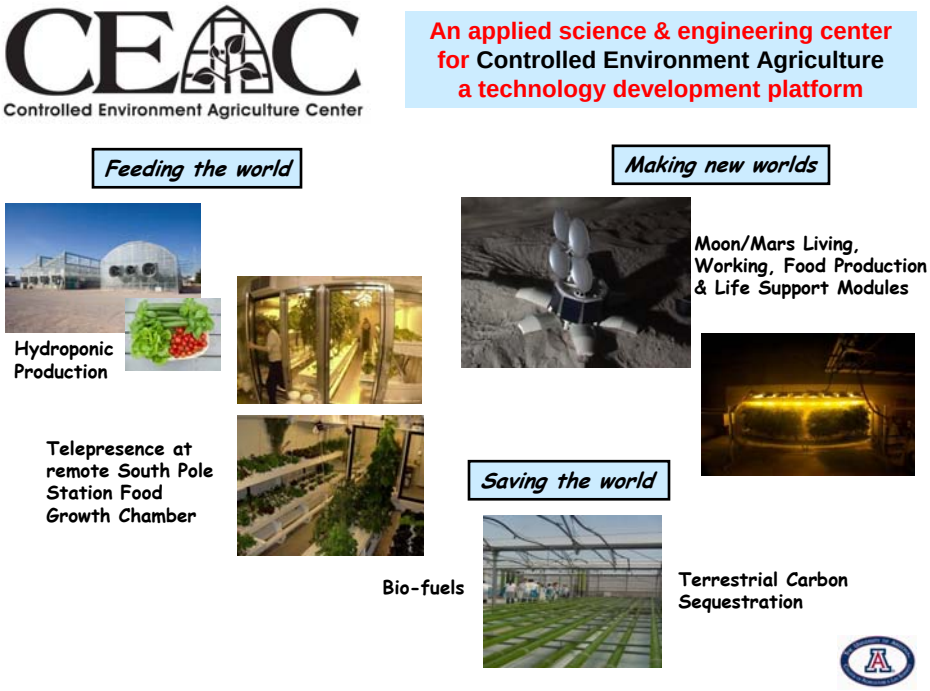


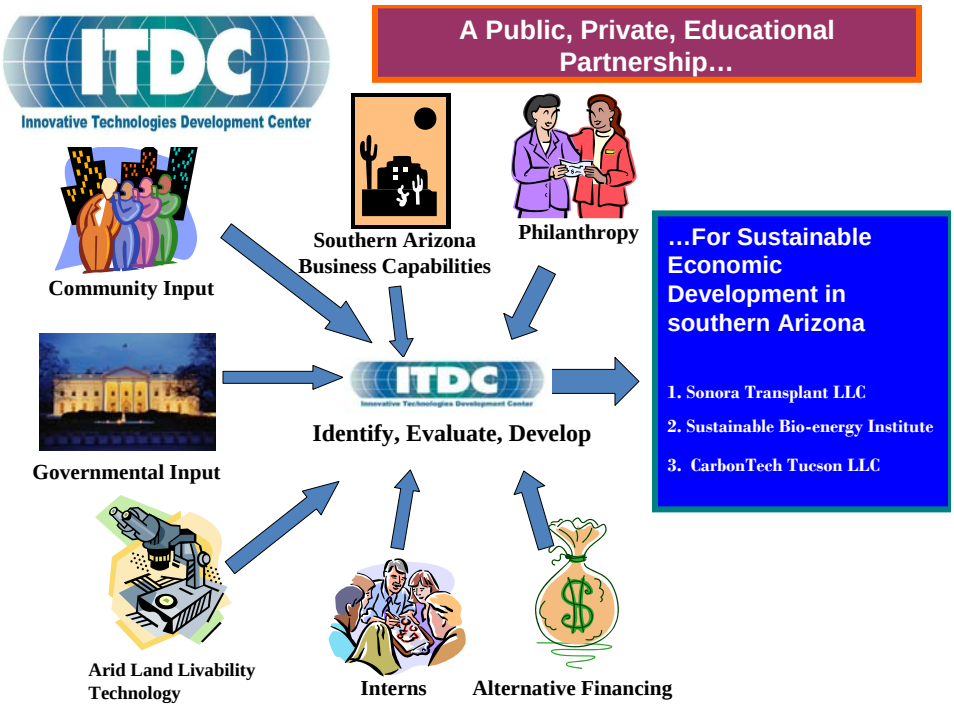
Fig 3. The automated FHS units are remotely monitored through the Internet using LabView for environmental parameters including EC, pH, dissolved oxygen and nutrient temperature in root zone; air temperature, relative humidity, light intensity, and CO2 concentration in the aerial environment.

Controlled Environment Agriculture Center Tour
ISHS Workshop on Greenhouse Environmental Control and Crop Production in Semi-Arid Regions
Friday, October 24, 2008

Station 7 – Economic Development
Topic Title: Strategic Partnership with Innovative Technologies Development Center
Primary Contact: Ron Richman and Robert Shatz, ITDC
Contact Email: rjrichman@inno-tech.org
Collaborators: Drs. Chieri Kubota, Judy Brown, and Gene Giacomelli




CEAC
Controlled Environment Agriculture Center
An applied science & engineering center
for Controlled Environment Agriculture
a technology development platform
Feeding the world
Hydroponic Production
Telepresence at remote South Pole Station Food Growth Chamber
Making new worlds
Moon/Mars Living, Working, Food Production & Life Support Modules
Saving the world
Bio-fuels
Terrestrial Carbon Sequestration


ITDC
Innovative Technologies Development Center
A Public, Private, Educational Partnership…
Community Input
Southern Arizona Business Capabilities
Philanthropy
Governmental Input
ITDC
Identify, Evaluate, Develop
…For Sustainable Economic Development in southern Arizona
1. Sonora Transplant LLC
2. Sustainable Bio-energy Institute
3. CarbonTech Tucson LLC
Arid Land Livability Technology
Interns
Alternative Financing

ITDC and CEAC

"CEA is an awesome technology platform for the 21st century, but without the management, funding, and customers, the great ideas remain in the 'ivory tower'. ITDC is a 501(c)(3) non-profit that integrates the technologies and resources to commercialize sustainable enterprise (i.e. Sonora Transplant LLC), and we are creating a pipeline of opportunities for southern Arizona together with CEAC."

Ron Richman, COO, ITDC
Robert Shatz, CFO, ITDC

http://www.inno-tech.org

What are we working on?

- Sonora Transplant
- Pictorial Greenhouse Instruction
- Drought & Disease Resistant Plants
- Plant Made Pharmaceuticals
- GroLive
- Urban Food
- Carbon Sequestration
- Closed Systems
- Engineering & Design for Arid Land Development
- Economic Models
- Grafting Robot with College of Engineering
- Science Foundation Arizona Grants
- Executing Strategic Plan

Sonora Transplant LLC

Grafted Tomato Transplants

Sell innovative, high-quality, seedlings for greenhouse and open field production

Biopharmaceutical manufacturing platform

Plant based safer, cost-effective pharmaceuticals

Development tool for commercialization of novel proteins

Agroceuticals, Transgenic seeds, Biomaterials, Industrial enzymes

Sonora Transplant Methodology

Grafted seedling production under artificial light
- Greater and uniform growth
- 100% grafting success
- Less use of water

Double-headed grafted plugs (4 weeks after seeding)

Sustainable Bioenergy Institute

Mission
Create a commercially viable and responsible BioEnergy economy for Arizona and other desert environments.
Vision
Pioneer innovations for BioEnergy alternatives to fossil fuels
Objectives
1. Develop standards for measuring affordability, energy balance, carbon footprint, scalability, and sustainability of BioEnergy in Arizona;
2. Serve as the primary hub of research and commercialization in the field of BioEnergy for Arizona and other desert environments;
3. Provide education, training, and technical expertise to state, local, and tribal government entities, producers, refiners, and distributors of BioEnergy products;
4. Create and pursue funding opportunities that foster relationships between academics, government, and industry.
5. Create policies with stakeholders in the city, county, region, state, and region based on cost/benefit analysis

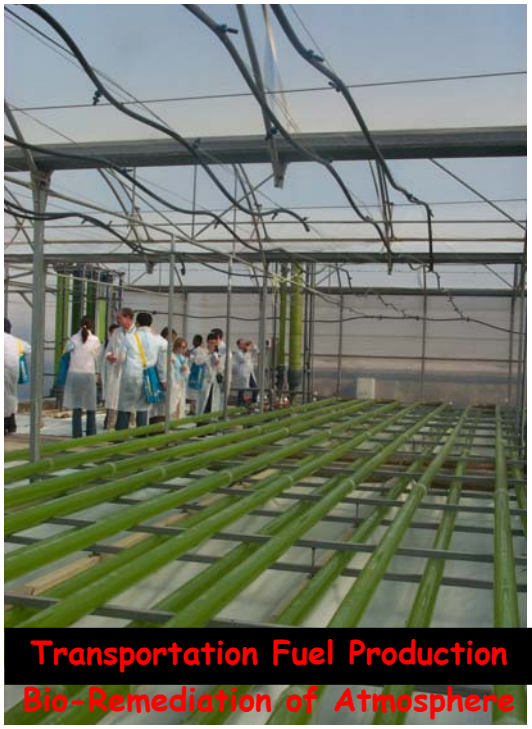
Greenhouse production of algae within plastic tube bioreactor, using exhaust gasses from combustion to sequester CO_2

Keesung Kim, PhD
ABE
Post-Doctoral Student

Joel Cuello
and Gene Giacomelli

Recirculating Hydroponic Plant Production System

Photo: Cajamar Research Center, Spain



Carbon Credits

- Long-term, integrated tree seedling nursery and forest plantation system consisting of:
  - 10 acre greenhouse
  - 40 seedlings per sq.ft., 3 production cycles/year
  - 2,000 seedlings per acre planted annually on 26,000 acres
- Greenhouse tree seedlings & reforestation consumes
  - 1,450,040 Ton CO_2/year
- 300 MW Power Station produces
  - 1,800,000 Ton CO_2/year
- 80% of carbon dioxide from power plant sequestered

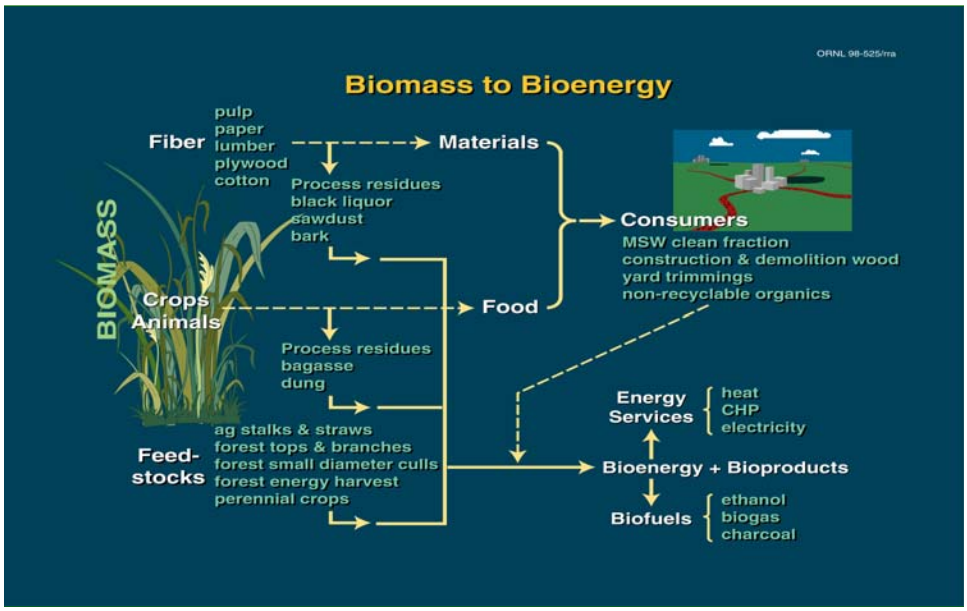
(Calculations done by CEAC)

CarbonTech Tucson, LLC

Mission Statement

- **CarbonTech Tucson LLC is proposing an interrelated, privately funded, recycling, renewable energy and job creation effort involving Pima County, Tucson Electric Power, the Union Pacific Railroad, and CarbonTech Tucson LLC.**
- **The project seeks to install and operate distributed facilities to reduce waste volumes and to recycle previously unused and unusable organic and plastic waste streams.**
- **The facilities will produce a unique solid organic fuel suitable for transportation by rail, for storage, and for co-energy generation or stand alone use.**
- **The program will convert problematic perpetual organic wastes into fuels able to substitute for petroleum fuels, coal, and natural gas, reducing dependence on imports and promoting sustainability.**
- **CarbonTech Tucson LLC invests a portion of proceeds to fund local education, training, and networking programs which will provide family-wage jobs, enhance professional development, and recognize excellence in small business development in sustainable and renewable fuels derived from organic and petroleum-based waste streams.**

CarbonTech Tucson LLC



Conclusion/Outcomes

Job Creation/ Job Retraining

Interns Trained

"Retired" Executives attracted

Applied Science to Commercialization

Increase in Local Management

Increased in Resident Participation

Stem the Brain Drain

→ Reputation of Tucson and Surrounding Region for Revitalizing and Reinvesting using Arid Lands Livability Systems and Tools as our Regional and Global Competitive Advantage

Sustainable Economic Development

Tucson recognized as world class innovative technologies development center that results in increased quality of life for all in southern Arizona

ISHS Workshop on Greenhouse Environmental Control and Crop Production in Semi-Arid Regions

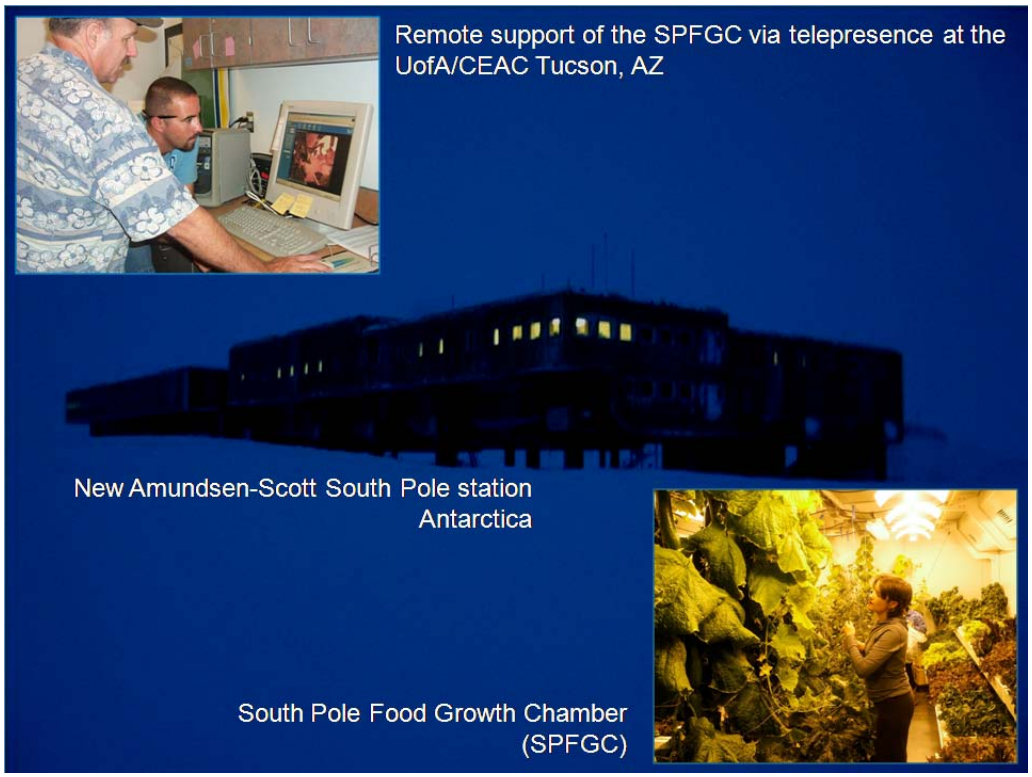
Friday, October 24, 2008

Station #8

Topic Title: South Pole Food Growth Chamber Live Webcast

Primary Contact: Lane Patterson, MS student
Contact Email: lane12345@rocketmail.com
Collaborators: Phil Sadler, Sadler Machine Company, Tempe, Arizona, Gene Giacomelli, Ph.D., Martin Lewis, Raytheon Polar Services Company, Denver, CO

The South Pole Food Growth Chamber (SPFGC) is an automated hydroponic plant growth chamber located within the U.S. National Science Foundation, New Amundsen-Scott South Pole station in Antarctica. It was designed and constructed by the Sadler Machine Company in conjunction with the University of Arizona Controlled Environment Agriculture (UA-CEAC) and continues with telepresence assistance from the CEAC.



Since initial operation in 2004 the SPFGC has provided the station researchers and support crew working at the South Pole with a multitude of fresh vegetables, and a unique causal space for enjoying bright, warm-colored lighting, comfortable humidity, and a green plant-filled environment.

Station # 9: Biomass Production in Aquaponics

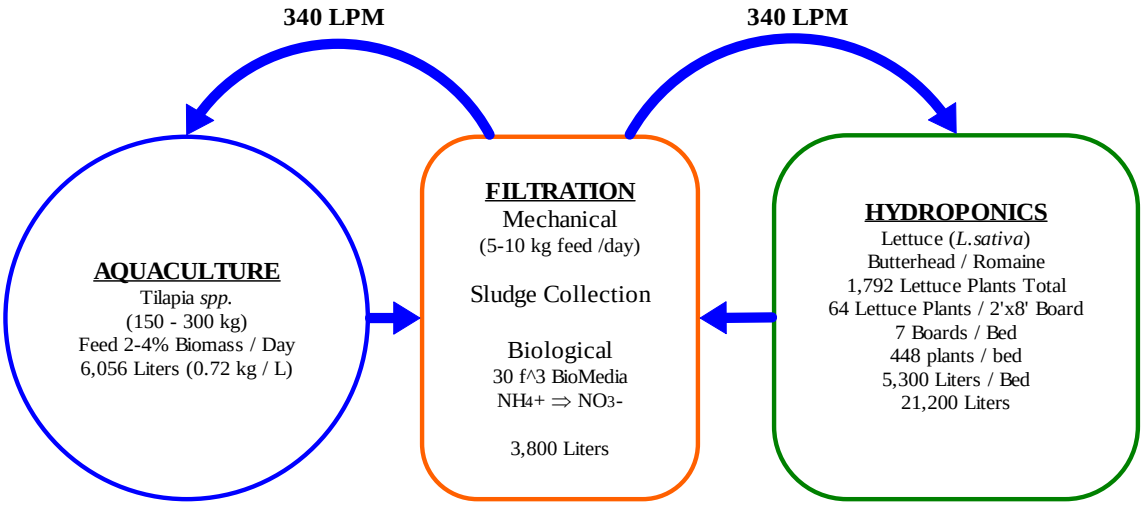
Topic Title: Nitrogen Dynamics and Biomass Production of an Aquaponics System

Primary Contact: Jason Licamele, MS student
Contact Email: licamele@email.arizona.edu
Collaborators: Dr. Gene Giacomelli, Agricultural & Biosystems Engineering, Dr. Kevin Fitzsimmons, Soil Water & Environmental Sciences, Dr Merle Jensen, Emeritus Professor, Plant Sciences

Aquaponics is the integration of recirculating fish culture and hydroponic plant production. The integration of plants into the fish culture system leads to the removal of nutrients omitting the need for water changes thus conserving water as well as bioremediation of food production effluents. The nutrient source is utilized by both the fish and plant systems generating more products per gram of nutrients or feed. Removal of nutrients from fish effluent via plant nutrient uptake is an efficient and productive method of filtration. Fish aquaculture systems can also provide a consistent organic source of nutrients for the hydroponic plants. Aquaponics systems can serve as valuable technologies in areas where there are little fresh water resources.

OBJECTIVES

-Quantify the amount of total biomass (fish and plant) that can be cultivated per gram of fish feed in an aquaponics system
-Model the water chemistry and nutrient flow dynamics in an aquaponics system
-Determine optimal ratios of fish to plants



AQUAPONICS SYSTEM SPECS	
H2O Volume	31,056 Liters
Flow Rate	340 LPM
Fish System Daily Turnover	50
Plant System Daily Turnover	29
Fish Biomass	150-300 kg
Total Plants	1,792

DATA COLLECTION	
Environmental:	Temperature (C)
	% Relative Humidity
	PAR (umol s-1 m-2)
H20:	Temperature (C)
	pH
	Electrical Conductivity (*uS*/cm)
	Dissolved Oxygen (mg/L)
	Ammonia (ppm)
	Nitrate (ppm)
H20 Chemistry	
Na	PO4
Ca	Cu
Mg	Zn
K	Mn
NH4	Fe
Cl	B
SO4	Fe
HCO3	Al
CO3	Mo
NO3	