

2008 International Meeting on Controlled Environment Agriculture
Organized by the North American Committee on Controlled Environment Technology and Use
(NCERA-101)

Saturday, March 8

Time	Title
12:00 – 6:00 pm	On-Site Registration (Manatee Ballroom Foyer)
1:00 – 6:00 pm	Poster and Exhibit Setup (Manatee Ballroom D)
3:30 – 5:30 pm	ASHS CEWG Business Meeting (Heron Room)
6:00 – 9:30 pm	Reception (Observation Deck, Oceanside Café)

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Sunday, March 9

Time	Title	Author(s)
7:00am – 5:00pm	On-Site Registration (Manatee Ballroom Foyer)	
8:00 – 8:15 am	Opening Remarks (Manatee Ballroom)	Gary W. Stutte David H. Fleisher
Session A: New Approaches for Control and Monitoring Environmental Conditions Moderator: Tony Agostino (Manatee Ballroom)		
8:15 – 8:35 am	<u>Changing the way light is delivered to plants in controlled environments: Novel practices with LED lighting</u>	G.D. Massa *, C.M. Bourget, R.C. Morrow, C.A. Mitchell
8:35 – 8:55 am	<u>Comparing photoperiodic lighting strategies in controlled greenhouse environments</u>	S. Padhye, E. Runkle*
8:55 – 9:15 am	<u>Transmission and distribution of photosynthetically active radiation (PAR) from solar and electric light sources for crop production</u>	T. Nakamura *, A.D. Van Pelt, D.C. Rossi, B.K. Smith, N.C. Yorio, A.E. Drysdale, R.M. Wheeler, J.C. Sager
9:15 – 9:35 am	<u>Effect of light quality on production of bioprotective compounds in red leaf lettuce</u>	G.W. Stutte *, I. Eraso, P. Bisbee, C. Ledeker, T. Skerritt
9:35 – 9:55 am	<u>Integrated light and CO₂ control to optimize commercial greenhouse plant growth and energy efficiency</u>	T.J. Shelford *, L.D. Albright, D.S. de Villiers
9:55 – 10:15 am	<u>Plant performance monitoring via non- invasive image acquisition and processing</u>	F. Gilmer *, A. Walter, A. Ulbrich
10:15 – 10:40 am	Catered Break (Manatee Ballroom D)	
10:40 – 10:55 am	<u>ENVIRONET[®]: the next advancement in control technology</u>	H. Imberti *, D. Kiekhaefer
10:55 – 11:10 am	<u>Six highly specialized walk-in chambers with atmospheric gas composition control. A discussion of the challenges and possibilities of multiple atmospheric gas control in walk-in chambers</u>	R. Quiring

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Session B: New Responses / Research Results from Experiments in CEA

Moderator: Erik Runkle

(Manatee Ballroom)

11:10 – 11:25 am	<u>Plant growth and flavonoid content in a red-pigmented <i>Lactuca sativa</i> variety as affected by different light conditions</u>	A. Ulbrich*, H. Behn, C. Wieland, S. Tittmann, F. Gilmer
11:25 – 11:40 am	<u>Supplemental UV radiation differentially increases phenolic acid esters and flavonoids in cultivars of greenhouse-grown red and green leaf lettuce (<i>Lactuca sativa</i>)</u>	C. Caldwell, S. Britz*, R. Mirecki, J. Slusser, W. Gao
11:40 – 11:55 am	Changes in the concentration of some secondary metabolites after treatment with ultra-violet light on St. John's wort, <i>Hypericum perforatum</i>	M.L. Brechner*, L.D. Albright
11:55 – 12:10 pm	<u>Enhancing nutritional value of fresh tomato under controlled environments: a summary of collaborative research effort</u>	C. Kubota*, C.A. Thomson
12:10 – 1:25 pm	Catered Buffet Lunch (Manatee Ballroom D)	
12:20 – 1:25 pm	ICCEG Meeting (Heron Room)	
1:25 – 1:40 pm	<u>Photosynthetic characteristics and growth of rice plants under red light with or without supplemental blue light</u>	R. Matsuda*, K. Ohashi-Kaneko, K. Fujiwara, K. Kurata
1:40 – 1:55 pm	<u>Effects of duration of temperature perturbations during flowering on tomato fruit</u>	A.J. Both*, L.S. Logendra, D.L. Ward, T. Gianfagna, H.W. Janes, T-C. Lee
1:55 – 2:10 pm	<u>Grapevine physiology in controlled environments</u>	D. Greer
2:10 – 2:25 pm	<u>Hypobaria, hypoxia and ethylene influence growth and gas exchange of lettuce plants</u>	F.T. Davies*, C. He, R.E. Lacey
2:25 – 3:00 pm	Session B General Discussion	E. Runkle

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Session C: Non-traditional Applications in Controlled Environments
Moderator: L.D. Incoll
(Manatee Ballroom)

3:00 – 3:25 pm	<u>Guidelines for measuring and reporting environmental parameters in controlled environments used for plant tissue culture experiments</u>	M.P. Fuller [*] , S. Millam, L.D. Incoll
3:25 – 3:40 pm	<u>Biopharmaceutical production under controlled environments: photosynthetic rate, soluble protein concentration and growth of transgenic tomato plants expressing a <i>Yersinia pestis</i> F1-V antigen fusion protein</u>	R. Matsuda [*] , C. Kubota, L.M. Alvarez, J. Gamboa, G.A. Cardineau
3:40 – 4:10 pm	Catered Break (Manatee Ballroom)	
4:10 – 4:25 pm	Plant-made pharmaceuticals: scaling up production	J.H. Norikane
4:25 – 4:40 pm	Waste-energy-leveraged CEA for year-round specialty-crop and bio-fuel feedstock production in temperate climates	C.A. Mitchell [*] , G.D. Massa, C. Alexander, R. Turco, J. Dennis, A. Murphy, S. Weller, B. Bordelon, R. Lopez
4:40 - 4:55 pm	<u>Commercial aeroponic farming of baby leafy greens</u>	E.D. Harwood
4:55 – 5:10 pm	<u>Climate change and controlled environments</u>	M. Stenning
5:10 – 5:30 pm	Session F General Discussion	L.D. Incoll
6:30 – 9:30 pm	Hosted Dinner (Tiki Lawn, Holiday Inn)	

* Denotes presenter.

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Monday, March 10

Time	Title	Author(s)
7:00am – 5:00pm On-Site Registration (Manatee Ballroom Foyer)		
Session D: Novel Instrumentation, Sensors, and/or Analysis Approaches Moderator: Bruce Bugbee (Manatee Ballroom)		
8:00 – 8:20 am	<u>Estimating carbon use efficiency, growth respiration, and maintenance respiration from canopy gas exchange measurements</u>	M.W. van Iersel
8:20 – 8:40 am	<u>Hands-off sensors: applications of spectral devices to controlled environment agriculture</u>	G.L. Ritchie*, J. Frantz, C. Bednarz, B. Bugbee
8:40 – 9:00 am	<u>Evaluation of two new net radiometers</u>	J. M. Blonquist Jr*, B Tanner, B. Bugbee
9:00 – 9:15 am	<u>Effect of atmospheric pressure on wet bulb depression</u>	R.M. Wheeler*, M.A. Stasiak, J.Lawson, C.A. P. Wehkamp, M.A. Dixon
9:15 – 9:30 am	<u>Large high-output LED arrays for plant growth</u>	R.C. Morrow*, C.M. Bourget
9:30 – 9:45 am	Probing responses of plants by chlorophyll fluorescence under controlled environments	H.M. Kalaji
9:45 – 10:00 am	<u>Automatic and 3-dimensional phenotyping of complete plants in greenhouses</u>	J. Vandenhirtz*, M. Eberius, D. Vandenhirtz, H.G. Luigs, G. Kreyerhoff, U. Bonger, M. Radermacher, H. Lasinger, R. Schunk
10:00 – 10:30 am Catered Break (Manatee Ballroom)		
10:30 – 10:45 am	<u>Uniformity in soil plant atmosphere chambers</u>	D.H. Fleisher*, D.J. Timlin, V.R. Reddy

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10:45 – 11:00 am	<u>Real-time measurement of whole plant transpiration and stomatal conductance using electronic balances and infrared sensors</u>	B. Bugbee [*] , J. Chard
11:00 – 11:15 am	<u>Monitoring and controlling substrate water content in controlled environments</u>	M.W. van Iersel

Session E: Design and Development of New Facilities

Moderator: Alex Turkewitsch

(Manatee Ballroom)

11:15 – 11:45 am	<u>Engineering in sustainability and innovative development of controlled environments: a UK perspective on refrigerants, achieving efficient systems and energy management</u>	G. M. Waimann
11:45 – 12:00 pm	Description, operation and production of the South Pole Food Growth Chamber (SPFGC)	R.L. Patterson [*] , G.A. Giacomelli, P. Sadler
12:00 – 12:15 pm	<u>New Bioscience Complex at University of Maryland</u>	G. F. Deitzer
12:15 – 12:20 pm	Session E Short Discussion	A. Turkewitsch
12:20 – 1:50 pm	Catered Buffet Lunch (Manatee Ballroom)	
1:50 – 2:05 pm	The Biotron and Guelph's Plant Productivity Model	E.D. Leonardos, M.J. Iqbal, A. Singh, N. Hüner, B. Grodzinski [*]
2:05 – 2:20 pm	<u>Containment level 3 facility for growing genetically modified plants and plant pathogens</u>	J. Franklin [*] , R. Taberer
2:20 – 2:35 pm	<u>The Australian Plant Phenomics Facility</u>	T. Agostino
2:35 – 2:45 pm	Session E Short Discussion	A. Turkewitsch
2:45 – 4:10 pm	General Poster Session with Break (Manatee Ballroom)	
4:10 – 5:45 pm	NCERA-101 Business Meeting (Manatee Ballroom)	
6:30 - 10:00 pm	Hosted Dinner (Mango Tree, Cocoa Beach, FL) Meet shuttle bus at Hotel Lobby	

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Tuesday, March 11

Time	Title	Author(s)
Session F: Reliability and Quality Control for CEA Facilities Moderator: Mark Romer (Manatee Ballroom)		
8:15 – 8:40 am	Quality standards in CE; implications for the user	L. Benjamin
8:40 – 9:00 am	Performance verification of new research greenhouse facilities	A. Turkewitsch [*] , D. Brault, B. Faucher
9:00 – 9:20 am	Energy efficiency and green technologies in environmental chambers	D. Kiekhaefer [*] , H. Imberti
9:20 – 9:40 am	Supervisory control – implications for environmental control systems	A. Mackenzie
9:40 – 10:00 am	General Discussion	D.H. Fleisher
10:00 – 10:20 am	Catered Break (Manatee Ballroom)	
10:20-10:45 am	Space Life Science Laboratory	S. Vangen
10:45-11:30 am	Awards (Manatee Ballroom)	M. Romer
11:30 – 12:30 pm	Catered Lunch (Manatee Ballroom)	
12:30 am	Buses leave for Kennedy Space Center (Meet buses at the Hotel Lobby)	
1:00 – 6:00 pm	Kennedy Space Center and Space Life Sciences Laboratory Tour	
6:00 pm	Return to Hotel	

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Poster Presentations
(Manatee Ballroom D, March 9 - 11)

Title	Author(s)
Session A: New Approaches for Control and Monitoring Environmental Conditions	
<u>Evaluation of a humidity insensitive sorbent-based air sampling system</u>	A. Flanagan*, D. Braithwaite, T.S. Topham, G.E. Bingham, O. Monje
Predicting night-time low temperatures in unheated high tunnels	A. Ogden*, M. van Iersel
Session B: New Responses / Research Results from Experiments in CEA	
<u>Development of a production system for basil on the International Space Station</u>	A.R. Beaman*, R.J. Gladon
<u>Harvest index of 'Rocky' cucumber plants (<i>Cucumis sativus</i> L.) grown in elevated CO₂ is not different from 'Rocky' cucumber grown in ambient CO₂</u>	L. Crosby*, E. Peffley, L. Thompson
<u>Modified field environments for high latitude crop production</u>	M. Karlsson*, J. Werner
The potential for autotoxicity of root exudates in commercial hydroponic lettuce (<i>Lactuca sativa</i>) production	N.S. Mattson*, L.D. Albright, M.L. Brechner
Research plants in controlled environments – does green waste compost make a reliable alternative substrate to peat?	G. Pitkin*, R. McHutchon
<u>Effect of light quality on growth of <i>Salvia miltiorrhiza</i> Bunge</u>	Q. Li*, Z.-S. Liang
<u>Effects of a new cyclical lighting system on flower induction in long-day plants: a preliminary investigation</u>	M.G. Blanchard, E.S. Runkle*

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Session C: Non-traditional Applications in Controlled Environments

<u>Isotopic labeling of red cabbage anthocyanins with atmospheric ¹³CO₂ in closed environments</u>	C. Charron, S. Britz [*] , R. Mirecki, D. Harrison, B. Clevidence, J. Novotny
<u>Effect of elevated CO₂ and harvest schedule on <i>Allium</i> biomass and sensory quality of <i>Allium fistulosum</i></u>	A. Broome [*] , E. Peffley, L. Thompson, D. Wester
How to measure and report growing conditions for experiments in plant tissue culture facilities	ICCEG

Session D: Novel Instrumentation, Sensors, and/or Analysis Approaches

Maintaining and quantifying drought stress in containers	J. Chard, B. Bugbee [*]
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Session E: Design and Development of New Facilities

<u>Energy saving measures in controlled environments at Rothamsted Research</u>	I. Pearman, J. Franklin [*] , G. Waimann
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Session F: Reliability and Quality Control for CEA Facilities

<u>Containment of quarantined insects</u>	R. Natt
<u>Growth chamber maintenance costs and factors influencing equipment longevity, reliability and operating quality</u>	M. Romer [*] , C. Cooney, F. Scopelleti, G. Orr
<u>A risk analysis of the production of hydroponic baby leaf spinach with respect to <i>Pythium aphanidermatum</i></u>	T.J. Shelford [*] , L.D. Albright

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Wednesday, March 12

Post Meeting Tour of Central Florida Foliage Plant Industry
Guide: Wayne Makay, Ph.D. Director and Professor
University of Florida, Mid-Florida Research and Education Center,
Apopka, Florida

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|------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| 7:45 am | Buses leave for Apopka
(Meet buses at the Hotel Lobby) |
| 8:00 – 9:30 am | Transit to Mid-Florida Research and Education Center, Apopka, FL |
| 9:30 – 10:30 am | Mid-Florida Research and Education Center, Apopka Florida
http://mrec.ifas.ufl.edu/ |
| 10:30 – 11:00 am | Board buses/Transit |
| 11:00 – 12:00 am | Hermann Engelmann Greenhouses, Ranges # 8/9, Apopka Florida
www.exoticangel.com |
| 12:00 – 12:30 pm | Board buses/Transit |
| 12:30 – 1:30 pm | Lunch at Hermann Engelmann Greenhouses, Range # 6, Apopka, Florida
www.exoticangel.com |
| 1:30 – 2:00 pm | Board Buses/Transit |
| 2:00 – 3:00 pm | Delroose Plants, Apopka, Florida
www.derooseplants.com/en/over_us.asp |
| 3:00 – 3:15 pm | Board Buses/Transit |
| 3:15 – 4:15 pm | Agristarts, Inc, Apopka, Florida
www.agristarts.com |
| 4:15 – 6:00 pm | Board Buses and return to Holiday Inn, Cocoa Beach, FL |
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Abstracts: Session A
New Approaches for Control and Monitoring
Environmental Conditions

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Changing the Way Light is Delivered to Plants in Controlled Environments: Novel Practices with LED Lighting

Gioia D. Massa^{1*}, C. Michael Bourget², Robert C. Morrow², Cary A. Mitchell¹

¹ Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, 47907-2010, USA.

² Orbital Technologies Corporation (ORBITEC), 1212 Fourier Drive, Madison, WI, 53717, USA.

* Email address: gmassa@purdue.edu

Controlled-environment plant-growth lighting traditionally is overhead, perpendicular to the top of the crop stand, and with adequate separation such that hot lamps do not scorch leaves. For planophile crops that orient their leaves horizontally and close their canopies as stands develop, canopy closure leads to the problem of mutual shading in which lower leaves are completely shaded by those above, thereby causing premature leaf senescence. Upper and outer leaves of the crop, estimated to be 15% to 20% of potentially available photosynthetic surface, therefore must do all of the photosynthetic work for the entire crop stand. LEDs have the potential to shift this imbalance for the better. Due to their small size and the capability of heat removal separate from light emission, this light source can be placed in close proximity to leaves. Other aspects of LEDs, such as their voltage-dependent light intensity, availability in a wide variety of narrow-band emissions, and electrical conversion efficiencies that are continuously being improved, make this solid-state lighting technology ideal for plant growth in controlled environments. Working in a collaborative project between ORBITEC and Purdue University, a reconfigurable LED lighting array was developed that allows for the vertical intracanopy arrangement of separate LED-bearing “lightsicles” for planophile crops. In the intracanopy system, light engines containing many small printed-circuit LEDs are switched on from the bottom up to keep pace with growth in height of the crop stand. The lightsicles can also be reconfigured into a continuous overhead horizontal arrangement, to serve both as a control and as an alternate lighting system for erectophile and rosette crops. In this “close-canopy” type of arrangement, the light-emitting surface is brought near the crop, where light engines can be switched on individually to keep pace with leaf expansion. Both lighting arrangements are designed to reduce energy usage for lighting while maintaining high levels of crop productivity. Results from preliminary crop analysis with cowpea and pepper will be discussed. Both crops showed greater leaf retention and higher productivity for given energy input with intracanopy lighting compared to overhead-lit controls. Early results led to hardware modifications and these plus other issues such as the occurrence of oedema in certain species will be highlighted. In addition, the development and testing of an automated detection-and-switching system to fully realize the potential of the hardware will be described. This research has been supported by NASA grants NAG5-12686 and NNK05OA20C.

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Comparing Photoperiodic Lighting Strategies in Controlled Greenhouse Environments

Sonali Padhye* and Erik Runkle

Department of Horticulture, Michigan State University, East Lansing, MI, 48824, USA

* Email address: padhyeso@msu.edu

Commercial floriculture growers provide long-day (LD) photoperiods in greenhouses using day extension (DE), night interruption (NI) or cyclic lighting to promote flowering of LD plants and inhibit flowering of short-day (SD) plants. Traditionally, incandescent (INC) lamps have been used to provide low intensity photoperiodic lighting. The use of fluorescent tubes can provide substantial energy savings over INC lamps, but shading created by ballasts has limited their use. Compact fluorescent (CF) lamps can replace existing INC bulbs and save energy and hence, use of CF lamps for LD lighting has sparked the interest of many commercial greenhouse growers. The ratios of red (600 to 700 nm) to far-red (700 to 800 nm) light emitted by INC and CF lamps are 8.5 and 0.6, respectively. Flowering of LD plants can be delayed when grown under an environment deficient in far-red light, which suggests that providing LD using CF lamps may delay flowering of LD plants. The objective of this experiment was to quantify the efficacy of NI lighting on floral evocation of LD and SD plants using CF lamps alone or in combination with INC lamps. *Campanula carpatica* 'Deep Blue Clips', *Coreopsis grandiflora* 'Early Sunrise', *Petunia multiflora* 'Purple Wave' and *Rudbeckia hirta* 'Orange Becky' (LD plants) and *Dendranthema* 'Auburn' and 'Bianca' (SD plants) were grown under a 9-h truncated natural day supplemented when necessary with light from high pressure sodium lamps. Plants received 2- or 4-h NI or DE for 7 h (to create a 16-h photoperiod). The lighting treatments were provided by CF, INC, or 50% of each lamp type and delivered a PPF of 1.5 to 2.5 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. An additional group of ten plants was grown under a 9-h photoperiod as a control. Flowering and stem extension responses were assessed and data will be presented. Implications on controlled environment research will also be discussed.

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Transmission and Distribution of Photosynthetically Active Radiation (PAR)
from Solar and Electric Light Sources for Crop Production

Takashi Nakamura^{1,*}, Aaron D. Van Pelt¹, David C. Rossi¹, Benjamin K. Smith¹, Neil C. Yorio², Alan E. Drysdale³, Raymond M. Wheeler⁴, and John C. Sager⁴

¹ Physical Sciences Inc., 2110 Omega Rd. Suite D., San Ramon, CA 94583, USA

² Dynamac Corporation, Mail Code : DYN-3, Kennedy Space Center, FL 32815-0233, USA

³ Consultant, 6208 Windover Way, Titusville, FL 32780, USA

⁴ NASA Kennedy Space Center, FL 32899, USA

* Email address: nakamura@psicorp.com

This paper discusses the development and initial testing of a solar plant lighting system which collects, transmits and distributes photosynthetically active radiation (PAR) for controlled environment crop production. In this system, solar light, or light from an electric lamp, is collected by reflector optics and focused on the end of an optical waveguide cable. The light is filtered by the selective beam splitter to reject non-PAR ($\lambda < 400$ nm and $\lambda > 700$ nm) from the light path to minimize the introduction of heat into the plant growth chamber. The PAR (400 nm $< \lambda < 700$ nm) is transmitted to the plant growth chamber where the light is distributed uniformly over the growing area.

In the Phase I program the lighting capability of the system was evaluated for solar and electric light sources. Based on the results we conclude that the solar plant lighting system with a supplemental electric light source is a viable and effective concept for space based crop production. In the Phase II program we are building an engineering prototype of the solar plant lighting system to be installed in the Controlled Environment Lab at NASA/KSC's Space Life Sciences Laboratory (SLS Lab). The engineering prototype system is to be used for: (1) evaluate performance and demonstrate engineering feasibility; and (2) develop a technology base for space-deployment of the solar plant lighting system in applications to regenerative life support. In (1) we will develop a research tool which enables researchers in the ALS community to evaluate solar plant lighting. In (2) we will prepare for space-deployment of the solar power system for human exploration of the moon.

In this paper, results of the Phase I and the status of the Phase II program will be discussed in detail.

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Effect of Light Quality on Production of Bioprotective Compounds in Red Leaf Lettuce

G.W. Stutte^{1*}, I. Eraso¹, P. Bisbee¹, C. Ledeker², and T. Skerritt³.

¹Dynamac Corporation, Mail Code DYN-3, Kennedy Space Center, FL, USA, ²Dept. Animal and Food Science, University of Delaware, Newark, DE, USA, ³Dept Applied Science, Limerick Institute of Technology, Limerick, Ireland
e-mail: gary.w.stutte@nasa.gov

Exposure to ionizing radiation during long-duration space missions is expected to cause short term illness and increase long-term risk of cancer for astronauts. Radiation-induced free radicals overload the antioxidant defense mechanisms and lead to cellular damage at the membrane, enzyme and chromosome levels. Red leaf lettuce contains relative high concentration of anthocyanins. These pigments, as well as other antioxidant molecules, have radioprotective properties.

Red leaf lettuce cv. Outredgeous was grown under either fluorescent lamps or light emitting diodes (LEDs) at $300 \mu\text{mol m}^{-2} \text{s}^{-1}$ of photosynthetically active radiation (PAR), $1200 \mu\text{mol mol}^{-1} \text{CO}_2$, 23°C , and an 18h light /6 hr dark photoperiod in controlled environment chambers. The LED treatments were selected to provide different amounts of red (640 nm), blue (440 nm), green (530 nm) and far red (730 nm) light in the spectra. Total anthocyanin content and the oxygen radical absorbance capacity (ORAC) of the tissue was measured at harvest. The results were compared to effects of light intensity under fluorescent lamps from 100 to $450 \mu\text{mol m}^{-2} \text{s}^{-1}$ PAR and CO_2 concentrations of 400, 1200 and $3000 \mu\text{mol mol}^{-1}$.

The source of light had a dramatic effect on both plant growth and production of radioprotective compounds. LED's resulted in 50% greater bioprotectant content per plant at the same light level over triphosphore fluorescent lamps. Blue LED's (440 nm) appeared to activate the pathways leading to increased concentration of bioprotective compounds in leaf tissue. LED's also provided a number of indirect effects that increased the bioprotective content. LED's also allow the ability to alter the spectral quality that can enhance leaf expansion and maximizes light interception. In addition, LED lighting systems can minimize the use of non-photosynthetic light and increase the photosynthetic efficiency of the lighting system.

These experiments have shown that the development of the bioprotective pigments (anthocyanin) and antioxidants (ORAC) are strongly affected by both light intensity and light quality. In particular, there appears to be a requirement for blue (440 nm) light to maintain the bioprotective properties in lettuce.

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Integrated Light and CO₂ Control to Optimize Commercial Greenhouse Plant Growth and Energy Efficiency

T.J. Shelford*, L.D. Albright, D.S. Devilliers

Cornell University, 164 Riley-Robb Hall, Cornell University, Ithaca, NY, 14853, USA

* Email address: tjs47@cornell.edu

Due to the high cost associated with providing supplemental light to a greenhouse crop, minimizing this expense is a priority for commercial growers.

In previous work at Cornell a patented control algorithm that demonstrates the possibilities of synergistic environmental control involving supplemental lights, moveable shades and CO₂ supplementation was developed. Outdoor air temperature and the expected solar integral for the next hour are predicted based on data collected in the previous several hours. An energy balance then predicts the ventilation rate required for temperature control for the next hour. A growth model utilizing CO₂ concentration and daily light integral is then utilized to develop costs associated with providing a consistent level of growth with varying levels of CO₂ and supplemental light. For each combination the cost of the supplemented CO₂ is compared to the savings of less need for supplemental light and the least cost combination is chosen. Previous computer simulations using real weather data and a virtual greenhouse predicted that supplemental lighting costs in a cold, cloudy climate represented by Ithaca, NY, would be reduced by 50%. The cost of the CO₂ reduced this savings to 40% of the lighting cost with no supplemental CO₂ but the same growth.

This control algorithm was implemented in a greenhouse compartment at Cornell, and production data of a lettuce crop grown under these conditions, CO₂ use, and lighting energy data were collected for 3 months. This production data was compared to previously collected data and computer simulations used to develop the CO₂ daily light integral model.

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Plant Performance Monitoring via Non-invasive Image Acquisition and Processing

Frank Gilmer^{*}, Achim Walter, Andreas Ulbrich

Forschungszentrum Jülich, Leo-Brandt-Strasse, 52428 Jülich, Germany

^{*} Email address: f.gilmer@fz-juelich.de

Controlled environment agriculture with its benefits of improved water or energy use efficiency in out-of-season growth periods needs in most cases a human decision maker to close the control feedback loop. Based on his expert knowledge, this person evaluates growth progress to maintain optimal growth including the triggering of necessary stresses needed to maximize final yield. To develop an autonomous and stand-alone controlled environment directly coupled to plant development, the human knowledge base can be assisted by a decision support system used for growth monitoring on the one hand and for growth manipulation on the other hand via appropriate climate conditions. Growth monitoring needs non-invasive techniques to continuously measure related parameters like leaf area or canopy volume without disturbing plant development. The increase of such techniques related to plant developmental stage and environmental conditions gives good information about the plant performance.

Non-invasive growth monitoring can be done by color segmentation on plant images referring to leaf area development. Depending on demands of speed or accuracy, image acquisition and processing can be rough and simple, using a larger batch of individual plants to get statistically acceptable results in a short time. It can also focus on details on growth measurements with high spatial or temporal resolutions in order to locate regions or periods of interest with maximized or minimized growth and cell elongation respectively. Growth velocity is defined as the increase in mass or area in percentage per day (relative growth rate, RGR) and is a good descriptor for plant dynamics in a dynamic environment. Possibly, growth velocity can be used as a model of plant performance with a focus on the physiological and morphological development aspects. This model is not only useful for knowledge based decisions in climate control for short-term optimization of heat consumption and humidity regulation, especially in high prized plant production like plant made pharmaceuticals, but also for plant phenotyping to distinguish between lines, genetically modified or smart bred, or to quantify benefits or disadvantages of applications or chemical additives.

Sensitivity of this method becomes obvious in experiments comparing two *Arabidopsis thaliana* lines, where absolute leaf area shows wide variations in all developmental stages, but relative growth rates of the populations proved to be significantly different especially in the early growing period. Plant phenotyping or Phenomics is a task required to validate results from Genomics and Metabolomics. The detection of plant dynamics in a dynamic environment can generate a vast amount of data. So, in between research and user groups reasonable descriptors have to be identified and common processes have to be defined to get comparable and reproducible results.

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Advancement in Control Technology

Henry Imberti* and Daniel Kiekhaefer

Percival Scientific, Inc, Perry, IA 50220, USA, (515) 465-9363

* Email address: himberti@percival-scientific.com

Percival Scientific, Inc. in conjunction with the USDA-ARS has developed a software package that introduces new advancements in the control of environmental chambers. The software can simulate natural environmental conditions for any specified point on the globe at any time using statistical models developed by USDA-ARS. Additionally the software can synchronize with METAR (weather) stations throughout the globe for near real-time weather reproduction in a controlled environment.

The software controls Percival environmental chambers by outputting the following information to the Intellus controller:

- Temperature, humidity and CO₂ variations based on empirical data or near real time data.
- Fluctuations in solar radiation intensity.
- Fluctuations in solar radiation quality.

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Six Highly Specialized Walk-in Chambers with Atmospheric Gas Composition Control.
A Discussion of the Challenges and Possibilities of Multiple Atmospheric Gas Control in
Walk-in Chambers

Reg Quiring

Conviron Inc., 590 Berry Street, Winnipeg, Manitoba Canada R3H 0R9

* Email address: rquiring@conviron.com

A description of a unique project for Dr. Jennifer McElwain at the School of Biology and Environmental Science University College, Dublin, Ireland. A suite of 6 specialized growth chambers will be used to investigate effects of atmospheric gas concentrations on plant growth. All 6 chambers have additive CO₂ control up to 2000 ppm as well as subtractive oxygen (O₂) concentration control from the normal atmospheric 21% to as low as 13%. This is accomplished by injecting nitrogen gas (N₂) to displace air in the chambers.

At the same time CO₂ and O₂ are actively controlled, 3 of 6 units also control additive sulfur dioxide gas (SO₂) up to 2000 parts per billion. Accurate detection and control of SO₂ at low concentrations is very demanding. The raw cost for the SO₂ gas analyzer alone for each room is more than \$15,000. Interiors of the chambers are modified with corrosion resistant coatings and materials to resist long-term SO₂ exposure. In addition to the gas control options, 2 of the chambers operate down to -5°C with all lights on. In all 6 rooms, the lighting is closed-loop dimming metal halide and 3-level supplementary incandescent to 1100 μmol m⁻² s⁻¹. Additive and subtractive humidity control was also specified.

Dr. McElwain's specialty is Plant Palaeoecology (prehistoric plant growth). Since there was less oxygen and more CO₂ and SO₂ in the atmosphere then, it explains why she needed chambers to simulate that environment. Her research will also have direct application in the field of greenhouse gas and global warming.

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Abstracts: Session B
New Responses/ Research Results
from Experiments inCEA

Plant Growth and Flavonoid Content in a Red-pigmented *Lactuca sativa* Variety as Affected by Different Light Conditions

Andreas Ulbrich*, Helen Behn, Christine Wieland, Susanne Tittmann, Frank Gilmer

Research Centre Jülich, Leo-Brandt-Strasse, 52428 Jülich, Germany
Institute of Crop Sciences and Resource Conservation, Bonn, Germany

* Email address: a.ulbrich@fz-juelich.de

Light serves as a source of energy and information in plant life and thus represents a major determinant of metabolism and development. At the same time, short wavelength UV-B radiation may have damaging effects on molecular structures and therefore activates various mechanisms of protection, physiological as well as morphological. Metabolic adaptation includes for example the accumulation of metabolites with UV-B shielding and possibly antioxidative capacity, e.g. flavonoids. Plant morphology is affected in terms of growth and “habitus”. The objective of this study was to monitor anthocyanidin accumulation and leaf development in *L. sativa* ‘Bughatti’ cultivated under green house foils and glasses differing in the rate of light transmission particularly in the UV-B region. An elevated content in UV-B shielding pigments and antioxidants may facilitate adaptation to outdoor conditions when transferring plants to the field.

Experiments were performed in six greenhouses covered with three different materials which provide an UV-B transmission of 16% (Floatglas), 37% (MM-AR glass) and 74% (ETFE foil), respectively. The abbreviation ‘MM-AR’ describes the microstructured surface of the glass which is coated with an antireflex layer; ‘ETFE’ is a fluorized polymer. The red-pigmented lettuce cultivar was grown from seed in trays containing 100 small press pots. In order to examine pre-adaptation to outdoor conditions, a part of the propagation plants was transplanted to the field 22 days after sowing for determining yield and plant quality. The greenhouse cultivar was sampled approximately every 4 days from the 15th to the 30th day and the field cultivar once a week from the 22nd to the 36th day. Anthocyanidine content was measured spectrophotometrically at 535 nm. Growth was examined by means of leaf area index (LAI) and specific dry weight (SDW). Experiments were repeated three times from April to June 2007. Throughout the whole experimental period radiation intensities were monitored in the greenhouses and in the field.

The results indicated a positive correlation between anthocyanidine content in *L. sativa* and the degree of UV-B transmission of the covering materials. Consequently, plants grown under Floatglass showed the lowest anthocyanidine content, under MM-AR glass and ETFE foil values were 27% and 47% higher, respectively. After transfer of plants to the field, differences in the flavonoid content among treatments were completely compensated within 24 h as well as a possible advantage provided by a higher flavonoid content of plants grown under a UV-B transmissive material. The growth of the cultivar was not significantly influenced by the degree of UV-B transmission of the covering materials. Seedlings grown under MM-AR and ETFE-foil indicate a more compact habitus compared to plants which are cultivated under Floatglas.

Supplemental UV Radiation Differentially Increases Phenolic Acid Esters and Flavonoids in Cultivars of Greenhouse-Grown Red and Green Leaf Lettuce (*Lactuca sativa*)

Charles Caldwell¹, Steven Britz^{*1}, Roman Mirecki¹, James Slusser², and Wei Gao²

¹ USDA Food Components and Health Lab, Bldg. 307C, 10300 Baltimore Ave., Beltsville, MD 20705-2325, USA

² USDA UV-B Radiation Monitoring Program, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523-1499, USA

* Email address: steven.britz@ars.usda.gov

Leaf lettuce can be an important source of valuable dietary phytonutrients given its steady increase in consumption, but greenhouse cultivation often results in the reduction of polyphenolic compounds. Eight cultivars each of red and green leaf lettuce were grown simultaneously during winter in a greenhouse with supplemental photosynthetically active radiation as well as with or without supplemental UV radiation (either UV-B+UV-A [wavelengths greater than 290 nm; 6.4 kJ m⁻² biologically effective UV-B] or UV-A [wavelengths greater than 315 nm]). Neither UV treatment deleteriously affected plant growth. There were large quantitative differences between cultivars in phenolic compounds under control conditions and also large differences in UV effects. In the absence of supplemental UV radiation, red leaf varieties contained on average 2 fold higher levels of phenolic acid esters (chiefly caffeoylquinic acid and dicaffeoyltartaric acid) and 10 fold higher levels of flavonol (chiefly quercetin-3-malonylglucoside) than green lines. Red leaf varieties also contained an anthocyanin, cyanidin-3-malonylglucoside. However, anthocyanin levels were generally less than 5% percent that of flavonol. Phenolic acid esters increased ca. 45% on average in both red and green lines following 9 days of supplemental UV-B+UV-A radiation. In contrast, quercetin increased 3 fold in green leaf lettuce but only 2 fold in red leaf lettuce during the same treatment, whereas cyanidin increased over 3 fold in red leaf lettuce. Red and green leaf varieties were distinguished by large differences in the relationship between relative increases in flavonoids and absolute increases in phenolic acid esters, indicating possible genetic differences in the control over channeling of phenylpropanoid metabolism. Nonetheless, several varieties stood out as having unusually high UV-stimulated flux into flavonoids as compared to phenolic acid esters. Supplemental UV-A exposure had no effect on polyphenolics. In conclusion, UV-B radiation is useful to manipulate polyphenolics in greenhouse lettuce, both to enhance nutritional value for controlled environment agriculture and to produce foods for nutritional studies. Judicious selection of varieties can result in crops with both good growth and high levels of polyphenolic compounds, even under low light environments during winter greenhouse cultivation.

Changes in the Concentration of Some Secondary Metabolites after Treatment with Ultra-violet Light on St. John's Wort, *Hypericum perforatum*

M.L. Brechner*, L.D. Albright.

Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY
14850, USA

* Email address: mlk38@cornell.edu

The medicinal plant industry is under scrutiny because of studies finding active ingredient concentrations in products do not agree with values claimed on labels. Metabolite concentrations in herbal preparations can differ by a factor of two compared to labeled concentrations. Reasons include plants not being harvested at physiological stages conducive to producing the desired metabolites. *Hypericum perforatum*, St. John's wort, a popular herbal remedy, has this problem. This study evaluated concentration changes of three metabolites of *H. perforatum* after exposure to ultra-violet light while plants were still in a vegetative state. Treatments were started on fifty-five day old plants grown under $400 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PAR for sixteen hours a day. Three ultra-violet light treatments were evaluated: a single dose, a daily dose, and an increasing daily dose. Metabolite concentrations (hyperforin, pseudohypericin and hypericin) were monitored for seven days after each treatment. A temporary three-fold hyperforin increase was observed in the single-dose experiment while hypericin production increased from zero before treatment to a concentration comparable to the beginning stages of flowering (metabolite concentrations were highest in untreated plants when they flowered). These results suggest significant transient metabolite concentration increases in *Hypericum perforatum* can be induced by ultra-violet light exposure. Total metabolite production is the product of concentration and biomass. Information from this study can be useful in optimizing total product harvest in continuous production systems.

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Enhancing Nutritional Value of Fresh Tomato Under Controlled Environments: A Summary of Collaborative Research Effort

Chieri Kubota^{1*} and Cynthia A. Thomson²

¹ Department of Plant Sciences, The University of Arizona, Tucson, AZ, 85721, USA

² Department of Nutritional Sciences, The University of Arizona, Tucson, AZ, 85721, USA

* Email address: ckubota@ag.arizona.edu

Improving consumption of fruits and vegetables has been a major public health effort in many countries. Through a multi-year interdisciplinary collaboration between controlled environment plant production physiology and human nutritional sciences, we evaluated an approach of developing fresh produce containing a greater concentration of health-promoting phytochemicals such as lycopene in tomato, as a means to increasing nutrient/phytochemical intake. Controlled environments provide a unique opportunity to modify the concentrations of selected phytochemicals in fruits and vegetables, yet practical information on produce quality and efficacy of such products consumed in humans is limited. Our research has shown that application of moderate salt stress to tomato (*Solanum lycopersicum* cv. 'Durinta') plants [2.8 ± 0.2 (low or standard EC) or 7.7 ± 1.0 dS m⁻¹ (high EC) measured daily for discharged nutrient solution from the rockwool slab] can enhance lycopene and other antioxidant concentrations in fruits. Fruit quality attributes of tomato monitored for 6-7 month crop cycles (four cycles over 2 years), as a part of an intervention study on consumption of fresh tomatoes showed that the EC of the nutrient solution was the primary factor affecting lycopene concentration either in dry or fresh weight basis, regardless of the other environmental variables inside the greenhouse associated with seasonal changes outside the greenhouse. The high EC treatment induced an overall average of 18% or 20% greater lycopene concentration at a dry or fresh weight basis, respectively. Lycopene was also positively correlated to daytime mean air temperature and daily PAR, respectively (Kroggel et al., 2007). In addition to lycopene, we have also observed a significant increase in carotenes, phenolics and vitamin C concentrations on a fresh weight basis but no significance on dry weight basis. This indicates that these compounds were enhanced as a result of 'concentration effect' due to the limited water flux to the fruit under the high osmotic stress. However, increased lycopene concentration under high EC was considered as an environmental stress driven response as suggested in a separate experiment in our group, testing varied application timings of high EC (Wu and Kubota, 2007). These small increases in antioxidants in fruit did not affect biomarkers of oxidative stress and inflammation tested during the randomized, crossover, controlled feeding study employing forty *healthy* men and women, although the study tomatoes under high EC significantly elevated plasma lycopene levels as compared to baseline carotenoid levels (Thomson et al, 2008).

Photosynthetic Characteristics and Growth of Rice Plants under Red Light with or without Supplemental Blue Light

Ryo Matsuda^{1,2*}, Keiko Ohashi-Kaneko¹, Kazuhiro Fujiwara¹ and Kenji Kurata¹

¹ Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo 113-8657, Japan

² Department of Plant Sciences, The University of Arizona, Tucson, AZ 85721-0036, USA

* Email address: matsuda@email.arizona.edu

Red light-emitting diodes (LEDs) are advantageous as a light source for plant production due to small mass and volume, solid state construction, long life and effective spectrum for photosynthesis (Bula et al. 1991). However, it was observed in several plant species that dry weight of plants grown under red LEDs was significantly smaller than those grown under white fluorescent lamps or metal halide lamps (Brown et al. 1995, Goins et al. 1997, Yorio et al. 2001). Supplemental blue light to red light from red LEDs significantly enhanced dry weight compared to red LEDs alone (Brown et al. 1995, Goins et al. 1997, Yorio et al. 2001) while the physiological and biochemical mechanisms underlying the enhancement has not yet been fully understood. We conducted experiments to better understand of the photosynthetic characteristics and dry matter production under supplemental blue light to red light (Matsuda et al. 2004, Ohashi-Kaneko et al. 2006). Rice (*Oryza sativa* L. cv. Sasanishiki and Nipponbare) plants were grown hydroponically for one month under red light alone (R) or red light with supplemental blue light (RB, red/blue-light PPFD ratio was 4/1) at 300 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Red and blue LEDs (peak wavelength: 650 and 470 nm, respectively) were used as the light source. Net photosynthetic rates measured for a young, fully expanded leaf blade at 240 and 1,600 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD provided by a white halogen lamp were significantly higher in RB plants than in R plants. These higher photosynthetic rates were correlated with higher leaf N content. The amounts of key biochemical components of photosynthesis including ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), cytochrome f, chlorophyll (Chl) and light-harvesting Chl-binding protein of photosystem II (LHCII) were also higher in RB leaves associated with higher leaf N, which contributed to the higher photosynthetic rate.

Dry matter production is influenced not only by single-leaf photosynthesis but by whole-plant characteristics such as leaf area expansion. RB plants showed significantly larger leaf area as well as greater whole-plant dry weight than R plants. Growth analysis indicated that higher net assimilation rate (NAR) contributed to higher relative growth rate (RGR) in RB plants. In 'Sasanishiki', higher leaf area ratio (LAR) also contributed to the higher RGR in RB plants, but not in 'Nipponbare'. RB plants had significantly higher leaf N content per unit leaf area at the whole-plant level than R plants, which was associated with higher Rubisco and Chl contents. This suggested that leaf photosynthesis of a whole plant was promoted in RB plants.

The results showed that supplemental blue light to red light promoted leaf photosynthesis associated with an increase in leaf N. Since an increase in NAR contributed to the higher growth rate under RB conditions, we conclude that the higher photosynthetic rate at the single-leaf level contributed to the higher dry matter production.

Effects of Duration of Temperature Perturbations during Flowering on Tomato Fruit

A.J. Both^{1,2*}, L.S. Logendra², D.L. Ward², T. Gianfagna², H.W. Janes², and T-C. Lee³

¹ Bioresource Engineering Group

² Department of Plant Biology and Pathology

³ Department of Food Science

Rutgers, The State University of New Jersey, New Brunswick, NJ 08901, USA

* Email address: both@aesop.rutgers.edu

Three consecutive growth chamber experiments were conducted to evaluate the effects of temperature perturbations during the flowering stage of tomato plants (*Lycopersicon esculentum* Mill., cv. Laura) grown in a hydroponic production system. The duration of the temperature perturbations varied from two to fourteen days. The plants were top-pruned to allow only a single truss to develop to maturity. Tomato seeds were sown in rockwool plugs and transplanted nine to fourteen days after seeding (DAS) into 150 mm diameter pots filled with perlite. At 44-49 DAS, when 85% of the plants had developed three flowers, the temperature treatments were implemented and maintained for 2, 4, 8, or 14 days. The temperature treatments included the control 23/18°C (day/night, CT), high (HT; 30/25°C), and low (LT; 16/11°C) temperature treatments. The HT and LT temperature treatments were administered in four different reach-in growth chambers (two chambers per treatment). A constant 16-hour photoperiod was maintained during all treatments. Other environmental conditions maintained during the experiments included 70-90% relative humidity, 350-400 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR, and 950-1,050 $\mu\text{mol mol}^{-1} \text{CO}_2$. Prior to and after treatments, plants were kept in a single walk-in growth chamber maintained at day/night temperatures of 23/18°C. During each experiment, all plants were top-irrigated on a two-hour interval during the photoperiod from a single nutrient solution tank that was controlled manually for pH and EC. Tomato plants were harvested at two different stages: breaker (B; when 25% of the fruit exhibited a red/orange tint), and breaker plus six days (B+6). All harvestable fruits were used for mass and quality measurements, including moisture content, soluble sugar content, pH, acidity, Bostwick consistency, color indices, firmness, lycopene and ascorbic acid content. All treatments were terminated no later than 122 DAS. Summarized results of the measurements will be reported.

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Grapevine Physiology in Controlled Environments

Dennis Greer

School of Wine and Food Sciences, Charles Sturt University, Locked Bag 588, Wagga Wagga
NSW 2678, Australia

* Email address: Dgreer@csu.edu.au

Controlled environment chambers are extremely useful to grow plants to evaluate their physiology. To this end, using Thermoline 2.4 x 1.8 m chambers, potted grapevines were grown at constant conditions to evaluate two different projects. The first was to use controlled environments to grow and expose Semillon grape vines and bunches to heat stress. The second project was to reduce the CO₂ concentration to lower photosynthesis and manipulate Chardonnay vines to use carbohydrate reserves between flowering and fruit set.

Semillon vines were grown from budbreak at 25/15°C (day/night) and 700 μmol m⁻² s⁻¹ PAR. At selected stages of bunch development, whole vines were treated to a 40/25°C (day/night) regime to assess the impact of heat on shoot and bunch growth and on berry sugar accumulation. This heat regime had no obvious visual effects on the vines until the stage of early berry ripening. At this stage, some berries showed visual effects but the main effects were that heat stress imposed early in bunch development enhanced ripening compared with control vines.

Chardonnay vines that had previously been grown at different root temperatures in glasshouse conditions were transferred to two controlled environment chambers both at 22/8°C and 500 μmol m⁻² s⁻¹ PAR. In one case, the CO₂ concentration was maintained at ambient (380 μmol mol⁻¹) and in the other, using Sodalime as a CO₂ scrub, the concentration was maintained at 120 μmol mol⁻¹ from flowering to fruit set. The main results of this experiment were that fruit set was markedly delayed in the low CO₂ concentrations consistent with low rates of photosynthesis and indicating current photosynthate was required for fruit set to occur.

In both projects, innovative uses of controlled environments were employed to achieve results that could not be obtained using field-grown vines.

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Hypobarica, Hypoxia and Ethylene Influence Growth and Gas Exchange of Lettuce Plants

Fred T. Davies^{1,*}, Chuanjiu He¹ and Ronald E. Lacey²

¹ Department of Horticultural Sciences and interdisciplinary program of Molecular and Environmental Plant Sciences (MEPS), Texas A&M University, College Station, TX, 77843-2133, USA

² Department of Biological & Agricultural Engineering and MEPS, Texas A&M University, College Station, TX, 77843-2117, USA

* Email Address: f-davies@tamu.edu

There are engineering advantages in growing plants at hypobaric (reduced atmospheric pressure) conditions in biomass production for extraterrestrial base or spaceflight environments. Elevated levels of ethylene occur in enclosed crop production systems and in spaceflight environments leading to adverse plant growth and sterility. The Low Pressure Plant Growth system (LPPG) was designed to grow plants under ambient or hypobaric conditions. Objectives of this research were to characterize the influence of hypobarica on growth, gas exchange and ethylene evolution of lettuce (*Lactuca sativa L.* cv. Buttercrunch). Lettuce plants were grown under variable total gas pressures [25 and 101 kPa (ambient)] at 6, 12 or 21 (normal air) kPa pO₂. While plant growth was comparable between ambient and low pressure lettuce during the 10-day study, growth was lower at 6 kPa pO₂ than 12 or 21 kPa pO₂. There were comparable CO₂ assimilation (net photosynthesis) and lower dark respiration rates in low (25/12 kPa pO₂), but not ambient (101/21 kPa pO₂) pressure plants. The ratio of CO₂ assimilation/dark respiration was higher at low than ambient total pressure, particularly at 6 kPa pO₂ — indicating a greater efficiency of CO₂ assimilation/dark respiration with low pressure plants. Hypobaric plants were more resistant to hypoxic conditions (6 kPa pO₂) that reduced gas exchange and plant growth. There were negative linear correlations between increasing ethylene concentrations in the LPPG with net CO₂ assimilation, dark-period respiration, total leaf area, and relative growth rate (RGR) in both hypobaric and normal total pressure conditions. A decline in CO₂ assimilation and dark-period respiration were observed with both exogenous and endogenous ethylene treatments.

Abstracts: Session C
Non-traditional Applications
in Controlled Environments

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Guidelines for Measuring and Reporting Environmental Parameters in Controlled Environments used for Plant Tissue Culture Experiments

M.P. Fuller ^{1*}, S. Millam ² and L.D. Incoll ³

¹ The Graduate School, University of Plymouth, Devon, PL4 8AA, UK

² Chichester College, Westgate Fields, Chichester, West Sussex, PO19 1SB, UK

³ Faculty of Biological Sciences, Miall Building, University of Leeds, Leeds LS2 9JT. UK

* Email address: mfuller@plymouth.ac.uk

The science of plant tissue culture, though based on principles that have been in place for over 30 years, has been the focus of some recent innovation. Developments in other fields have been rapidly taken up and applied, and offer opportunities for future expansion of the industry. Fundamental to the accurate replication of all plant tissue culture experimentation and the transfer of technology between labs and end users is the need for a set of common guidelines that would be applicable to the reporting of the wide range of experimental conditions used. During 2006 following the successful introduction of the 'Minimum Guidelines' for measuring and reporting environmental parameters in CE facilities, it was mooted that a similar publication would be useful for plant tissue culture facilities. In 2007, an international sub-committee of the three international CE user groups was established to put together proposals for a guidelines pamphlet for plant tissue culture CE's. The sub-committee was led initially by Steve Millam and latterly by Lynton Incoll. By the end of 2007 the pamphlet was finalized and it will be formally launched at the international meeting in Florida in March 2008.

Biopharmaceutical Production under Controlled Environments: Photosynthetic Rate, Soluble Protein Concentration and Growth of Transgenic Tomato Plants Expressing a *Yersinia pestis* F1-V Antigen Fusion Protein

Ryo Matsuda^{1*}, Chieri Kubota¹, Lucrecia M. Alvarez², Jessica Gamboa¹ and Guy A. Cardineau²

¹ Department of Plant Sciences, The University of Arizona, Tucson, AZ 85721-0036, USA

² Center for Infectious Diseases and Vaccinology, The Biodesign Institute, Arizona State University, Tempe, AZ 85287-4501, USA

* Email address: matsuda@email.arizona.edu

Transgenic plants that express an antigen in their edible tissue have great potential for an inexpensive and scalable oral-vaccine production and delivery system. Our ultimate goal is to develop an efficient production system of edible vaccine under controlled environments, using transgenic tomato plants transformed with the *Yersinia pestis fl-v* gene (Alvarez et al. 2006) as a model. *Y. pestis* is the causative agent of plague, and F1-V is a predominant antigen fusion protein. In this study, to characterize growth and development of the *fl-v* transgenic plants under the environmentally-controlled greenhouse conditions, stem length, number of leaves, the light-saturated rate of photosynthesis and total soluble protein (TSP) concentration were examined.

Two transgenic lines, 22.11 and 3D1.2 were evaluated. '22.11' was obtained by transforming tomato (*Lycopersicon esculentum* Mill. cv. TA234) plants with the *Y. pestis fl-v* gene. '3D1.2' was obtained by super-transforming the *fl-v* transgenic plants with the *pI9* gene (Alvarez et al. submitted) encoding the tomato bushy stunt virus P19 protein to suppress the gene silencing mechanism which might lower the *fl-v* expression. We also used 'Durinta' as a reference, which is a commercial greenhouse cultivar. All plants were grown hydroponically using rockwool substrate in an acrylic greenhouse (BSL-2) equipped with pad-and-fan cooling and over-head heating system. PPFD at noon and daily integrated PPFD on sunny days were approximately 1,200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and 25 $\text{mol m}^{-2} \text{d}^{-1}$, respectively. Day and night air temperatures were 20-25°C and 17-20°C, respectively. Stem length and number of leaves were compared among 80-d-old plants. Net photosynthetic rate at 1,500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD and 37 Pa ambient CO₂ partial pressure and TSP concentration per unit fresh weight were measured in young, fully expanded leaves of 71- to 82-d-old plants.

Stem length of '22.11' and '3D1.2' was almost the same but only 60-70% of that of 'Durinta'. Number of leaves was not significantly different among three genotypes. Light-saturated rate of photosynthesis was significantly lower in '22.11' than in 'Durinta' but was not significantly different between '3D1.2' and 'Durinta'. Similarly, TSP concentration was significantly lower in '22.11' but not in '3D1.2' than in 'Durinta'. Fruit yield and TSP concentration in the fruits are under investigation. We are also growing wild type 'TA234' to examine whether those differences between the transgenic plants and 'Durinta' were caused by the transformation, the cultivar difference, or both.

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Plant-Made Pharmaceuticals: Scaling Up Production

J.H. Norikane*

Fraunhofer-CMB, 9 Innovation Way, Suite 200, Newark, DE 19711, USA

* Email address: jnorikane@fraunhofer-cmb.org

One of the promises of biotechnology has been the potential to deliver high value, value-added products using plants. Research and development efforts continue in this area and the laboratory benchtop technology continues to evolve. But, successful approaches would have to grow beyond the benchtop and mature into commercial scale pharmaceutical production. Currently, Fraunhofer – Center for Molecular Biotechnology (CMB) has been granted the opportunity to develop a pilot facility for the accelerated manufacture of pharmaceuticals using plants.

CMB uses *Nicotiana benthamiana* plants to produce vaccines and therapeutics. The plants are grown for five to six weeks, then they are vacuum infiltrated with agrobacteria. The infiltrated plants are then allowed to grow for several additional days before the aerial tissue is harvested and the proteins of interest are extracted. The focus of this presentation will be on the general operation of the system, plant production, and some of the challenges of scale-up.

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Waste-Energy-Leveraged CEA for Year-round Specialty-Crop and Bio-fuel Feedstock Production in Temperate Climates

Cary A. Mitchell^{1*}, Gioia D. Massa¹, Corinne Alexander², Ron Turco³, Jennifer Dennis^{1,2}, Angus Murphy¹, Steve Weller¹, Bruce Bordelon¹, Roberto Lopez¹

¹ Department of Horticulture and Landscape Architecture,

² Department of Agricultural Economics, and

³ Department of Agronomy

Purdue University, West Lafayette, Indiana 47907, USA

* Email address: cmitchel@purdue.edu

Food is trucked an average 2000 miles (3,219 km) from point of production to the U.S. consumer's table. The rising cost of transportation fuel plus competing demands for grain as food/feed vs. feedstock for bio-refineries is driving up the cost of food worldwide, while engine emissions pollute the atmosphere and drive global climate change. Temperature limitations of northern climates preclude year-round crop production in the field, and infrastructural and energy costs prohibit extensive cold-season production of all but the highest-value crops by protected horticulture. However, combining low-cost high-tunnel infrastructure with hot water recirculated between a source of thermal waste and a crop-production site enables affordable year-round production of crops that otherwise are seasonal or impossible to grow in a given locale. High tunnels are transparent Quonset structures in which crops grow directly in the ground. Potential sources of waste heat during cold weather include power plants, factories, landfills, food-process plants, sewage-treatment plants, sawmills, dairies, feedlots, and bio-refineries. Where methane can be generated by anaerobic decomposition of organic waste, potential exists for simultaneous generation of heat, CO₂, and electrical energy to support off-season or year-round crop growth in high tunnels. A project is underway on the campus of Purdue University to harness thermal waste from the University's coal-fired power plant and pump hot water through buried pipes to a high-tunnel site where it will bottom heat the roots of crops growing in the tunnels. Following establishment during the 2008 growing season, the technical and economic feasibility of growing specialty and cellulosic-biomass crops in waste-energy-leveraged high tunnels will be tested throughout the 2008-2009 winter and subsequent 2009 growing season. It is expected that water-use efficiency of contained crops will improve by virtue of humidification, wind protection, and potential to recycle condensate of transpired water vapor to growth beds during cold weather. Compost will be tested as a replacement for commercial fertilizer, as well as a source of CO₂ for photosynthesis during periods of tunnel closure. Vegetables to be tested for year-round production include tomato, lettuce, cabbage, arugula (rocket), basil, and onion; small fruits include strawberry, blueberry, and raspberry; ornamentals include plugs of bedding plants and non-seasonal ornamentals such as orchids and tropical foliage plants. A number of prairie grasses and legumes are being evaluated for continuous production of low-lignin, vegetative biomass. Creating conditions for "off-season" production of crops, including artificial pollination and photoperiod extension, are emphasized. Generating electricity for supplemental winter lighting where waste CH₄ is available will be evaluated.

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Commercial Aeroponic Farming of Baby Leafy Greens

Edward D. Harwood*

GreatVeggies[®], LLC, 1114 Hanshaw Rd., Ithaca, NY, USA 14850

* Email address: EDH@GreatVeggies.com

GreatVeggies[®], LLC has a patent pending for a commercial aeroponic system of farming baby leafy greens. The growing medium is a commercially available polyester cloth formed into a horizontal conveyer allowing automation of the entire process in a controlled environment. The methods to seed, germinate, and produce at commercially viable yields and costs have been tested and salads were merchandised for two years. Mean yield from use of high pressure sodium (HPS) and metal halide luminaires is not significantly different and practical considerations favor HPS. The pH has a significant impact on nutrient contamination by algae as measured by nutrient solution turbidity. Both pH and variety selection have significant impacts on baby mustards, especially subjective organoleptic evaluation of *Eruca sativa*. A pH of $5.5 \pm .3$ is optimal. Commercial results and future research opportunities will also be presented.

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Climate Change and Controlled Environments

Martyn Stenning*

School of Life Sciences, University of Sussex, Brighton BN1 9QG, UK

* Email address: m.j.stenning@sussex.ac.uk

The world's climate is changing faster than at any time in known history, and anthropogenic factors may be playing a significant part in these changes (IPCC 2007). Global temperature has risen by 0.76 degrees Celsius in the last 100 years and is expected to rise by up to 4 degrees during this century. The 11 warmest years on record have been during the last 12. These changes are affecting the ecology of the world. There are physical changes such as ice melt, sea level rise, increased storminess and flooding. There are also biological changes such as species distribution and range expansion and contraction. Examples of range expansion include birds such as the European blackcap, crops such as bananas and diseases such as blue tongue, whereas the range of polar bears is contracting.

There is an increasing requirement for scientists to test hypotheses about the effects of climate change on the ecology and physiology of plants and animals using controlled environment (CE) chambers. Examples include work at the Ecotron at Imperial College, Silwood Park, UK by Lawton, Hartley and colleagues. This facility consists of 16 physically and electronically integrated CE chambers 2 m x 2 m floor area. It allows ecologists to construct and manipulate replicate miniature terrestrial ecosystems for long periods under strict control of temperature variation, light quality and duration, humidity, rainfall etc. For example; the living community model can sustain around 30 species of plants and metazoans, in four trophic levels (plants, herbivores, parasitoids, and detritivores) able to interact over several generations. The impacts of elevated carbon dioxide on these communities can be studied. There has also been innovative work on model tree and moth systems using solar domes at the Institute of Terrestrial Ecology, Wales, by Buse and colleagues. It is evident that increasing temperatures will lead to range shift by many crop plants. However, many of these plants may depend on day-length (not temperature) as a cue for flowering and hence fruit production. Using CE technology, it should be possible to resolve the relative contributions of photoperiod and temperature to production of current crops at higher latitudes. Others are investigating disrupted relationships between plants, herbivores and their predators (again by Buse and colleagues), even investigating bird breeding times (by Visser at the Netherlands Centre for Terrestrial Ecology).

It follows that all 6.6 billion people in the world are required to reduce their carbon footprint. CE users are no exception. We as a group must seek ways of improving the energy efficiency of our facilities. This can be done by investigating novel light sources such as light emitting diodes, improving the insulation of CE chambers, installing the most energy efficient refrigeration units, and maybe even incorporating energy capture mechanisms that utilise waste heat to feed back into the unit. Controlled environment technologists should be at the forefront of tackling problems surrounding anthropogenic climate change.

Abstracts: Session D
Novel Instrumentation, Sensors,
and/or Analysis Approaches

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Estimating Carbon Use Efficiency, Growth Respiration, and Maintenance Respiration from Canopy Gas Exchange Measurements

Marc W. van Iersel*

Department of Horticulture, The University of Georgia, 1111 Miller Plant Science Building,
Athens, GA 30602, USA

* Email address: mvanier@uga.edu

Controlled environments provide unique opportunities to study plant growth and development. Since photosynthesis drives almost all dry matter accumulation of plants, photosynthesis measurements can be a valuable tool in understanding how environmental or genetic factors affect plant growth. However, leaf photosynthesis measurements commonly are poorly correlated with plant growth. Canopy or whole-plant photosynthesis and respiration measurements, on the other hand, can provide accurate measurements of growth. In addition to studying plant growth, canopy gas exchange measurements can be used to look at important physiological processes controlling who plants utilize photosynthates. Carbon use efficiency, growth respiration, and maintenance respiration can be estimated from continuous gas exchange measurement. This is done by initially using gas exchange measurements to calculate daily carbon gain (DCG, the net amount of C fixed in a 24 hour period, and a direct indicator of growth rate). Integrating DCG results in estimates of cumulative carbon gain (CCG, the net amount of C fixed during the entire measurement period, and a direct indicator of plant size). These data can be used to calculate specific respiration (R_{spc}) and relative growth rate (RGR), which allows the growth (g_r) and maintenance respiration (m_r) coefficients to be estimated from $R_{spc} = m_r + g_r \times RGR$. Subsequently, growth respiration can be estimated as $g_r \times$ growth rate, while maintenance respiration equals $m_r \times$ plant mass. Carbon use efficiency (CUE, DCG divided by gross amount of C fixed in 24 hours) is related to m_r and g_r : $1 / CUE = 1 + g_r + (m_r / RGR)$. Since RGR normally decreases over time, CUE also decreases over time, unless there are changes in m_r or g_r that can offset the decrease in RGR.

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Hands-Off Sensors: Applications of Spectral Devices to Controlled Environment Agriculture

Glen L. Ritchie^{1,*}, Jonathan Frantz², Craig Bednarz³, and Bruce Bugbee⁴

¹ Dept. of Crop and Soil Sciences, University of Georgia, Tifton, GA 31793, USA

² Application Technology Research Unit, Greenhouse Production Research Group, USDA-ARS, Toledo, OH 43606, USA

³ Plant and Soil Science, Texas Tech University, Lubbock, TX 79609-3121, USA

⁴ Crop Physiology Laboratory, Dept. of Plants Soils, Biometeorology, Utah State University Logan, UT 84322-4820, USA

* Email address: gritchie@uga.edu

Although controlled environment research allows closer supervision of crop growth than field experiments, many of the applications developed to increase efficiency in field research are useful for controlled environments as well. Examples include remote sensing techniques, such as spectral imaging, photography, and thermal sensing. However, some critical issues must be addressed in the conversion of these instruments to controlled environments, particularly under electric lighting. Methods of camera and spectrometer-based imaging under electric lights are discussed herein.

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Evaluation of Two New Net Radiometers

J. Mark Blonquist Jr.^{1,*}, Bertrand Tanner², and Bruce Bugbee³

¹ Apogee Instruments Inc., 721 W 1800 N, Logan, UT, USA 84321

² Campbell Scientific Inc., Logan, UT, USA 84321

³ Crop Physiology Laboratory, Dept. of Plants Soils, Biometeorology, Utah State University
Logan, UT, USA 84322-4820

* Email address: mark@apogeeinstruments.com

Net radiation is a key component to the surface energy balance, but it is difficult and expensive to measure accurately. Two new net radiometer models (Hukseflux NR01 and Kipp & Zonen CNR 2) have been released in the past year. We evaluated and compared these models to each other, a Kipp and Zonen model CNR 1 net radiometer, and to two less expensive, older model net radiometers (Kipp & Zonen NR-Lite and REBS Q*7.1). Hourly averages and daily totals (over the course of the study; 33 days) from three replicate sensors of the two new net radiometers compared quite well to the CNR 1 radiometer. The difference was generally less than +/- 5 %. Three replicates of the two older model net radiometers did not agree as well with the newer models, particularly at night, with differences generally less than +/- 10 % during the day and +/- 20 % at night. Our data matched what others (Cobos and Baker, 2003; Brotzge and Duchon, 2000) have shown for these older radiometers. Our findings indicate that accuracy increases with increasing cost. Accurate net radiation measurements depend on proper placement of the sensor, proper leveling, and routine maintenance to keep the sensing surfaces clean.

Brotzge, J.A. and C.E. Duchon. 2000. A field comparison among a domeless net radiometer, two four-component net radiometers, and a domed net radiometer. *J. Atmos. Ocean. Technol.* 17: 1569-1582.

Cobos, D.R. and J.M. Baker. 2003. Evaluation and modification of a domeless net radiometer. *Agron. J.* 95: 177-183

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Effect of Atmospheric Pressure on Wet Bulb Depression

Raymond M. Wheeler^{*1}, Michael A. Stasiak², Jamie Lawson², Cara Ann P. Wehkamp², and Michael A. Dixon²

¹ NASA Biological Sciences Office, Kennedy Space Center, FL, 32899, USA

² Dept. of Environmental Biology, University of Guelph, Guelph, ON, N1G 2W1, CA

* Email address: raymond.m.wheeler@nasa.gov

Space exploration missions that might include plants for life support will likely operate at pressures less than 1 atm (~100 kPa). For example, NASA's planned Lunar return mission would use a cabin pressure of 65 kPa to save on gas leakage and structural mass. Thus understanding environmental monitoring, control, and plant physiological processes at reduced pressures will be required to assure mission success. Wet / dry bulb psychrometers are useful devices for monitoring humidity and provide insights into cooling phenomena for wet, evaporating surfaces. To study the effects of pressure on psychrometers we conducted a series of tests in a hypobaric chamber at University of Guelph. Chamber RH monitoring and control were based on capacitance type devices, which previous testing and manufacturer's specifications have shown to be unaffected by pressure. Test data were gathered using an Enercorp psychrometer with matched platinum RTD temperature probes positioned side-by-side with a dew point (chilled mirror) device and two capacitance sensors. The chamber was kept dark and measurements were taken at three RHs (30, 50, and 70%) and four pressures (10, 25, 50, and ~100 kPa). Results showed an increase in wet bulb depression (i.e., a drop in wet bulb temperature) for a given RH as the pressure decreased, with the largest changes occurring as pressure dropped from 25 and 10 kPa. At a dry bulb temperature of 25°C, the normal wet bulb temperature at 30% RH and 100 kPa is ~15°C, but this dropped to ~8°C at 10 kPa. These observations are consistent with previous reports of increased evaporation rates at reduced pressure and match recently published psychrometric models for different pressures. The results suggest that psychrometers would need direct calibration at the target pressures or that pressure corrected charts would be required. Moreover, for a given vapor pressure deficit, any moist surfaces, including transpiring plant leaves, will be cooler at lower pressures due to the increased evaporation rates.

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Large High-Output LED Arrays for Plant Growth

Robert C. Morrow* and C. Michael Bourget

ORBITEC, 1212 Fourier Drive, Madison, WI 53711, USA

* Email address: morrowr@orbitec.com

A large LED array composed of four, 15 square-foot grids was fabricated as a lighting source for a walk-in plant growth room, part of a suite of three rooms that will utilize solid state lighting. This LED array is composed of 80% red devices (640nm) and 20% blue devices (460nm). The maximum PAR output of the LED array is in excess of $1700 \mu\text{mol m}^{-2} \text{s}^{-1}$. The light system turns on/off instantly and is dimmable between 0 and maximum output. Digital control is provided for light level, red/blue ratio, and photoperiod. It is divided into 12 different control zones in which light levels and red/blue ratios can be controlled independently. Each LED array is liquid cooled to keep it near room temperature. The low array temperature and the low radiant output of LEDs allows placement of the light system adjacent to plant tissue. At $600 \mu\text{mol m}^{-2} \text{s}^{-1}$, leaf temperature was elevated 0.6°C at 3 cm and 0.2°C at 10cm. Being in an array configuration and capable of operating adjacent to plant tissue reduces the power required for a specific level of plant lighting. Preliminary comparisons between this LED lighting system and a HID system in a similar size chamber indicates the LED system uses at least 35% less power for an equivalent light output. Because the current red/blue array makes most plants look black or yellowish, next generation LED arrays are being modified to provide a balanced RGB mode that can be triggered for photography or to provide a more “normal” environment for short periods of time when personnel are working with the plants. To date, this array has been used primarily to grow tobacco.

Probing the Responses of Plants by Chlorophyll Fluorescence under Controlled Environments

Hazem M. Kalaji*

Department of Plant Physiology, Faculty of Agriculture and Biology, Warsaw University of Life Sciences SGGW, Nowoursynowska 159, 02-776 Warsaw, Poland.

* Email address: hazem@kalaji.pl

Substantial progress in agriculture and biological sciences has been achieved due to developments in computerized and portable lightweight instruments. They allow prompt, non-destructive and reliable analysis of the physiological state of plants. **Chlorophyll fluorescence** helps to detect the effects of favorable and un-favorable environmental conditions on growth and enables monitoring of any stress impact on plants. As the goal of controlled environment managers is to find what environmental conditions fit to experimenters needs, chlorophyll fluorescence measurements would be ideal to check the influence of these conditions on plant development. Fluorescence techniques have many advantages over other approaches (e.g. gas exchange measurements) under microgravity conditions, especially related to the investigation of plant growth and development and plant health testing, in the Space Shuttle and International Space Station. *In vivo* fluorescence measurements are highly recommended for testing photosynthetic efficiencies of plants grown in Biomass Production System (BPS) and Hydroponic Production Unit (HPU), where limited time and space are important factors. **Fast chlorophyll fluorescence OJIP rise-kinetics** (with μs time resolution) are widely used today and analyzed accordingly by the so called **JIP-Test**. This test, based on the recording of fast (1 sec duration) direct fluorescence kinetics, has the following advantages compared to modulated fluorescence approaches: early diagnosis of stress effects and stress resistance; screening of leaves and any green plant part; rapid – less than a few seconds are needed; can be applied *in vivo*; not expensive; can be carried out anywhere - in the field, under water, the greenhouse or sterile tissue cultures and suspensions on samples as small as 2 mm^2 ; non-invasive; low energy consumption; can be fully automated with a remote control; data can be treated by a solid theoretical concept, based on the energy flux in bio-membranes. This type of analysis provides a deeper understanding of the **structure-function** relationships concerning the biophysical and physiological properties of photosynthetic systems.

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Automatic and 3-dimensional Phenotyping of Complete Plants in Greenhouses

Dr. Joerg Vandenhirtz^{*}, Matthias Eberius, Dirk Vandenhirtz, Hans Georg Luigs, Georg Kreyerhoff, Ulf Bongler, Markus Radermacher, Hauke Lasinger, Ralph Schunk

LemnaTec, 18 Schumanstr. Wuerselen 52146, Germany

Tel.: 01149 2405 4126-12, Fax: 01149 2405 4126-26, <http://www.lemnatec.com>

* Email address: joerg.vandenhirtz@lemnatec.de

At the 2008 International Meeting on Controlled Environment Agriculture LemnaTec presents the Scanalyzer 3-D, a fully integrated automatic high-throughput phenotyping platform for complete plants like rice, corn, arabidopsis, poplars, barley or wheat etc. in greenhouses, combining information from all 3 dimensions.

Due to the waterproof design of the conveyor belt the system is able to move the plants around in the greenhouse in predefined or random patterns to standardize the growth conditions of the plants by preventing plants from staying in hot spots. The system is fully automated and can run 24 hours per day, 7 days a week. Plants are identified by RFID tags and can be watered and weighed automatically. Additional spraying stations are able to apply individual doses of plant protection agents or fertilizers per plant. The amount of water and plant protection agents can be automatically controlled by the results of the Scanalyzer imaging stations.

The Scanalyzer imaging stations are able to 3-dimensionally screen up to 4000 plants per day efficiently and precisely. With the Scanalyzer 3-D a wide range of visual evaluation parameters of plants can be sampled for a complete and reproducible and non-destructive analysis free of subjective influences (e.g. leaf area, leaf color, leaf length, shape parameters etc.). NIR (e.g. water content), fluorescence or temperature measurements are also possible and deliver a comprehensive growth and effect measurement. The produced data allows identification of statistically relevant phenotype effects by biotic or abiotic factors taking natural variability into consideration due to high numbers of plants to be analysed. Using transparent root columns, complementary non-destructive information on root growth can be quantified during the whole growth phase in VIS (root growth and density) and NIR (Water extraction efficiency) spectral ranges.

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Uniformity in Soil Plant Atmosphere Chambers

David H. Fleisher^{*}, Dennis J. Timlin, and V.R. Reddy

Crop Systems and Global Change, USDA-ARS-PSI, 10300 Baltimore Avenue, Beltsville, MD, 20705, USA

* Email address: david.fleisher@ars.usda.gov

Growth chambers provide precisely controlled environments in which to grow plants and evaluate the effects of one or more controllable parameters on plant responses. Because of this precise control, it is arguable that less plant replication is required in growth chamber versus field studies. However, when evaluating treatment effects in studies using multiple growth chambers, lack of uniformity of the controlled conditions between and within each chamber can bias experimental results if not accounted for. SPAR (soil-plant-atmosphere research) growth chambers are semi-closed outdoor naturally sunlit growth chambers that control temperature, humidity, and carbon dioxide concentration. SPAR chambers continuously monitor and record environmental conditions and whole plant photosynthesis at 5 minute, and evapotranspiration at 15 minute, intervals. Spring wheat (*Triticum aestivum* L.cv. USU-Apogee) was grown in 12 SPAR chambers in the summer of 2006 at USDA-ARS facilities in Beltsville, MD USA to evaluate variability between, and within, the chambers. Chambers were maintained at the same environmental conditions (e.g. 16 h 23/18°C day/night thermoperiod, 740 $\mu\text{mol mol}^{-1}$ daytime atmospheric CO₂ concentration) over the 70 day experiment. Periodic measurements of leaf and tiller number, stem length, organ dry weights as well as whole-season environmental and gas exchange data were used to evaluate the uniformity of the chambers.

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Real-time Measurement of Whole Plant Transpiration and Stomatal Conductance Using Electronic Balances and Infrared Sensors

Bruce Bugbee* and Julie Chard

Crop Physiology Laboratory, Dept. of Plants Soils, Biometeorology, Utah State University,
Logan, UT, 84322-4820, USA

* Email Address: bruce.bugbee@usu.edu

Recent advances in data acquisition have facilitated the use of electronic balances to make continuous measurements of whole plant mass in containers. Measurement of leaf temperature allows the calculation of stomatal conductance. Here we present the results of several studies with plants grown in containers and continuously weighed on balances. This technique allowed measurement of transpiration over 10 minute intervals. It also facilitated automated watering to maintain constant root zone water potential. Constant low water potentials were imposed by reducing the set point of the balances. Stomatal conductance was calculated by the ratio of transpiration to the driving gradient for transpiration, measured from the leaf to air temperature gradient.

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Monitoring and Controlling Substrate Water Content in Controlled Environments

Marc W. van Iersel*

Department of Horticulture, The University of Georgia, 1111 Miller Plant Science Building,
Athens, GA 30602, USA

* Email address: mvanier@uga.edu

Controlled environments provide control of such environmental conditions as light, temperature, and relative humidity. Substrate water content is often ignored or poorly watered during controlled environment studies. In extreme cases, a lack of water in the substrate can result in wilting and leaf abscission, while a less severe lack of water may result in partial stomatal closure and a reduction in leaf photosynthesis. Cell and leaf elongation are extremely sensitive to plant water status and can be reduced at very mild water deficits. To prevent such drought responses from affecting experiments, accurate monitoring of substrate water status is necessary. In recent years, a variety of new soil moisture probes has become available, and the suitability of these probes for controlled environment research will be discussed. Factors that need to be taken into consideration while using such soil water sensors include temperature sensitivity, EC sensitivity, and the need for substrate specific calibrations. Other benefits of using soil moisture sensors include the ability of remote monitoring as well as automation of irrigation based on plant water use. Automation can be achieved with commercially-available controllers or dataloggers with control capability.

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Abstracts: Session E
Design and Development of New Facilities

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Engineering in Sustainability and Innovative Development of Controlled Environments: a UK Perspective on Refrigerants, Achieving Efficient Systems and Energy Management

George M. Waimann*

Rothamsted Research, Harpenden, Hertfordshire, AL5 2JQ, UK

* Email address: george.waimann@bbsrc.ac.uk

Introduction: When designing a new controlled environment project a number of factors should always be considered first e.g. do we really need to use a CE facility and do we need to design it this way? Having agreed that it is the only way forward then all options should be explored. Too often an obvious route is taken (usually because it's easier, proven to work and is reliable) which is not very sustainable. We have to move beyond this attitude if we are to develop truly sustainable systems i.e. systems that we will still be operating in 20 years time and beyond.

Refrigerants: Refrigerants are now a major issue due to their Global Warming Potential (GWP) and Total Equivalent Warming Impact (TEWI). The future of 'F' Gases is uncertain, especially in Europe, and natural refrigerants such as CO₂, Ammonia and Hydrocarbons will increasingly play an important role in new systems as they have much lower GWP and TEWI values. Aspects of safety can now be managed for potentially toxic and flammable gases.

Technologies: To be explored are refrigeration compressors, fans, pumps and inverter (Variable Speed Drives) technologies which are moving fast, as are system designs and control systems. New compressor technologies will become available in the future, Stirling cycle refrigeration has possibilities in the future, however no commercial products are readily available at this time. Screw compressors are continually developed to be more economical. Magnetic bearing turbine compressors are being produced and are being further developed. Reciprocating compressors are having a resurgence due to their suitability for CO₂, the expected increasing use of CO₂ as a refrigerant being a driver.

System management and efficient use of energy: Also to be considered are: mechanical and passive free cooling, adiabatic cooling for both space cooling and cooling towers, thermal storage systems, ground source systems and absorption cooling generated by utilizing waste heat. Key to achieving efficiency is applying modern programmable control systems such as Building Management control Systems (BMS), these control systems allow the efficient control of CE systems and the energy management via the data acquired from the systems.

Financial management: The way that we design and put systems together is critical, integration is of paramount importance if we are to achieve sustainable systems that are indeed sustainable in terms of life cycle costs. To be considered are installation costs, energy usage through the system's life and are the system's operational and maintenance costs realistic during the system's life; maintenance costs are often overlooked.

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Description, Operation and Production of the South Pole Food Growth Chamber (SPFGC)

R. L. Patterson^{*}, Gene A. Giacomelli, Phil Sadler

The University of Arizona, Controlled Environment Agriculture Center, 1951 E Roger Road,
Tucson, AZ 85719, USA

* Email address: lane12345@rocketmail.com

The SPFGC is an automated hydroponic growth chamber located inside the Amundsen-Scott South Pole station. Data collected from Jan – Oct 2006 was used to document the measured material and energy consumption rates and biomass production (crop-schedule, index, crop areas and crop types) of the SPFGC. The chamber's primary control and system elements are described. Consumed materials measured were hydroponic chemicals, water, and carbon dioxide. Power consumed by the chamber in the form of electricity for the operation of pumps, lamps, actuators, sensors and environment control was measured and radiant energy emitted by the lamps calculated. Thermal energy for melt-water used by the SPFGC, and the heat extracted by the chamber's water-cooled lamp system was calculated. The primary automated control systems described are the chamber's sensors, nutrient delivery, carbon dioxide enrichment and lighting. The purpose of the chamber is to produce fresh vegetables, bright light and high humidity for station personnel and the objective of this paper is to serve as its initial technical reference and document a baseline of normal control, production and consumption by the SPFGC. From these findings a bioregenerative life support system model (SPFGC/BLSS model) was developed that acts as an empirical comparison to current accepted Advanced Life Support (ALS) models and demonstrates material, and energy consumption versus oxygen and food production via a polyculture cropping method under controlled environment.

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New Bioscience Complex at University of Maryland

Gerald F. Deitzer*

Maryland Agricultural Experiment Station, University of Maryland, College Park, MD 20742, USA

* Email address: gfd@umd.edu

The University of Maryland completed construction of their new Biosciences building (<http://chemlife.umd.edu/biosciencebuilding/>), which opened on September 18, 2007. A new controlled environment facility was incorporated as part of 68,000 square feet (6,300 m²) of flexible laboratory space. The 33 faculty-led research groups housed in the building are working on the forefront of research in three critical areas: neuroscience, genomics/proteomics and pathogenesis. The building is equipped with two Biosafety Level-3 laboratories, which enable researchers to safely work with pathogens, the microorganisms that cause disease. Other resources include a 475-seat lecture hall and eight conference rooms for teaching and professional meetings. Each of the four levels in the building is dedicated to a different area of research: plant molecular and cell biology on the ground floor; neuroscience on the first floor; genomics on the second floor; and host-pathogen interactions on the third floor. The controlled environment facility contains eight Percival Model AR-100L and four Percival Model AR-36L chambers. Both of these types of Percival units have the latest "Advanced Intellus Touch-Screen" Controllers. In addition, two Percival Model AR-66L chambers were moved from the previous facility belonging to Cell Biology and Molecular Genetics. These two units were purchased in 2006 and have the more generic "Standard Intellus" Controller. Three of the AR 36 Conviron growth chambers will also be moved into this new facility.

All of the remaining problems not taken care of when the new greenhouse was completed four years ago have been resolved. Fume hoods in the laboratories, the automated irrigation system (but still not the fertigation system), hot water loops, water supply to outside ground beds and shade houses are all now operational. An attempt to place all of the electrically controlled systems in the greenhouse on an emergency backup power generator has been scrapped due to cost. However, all of the essential systems, including ventilation, are now on backup power. In addition, we have determined that all 35 of the growth chambers and eight of the controlled environment rooms in the Plant Sciences building can be added to an existing generator.

No new facilities or equipment are planned for the next year. However, all of our extensive controlled environment facility that is being managed by Shaun Faulkner, is functioning very well. We do plan to install quantum sensors in all of the chambers in both Plant Sciences and the Greenhouse in the near future.

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The Biotron and Guelph's Plant Productivity Module

E.D. Leonardos¹, M.J. Iqbal¹, A. Singh², N. Hüner² and B. Grodzinski^{1*}

¹ Department of Plant Agriculture, University of Guelph, Ontario, Canada:

² Biotron, University of Western Ontario, Ontario, Canada.

* Email address: bgrodzin@uoguelph.ca

The Biotron is an interdisciplinary, international experimental climate change research facility located on the campus of the University of Western Ontario (Western) and dedicated to the elucidation of the impact of climate change and extreme environments on plants, insects and micro-organisms. Experimental climate change research represents an important new research approach whereby researchers can quantify the plasticity of organisms to adapt to new environments. Thus, this research approach not only provides important insights into the impact of climate change on biodiversity and ecosystem health but also identifies possible ways to maintain food and energy supplies under future, sub-optimal climate conditions. No other facility in Canada, exhibits the scale, flexibility and interdisciplinary scope encompassed by the Biotron which integrates research in ecology, basic environmental biology and earth sciences with medicine and agriculture. The principal, collaborating institutions for this initiative include Western, the University of Guelph and Agriculture and Agri-Food Canada, London.

The Biotron's major building and facilities including new climate control biomes are situated on the main campus of University of Western Ontario. However, a major part of the Plant Productivity Module is located at the University of Guelph. The research conducted in this module concerns the elucidation of the mechanisms underlying plant plasticity with respect to acclimation to and biomass production under environmental stress conditions typically associated with climate change such as increased CO₂ concentrations, broad temperature fluctuations, drought, and poor nutrition. The knowledge obtained can be used not only to develop crops with enhanced capacity to adjust to and resist the stress effects of climate change but also to develop crops that exhibit the potential for higher yields under stress conditions.

The Guelph facility includes custom-designed, computer controlled environment growth chambers capable of providing temperatures ranging from - 20 to + 40°C, irradiance from complete darkness to 80% full sunlight, and CO₂ from sub-ambient to 5000 µmol m⁻³. Unique features of these growth chambers are the incorporation of leaf and whole plant gas exchange systems, designed and developed by the Guelph group, which enable the continuous and non-invasive measurement of photosynthesis, growth and biomass production. In addition, radio/mass isotope labeling capabilities permit studying carbon metabolism/partitioning. Contiguous with this facility is a central laboratory for biochemical analyses using instrumentation for separation and quantification of metabolites. The system design and development will be discussed.

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Containment Level 3 Facility for Growing Genetically Modified Plants and Plant Pathogens.

Julian Franklin* and Ray Taberer

Rothamsted Research, Harpenden, Herts. AL5 2JQ, UK.

* Email address: julian.franklin@bbsrc.ac.uk

A new facility at Rothamsted Research for growing genetically modified plants and pathogens is described from concept to final testing and licensing.

The development of the new facility was proscribed by the organisms to be studied and the regulatory framework operating within the UK. The process of eliciting the initial design parameters from the research teams involved and the challenge of working with the various UK agencies that are responsible for genetically modified organisms and plant health matters is discussed.

Given the various design constraints, the solution, including the budgetary constraints is described. The facility consists of a large room housing four growth rooms and two supporting laboratories. These are all negatively pressured having been sealed and been tested for air tightness. Access is controlled via a lobby with air shower, with waste disposal via a double ended autoclave suite. Make up air and extracted air is filtered according to the risk. Currently a G7 filter is employed. The facility can be shutdown remotely for fumigation and safeguards (automatic shutoff) exist in the event of power fail or fire.

Effluent is treated via an UV treatment plant contained within the facility. Safeguards exist in the event of equipment failure to ensure a valid kill is produced as well as to prevent flooding.

The plant growth rooms are negatively pressured with respect to the containment room and exhaust to outside via a HEPA filter. Two of the rooms are multi tiered each providing up to 24 square metres of shelf space. The remaining two rooms are fitted with adjustable height trolleys with each room having a growing area of 9.75 square metres. PAR of up to 400 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at trolley/shelf level are achievable. The rooms are accessed by an individual lobby area for each room.

The final testing and validation regime required to ensure compliance with the various regulatory authorities is described

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The Australian Plant Phenomics Facility

Tony Agostino*

CSIRO Plant Industry, PO Box 1600, Canberra, ACT, 2601, Australia

* Email address: tony.agostino@csiro.au

In 2007, the Australian Government, in collaboration with a number of research institutions, provided funding for what will be one of the world's first dedicated plant phenomics facilities.

The Australian Plant Phenomics facility will be built as a two node facility (Canberra and Adelaide) and will enable the development of capabilities and facilities to provide a comprehensive, continuous analysis of plant growth and performance using modern technologies.

The facility will provide:-

- sophisticated controlled environments for growing plants across a range of climatic conditions
- glasshouse automation technologies to study large populations of plants rapidly and effectively
- leading edge digital imaging technologies and sophisticated software to measure, in real-time, plant characteristics and their performance
- the capacity to “scale up” plant performance measurements from glasshouse to the field
- a national focus for scientists to collaborate on key agricultural and biological research problems
- a unique and integrated system for the rapid capture of genetic resource information and its shared use across Australian and international agriculture

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Abstracts: Session F
Reliability and Quality Control for CEA Facilities

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Quality Standards in CE; Implications for the User

L. R. Benjamin

Rothamsted Research, West Common, Harpenden, Hertfordshire, UK, AL5 2JQ

* Email address: laurence.benjamin@bbsrc.ac.uk

There are few quality standards set specifically for users of controlled environments. Notable publications are those published by the International Committee for Controlled Environment Guidelines (2004) and Sager *et al.* (2005). These specify which environmental factors should be measured, and the accuracy and precision of such measurements. This review considers the effort and cost of meeting these standards as well as the likely implications for those facilities that do not meet these standards. Such implications are assessed by sensitivity analysis of various biological processes using published mechanistic models.

Three models have been selected that represent development and growth for a range of crop species. The model of Wurr *et al.* (1995) for time to vernalization in calabrese, Adams *et al.* (1997) for time to flowering in pansy and Kropff and van Laar (1993) for photosynthesis and dry matter increment in wheat were used along with their parameter values that have been published for these species. Simulations ran the models around the temperature range that the species are likely to encounter in nature. The Kropff and van Laar (1993) photosynthesis model had parameters for day length, light intensity and proportion of diffuse light typical for controlled environments.

The simulations revealed that deviations of only 2°C from a target temperature level can have a 25% effect on the rates of development. In some circumstances, the Wurr *et al.* (1995) model predicted that the duration of vernalization required was extended from 35 to 55 days. The Kropff and van Laar (1993) growth and photosynthesis model gave a 7 - 9 percent variation in yield after 50 days growth at 800 $\mu\text{mol m}^{-2} \text{s}^{-1}$ irradiance when the target temperature varied by only 2°C. This could extend the duration of experiments by around five days.

Hence, over a year when 7 fifty day experiments were planned, the cabinets would be working for 385 rather than for 365 days. Not only would this be an overrun of the schedule of a year, but there would be an additional cost of \$700, assuming a running cost of \$20 per day.

These results will be discussed in relation to the needs and costs for replication, the cost of sourcing and maintaining calibrated sensors and the importance of reproducibility of experiments

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Performance Verification of New Research Greenhouse Facilities

Alex Turkewitsch^{1*}, M.A.Sc., P.Eng., David Brault², M.Sc., M.G.P., ing., Bruno Faucher³, M.Sc., M.Env., ing.

¹ Greenhouse Engineering, 86 Glenview Avenue, Toronto, ON, Canada, M4R 1P8

² Greenhouse Engineering, 450 Valade Street, Winnipeg, MB, Canada, R2H 2G3

³ Envirosult, 570 Notre-Dame Est, Suite 301-B, Thetford Mines, QC, Canada, G6G 2S4

* Email address: alex@greenhouseengineering.com

A new research greenhouse project, designed by Greenhouse Engineering, has recently been commissioned at Laval University in Québec, Canada. The new facility consists of three separate greenhouse blocks, two of which will be used for containment to BL2-P and one of which to BL2-P+. We developed new methods of comparing the measured air exchange rates (infiltration) with the performance standards that were part of the project specifications. We tested the air exchange rates using a CO₂ decay method, under varying wind and temperature conditions. A method of normalizing the results is presented, along with a theoretical framework and the experimental results. This new approach should make performance testing of new facilities more practical and should allow for regular maintenance testing of existing facilities. With an appropriate CO₂ injection, monitoring and control system, this testing can also be automated. We review the air-exchange tests performed at the three new research greenhouse blocks at Laval University and the other performance tests that we undertook during the commissioning process.

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Energy Efficiency and Green Technologies in Environmental Chambers

Daniel Kiekhaefer* and Henry Imberti

Percival Scientific Inc., Perry, IA 50220, USA (515) 465-9363

* Email address: dkiekhaefer@percival-scientific.com

Percival Scientific is committed to energy efficiency and green technologies across our entire product line. Percival Scientific strives to incorporate new green or energy efficient technologies into our designs as they become viable. As an example, a comparison of yearly water and energy savings using environmentally friendly technologies was made between the 2007 Percival Model PGC-10 and its predecessor. In this example we will outline the differences in the following technologies: high efficiency lighting (Integration of T5 linear and compact fluorescent bulbs and patent pending solution for optimization of lamp output), ultrasonic humidification systems, foam in place chamber construction, high efficiency fans and blowers, electronic ballasts, refrigeration systems, etc. Percival Scientific's lamp bank patent application demonstrates a strong commitment to adapt new energy efficient technologies into our products without sacrificing performance.

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Supervisory Control – Implications for Environmental Control Systems

Alec Mackenzie*

Argus Control Systems Ltd., 1281 Johnston Road, White Rock, British Columbia, Canada, V4B 3Y9

* Email address: alec@arguscontrols.com

Accepting control instructions from other computer programs presents a number of issues for integrated equipment control. This presentation will discuss the challenges and opportunities when integrating environmental control systems with other intelligent entities.

Computerized greenhouse environmental control systems were developed to coordinate and integrate the activities of a wide range of equipment systems that were otherwise operated manually or with simple timers and feedback devices. They have proved their value through increased operating efficiency, labor saving, fuel economy, and disaster avoidance. As a result, they are now standard in almost all commercial and research settings. Traditionally, control systems are programmed with operator settings that establish the desired targets for factors of production including light levels, air temperature and humidity, CO₂ levels, irrigation, and nutrient content. These targets are then maintained by automatically applying specific control strategies to the greenhouse equipment. The control strategies are designed to respect the capabilities and limitations of the equipment while achieving these control targets. Most of the computer control logic is dedicated to this largely unseen and under-appreciated task.

Ongoing research continues to increase our knowledge about the relative and quantitative effects of the various factors of production. At the same time, there have been developments in artificial intelligence systems such as plant growth models. These can be used to replace or augment some of the operator entered targets and strategies that are available in the control computer software. A method for accepting supervisory control instructions is described that preserves the lower level equipment control strategies and the safety features of the greenhouse control system. With it, researchers can now direct control objectives from a higher, more 'abstracted' level, typically a computer model running outside of the greenhouse control system. This enables them to explore new crop production models not supported by commercially available control systems, while still taking advantage of the considerable equipment control strategies and feedback information available from the control system.

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Abstracts: Poster Presentations

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Evaluation of a Humidity Insensitive Sorbent-Based Air Sampling System

A. Flanagan^{1,*}, D. Braithwaite², T.S. Topham², G.E. Bingham² and O. Monje³

¹Limerick Institute of Technology, Limerick, Ireland

²Space Dynamics Laboratory, Logan UT, USA

³Dynamac Corporation, Kennedy Space Center, FL, USA

* Email address: Aisling.O.Flanagan@nasa.gov

Optimum plant growth in controlled environment chambers is generally attained at high relative humidities (60-75%). However, humid environments can interfere with air sampling methods utilizing thermally desorbing compounds to monitor volatile organic compounds (VOCs) in plant chambers. Co-adsorption of water vapor may interfere with quantitative analysis by decreasing the adsorptive capacity of the sorbent or reduce recoveries due to gas chromatographic artifacts. The objective of this study is to evaluate the performance of a sorbent-based air sampler designed specifically to minimize the effects of humidity. The sampling system was challenged with plant-produced VOCs at 70% relative humidity. The air sampler was used to monitor the air quality of radish plants growing in low mass plant chambers.

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Predicting Night-Time Low Temperatures in Unheated High Tunnels

Andrew Ogden* and Marc van Iersel

Department of Horticulture, University of Georgia, 1111 Miller plant Science Building, Athens, GA 30602, USA

* Email address: aogden@uga.edu

High tunnel agriculture is becoming increasingly popular for a wide variety of horticultural crops worldwide. Research is currently being conducted in six new high tunnels, each 53.5 m² at the University of Georgia. The feasibility of growing blueberries for out of season production is the primary aim of the research. The tunnels effectively promoted early flowering (13 and 36 d respectively for two cultivars trialed) and fruit set. The primary limitation of these single layer, small, high tunnels, is their inability to retain heat during night-time. High tunnels may even cool below outside temperatures. This lack of frost protection forced the use of propane heaters, making blueberry production in high tunnels cost-prohibitive. For the second year of the study, frost blankets were used to cover the plants during subzero nights in an effort to minimize propane use. Dataloggers recorded hourly measurements of air temperature inside of the tunnels, below the frost blankets, and out-side of the tunnels. By combining daily weather data, a model was generated to predict night-time lows for these single-bay high tunnels. Such models can be used to determine what level of freeze protection may be necessary on a given night.

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Development of a Production System for Basil on the International Space Station

A. R. Beaman^{*}, R. J. Gladon

Iowa State University, Department of Horticulture, 106 Horticulture Hall, Iowa State University, Ames, Iowa, 50011, USA

* Email address: abeaman@iastate.edu

Basil production in controlled environments may be enhanced by careful cultivar selection, a specific amount of irradiance, a specific concentration of N in the nutrient solution, and using cuttings rather than seeds for propagation. We used an NFT system with bottom heat, supplemented by high-pressure sodium lighting, and we used Hoagland's nutrient solution number 1. Our objectives were to learn what specific cultivar(s) and irradiance ranges would be optimal for overall growth in controlled environments, what total N concentration would be optimal for edible biomass production, and to evaluate the use of cuttings for propagation rather than seeds. We tested five cultivars commonly used in commercial production ('Aroma 2', 'Genovese', 'Genovese Compact Improved', 'Italian Large Leaf', and 'Nufar'). We have found that 'Genovese Compact Improved' had the lowest germination rate, whereas 'Nufar' exhibited the greatest germination rate. 'Italian Large Leaf' and 'Nufar' produced the greatest biomass, and 'Genovese Compact Improved' produced the least biomass. 'Genovese', 'Italian Large Leaf', and 'Nufar' produced the greatest biomass at irradiances of 400 to 500 $\mu\text{mol}/\text{m}^2/\text{s}$, and no additional biomass was produced when plants were grown at 600 $\mu\text{mol}/\text{m}^2/\text{s}$. To date, we do not have conclusive information regarding the optimal total N concentration in the nutrient solution. Testing of five concentrations of total N (50, 100, 150, 200, 250 mg N/L; 50:50 $\text{NO}_3^-:\text{NH}_4^+$) continues. The addition of supplemental lighting with high-pressure sodium lamps resulted in greater biomass production in the total N experiments. Preliminary research has shown that stem-tip cuttings can be transplanted into the hydroponic system at day five or six, whereas seed propagation requires 10 to 12 days before transplanting into the hydroponic system.

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Harvest Index of ‘Rocky’ Cucumber Plants (*Cucumis sativus* L.) Grown in Elevated CO₂ is Not Different from ‘Rocky’ Cucumber Grown in Ambient CO₂

Leah Crosby^{1*}, Ellen Peffley¹, and Leslie Thompson²

¹ Department of Plant and Soil Science, Texas Tech University, Lubbock, TX, 79409-2122, USA

² Department of Animal and Food Science, Texas Tech University, Lubbock, TX, 79409-2141, USA

* Email address: leah.crosby@ttu.edu

Cucumber (*Cucumis sativus* L.) is a diverse crop ranging in growth habit, pollination requirements, flower production, fruit type and preparation methods. Greenhouse trials were conducted at Texas Tech University to screen cucumber cultivars for parthenocarpy, flowering, growth habit, and fruit load. Candidate cultivars screened were; ‘Alibi’, ‘Amour’, ‘Cucumber Bush’, ‘Diva’, ‘Genuine’, ‘H-19 Little Leaf’, ‘Marketmore 76’, ‘Poona Kheera’, ‘Rocky’, ‘Socrates’, ‘Striped Armenian’ and ‘Tyria’. Of these, ‘Rocky’ was chosen for Environmental Growth Chamber trials because it is a gynocious, parthenocarpic pickler type and consistently yields fruit throughout the growing season. Plants were grown hydroponically in Environmental Growth Chambers at 16h light/8h dark, 24°/20°C, 75/99% relative humidity, ~650 μmol/m²/s PAR, and ambient (400 ppm) or elevated (2000 ppm) CO₂. Data collected was leaf area, fruit weight, plant weight, and harvest index. Fruit of marketable size were harvested weekly. Leaf area was measured by removing leaves from the 10th and 20th nodes and running leaves through a LI-3100 area meter. At the termination of the experiment plants were harvested and weighed. Leaf area and total fruit weight of plants grown in ambient CO₂ was significantly different than those grown in elevated CO₂. Mean weight of plants grown in ambient CO₂ (327g) was significantly different than mean weight of plants grown in elevated CO₂ (654g). Harvest indices of plants grown in ambient CO₂ were not significantly different than plants grown in elevated CO₂.

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Modified Field Environments for High Latitude Crop Production

M. Karlsson* and J. Werner

University of Alaska Fairbanks, 303 O'Neill Bldg., PO Box 757200, Fairbanks, AK, 99775-7200, USA

* E-mail address: ffmgk@uaf.edu

High tunnels have been shown to allow season extension, higher yields, improved quality as well as more consistent and predictably timed harvest. Non-traditional plastics may possibly support crop productivity in high tunnels under northern conditions with naturally extreme day lengths more efficiently. Therefore, specialty plastics were evaluated in relation to field and traditionally recommended cover materials. Four high tunnel structures were used to test the impact and use of plastic covering materials for northern field crop production. The selected covering materials are commercially available and vary in light absorption and transmission characteristics. The included plastic materials for covering the 7.3 m (length) by 3.7 m (width) structures were K50 Clear, K50 IR/AC, KoolLite380© (Klerks Plastic Product Manufacturing, Inc., Richburg, South Carolina) and Solatrol (Visqueen GCF 925C9, British Polythene Industries PLC, Greenock, United Kingdom). The K50 Clear material is a 6 mil ethylvinylacetate (EVA) plastic regularly used in commercial high tunnels and plastic greenhouses. The K50 IR/AC plastic is expected to hold infra-red wavelengths and conserve energy during cold nights. The KoolLite380 blocks ultra-violet radiation and selectively filters infra-red wavelengths to maintain a cooler environment during hot days. The Solatrol material selectively absorbs far-red wavelengths and alters the red to far-red ratio in the growing environment. The daily temperature and light profiles were identified for the various plastics and compared to adjacent field conditions. K50 Clear and K50 IR/AC blocked radiation below 360 nm, Solatrol below 390 nm and KoolLite380 as advertised, below 380 nm. In addition, KoolLite380 shifted the spectrum with relatively more radiation from 550 nm into the infrared wavelengths compared to the field. The temperature pattern in the K50 Clear and K50 IR/AC covered tunnels were similar although there was a trend for slightly lower temperatures during the warmest part of the day under K50 IR/AC. During cooler nights, the KoolLite380 material maintained a warmer environment compared to K50 Clear. To evaluate crop response in the various environments, raspberries were grown in a container system. Long canes of Tulameen, a well adapted cultivar for containers, were planted using 11.3 liter (3 gallon) large containers in June for immediate first season berry production. Excellent pollination and growth resulted in high yields of top quality fresh market raspberries in all environments including the field. More than 100 high quality marketable raspberries were harvested from each single cane plant. The highest yield was recorded in the high tunnel covered with K50 IR/AC and the least number of raspberries were harvested on plants grown in the adjacent field.

The Potential for Autotoxicity of Root Exudates in Commercial Hydroponic Lettuce (*Lactuca sativa*) production

N.S. Mattson^{1*}, L.D. Albright², M.L. Brechner²

¹ Department of Horticulture

² Department of Biological and Environmental Engineering

Cornell University, Ithaca, NY 14853, USA

* Email address: nsm47@cornell.edu

Allelopathy is defined as the beneficial or harmful chemical interaction between plants. Plant secondary compounds from root exudates in soil are well known for their allelopathic properties. Autotoxicity occurs when the released compounds inhibit growth of the source plants. Autotoxicity due to the accumulation of phenolic and organic acids has been reported to occur in greenhouse vegetables and ornamentals grown in solution culture. Successful methods for the removal of autotoxic compounds that have been reported include the use of activated charcoal or degradation by beneficial bacterial. The objective of this project is to 1) determine the concentration of known autotoxic compounds in commercial hydroponic lettuce production facilities and 2) determine the potential for identified compounds to inhibit plant growth either separately or in combination. Water samples are being taken periodically from ponds of two hydroponic lettuce facilities. Organic acids from the water samples are collected with resin columns and desorbed in methanol. Acid fractions of the methanol extract are then subjected to analysis via GC-MS. Initial results on the presence and concentration of known autotoxic compounds will be presented and the possibility for autotoxic compounds to limit plant growth in commercial scale hydroponic lettuce production will be discussed. The potential for autotoxic compounds to accumulate and affect growth of container-grown herbaceous ornamentals in ebb and flow bench systems will also be discussed.

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Research Plants in Controlled Environments – Does Green Waste Compost Make a Reliable Alternative Substrate to Peat?

G. Pitkin* and R. McHutchon

Scottish Crop Research Institute, Errol Road, Invergowrie, Dundee, DD2 5DA

* Email address: Graham.Pitkin@scri.ac.uk

Sphagnum moss peat is the main ingredient in SCRI's standard compost mix which has been used at SCRI since the 1960s and is based on a formula conceived by the University of California. SCRI uses approx 200 m³ a year out of a current annual UK consumption of 2.5 x 10⁶ m³. Environmental groups are lobbying against the use of peat in horticulture, proposing taxation of peat-based products. The UK Government has set a target for composts to be 90% peat free by 2010.

A study was made to find if the normal range of plants produced at SCRI can be grown in a medium with partial replacement of peat, in C.E.s, without reducing the quality or uniformity of the plants. Green Waste (GW) is a renewable substrate processed from household and amenity waste plant material. It was chosen because it can be sourced locally, is cheap and would have a positive environmental impact.

A selection of the most commonly grown plant species were grown in one of three mixes:-

- Standard (Control)
- 20% GW replacement
- 40% GW replacement

Normal plant production procedures were followed. All plants were harvested when plants in Standard Mix were at the size used for scientific purposes. Plant quality was assessed by measuring Fresh Weight, Height and number of Internodes. The plants were grown at the same temperature in three different facilities - a Cambridge Widespan glasshouse, a Venlo glasshouse and a walk-in CE room.

The poster depicts the results of this study, using three different plant species as examples (*Nicotiana benthamiana*, Barley 'Golden Promise', and *Chenopodium amaranticolor*), from the 16 species and varieties that were trialled.

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Effect of Light Quality on Growth of *Salvia miltiorrhiza* Bunge

Qian Li*, Zong-suo Liang

College of life sciences, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaan xi, 712100, China

* Email address: selenaliqian@gmail.com

The effect of light quality (spectral quality) was studied on growth of *Salvia miltiorrhiza* Bunge, “Dan Shen”, which is a traditional Chinese herb. The plants were placed under colorless (natural light) or colored (red, yellow, green, blue and purple) filters from acclimation after transplanting to flowering. The plant height, fresh weight, dry weight, chlorophyll concentration and net photosynthesis rate were quantified. Results show that the plants under yellow filter (absorbing blue and green lights) had higher plant height, weight of shoot systems and chlorophyll a/b ratio than those under blue filter (absorbing red light), but it came with less weight of root systems compare to others. The chlorophyll concentrations were higher under purple and blue filters (provide more blue light). The net photosynthesis rate of leaves was higher under green, yellow and purple filters than red, blue and colorless ones. Our study demonstrates the effectiveness of photo regulation on medicinal plant production.

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Effects of a New Cyclical Lighting System on Flower Induction in Long-Day Plants: A Preliminary Investigation

Matthew G. Blanchard and Erik S. Runkle*

Department of Horticulture, Michigan State University, East Lansing, Michigan, 48824 USA

* Email address: runkleer@msu.edu

Photoperiod is often manipulated during commercial production of many floriculture crops to induce or prevent flowering in photoperiodic species. To promote flowering in long-day plants, continuous 4-h night-interruption (NI) lighting at a low-intensity or cyclic lighting (e.g., 6 min on and 24 min off) for 4 h during the middle of the dark period is generally effective. A new technology for greenhouse long-day lighting was developed commercially using a stationary high-pressure sodium (HPS) lamp with an oscillating parabolic reflector (cyclic HPS lamp). The reflector provides an intermittent beam of light over a relatively large growing area. We performed an experiment to compare the efficacy of a cyclic HPS lamp on flower induction in long-day floriculture crops with traditional NI lighting strategies. *Asclepias tuberosa*, *Campanula carpatica* 'Pearl Deep Blue', *Coreopsis grandiflora* 'Early Sunrise', *Petunia* 'Easy Wave Coral Reef', and *Rudbeckia hirta* 'Becky Cinnamon Bicolor' were grown in a glass-glazed greenhouse at a constant temperature of 20 °C with natural short-day photoperiods and NI treatments. NI lighting was delivered during the middle of the dark period (2200 to 0200 HR) from a 400-W cyclic HPS lamp mounted at one gable end of the greenhouse or from incandescent (INC) lamps that were illuminated for the entire 4 h or for 6 min every 30 min for 4 h. Plants under cyclic HPS were grown at lateral distances of 1, 3, 7, 10, or 13 m from the lamp. Control plants were grown under a constant 9-h photoperiod. After 35 d, the reflector on the cyclic HPS lamp malfunctioned and stopped oscillating, although the lamp continued to turn on during the NI. Therefore, the results of this experiment are considered preliminary. As the lateral distance from the cyclic HPS lamp increased from 1 to 13 m, the maximum photosynthetic photon flux decreased exponentially from 20.9 to 0.4 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. After 11 weeks, 100% of all species except *Asclepias* and *Coreopsis* had a visible flower bud (VB) under cyclic HPS or INC lamps. In *Campanula*, *Petunia*, and *Rudbeckia*, flowering was delayed by 7 to 12 d when the INC lamps operated cyclically compared to being operated during the entire 4 h of the NI treatment. These results indicate that a cyclic HPS lamp can be used for NI lighting to induce flowering in these long-day species.

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Isotopic Labeling of Red Cabbage Anthocyanins with Atmospheric ^{13}C in Closed Environments

Craig Charron, Steven Britz*, Roman Mirecki, Dawn Harrison, Beverly Clevidence and Janet Novotny

USDA Food Components and Health Lab, Bldg. 307B, 10300 Baltimore Ave., Beltsville, MD 20705-2325, USA

* Email address: steven.britz@ars.usda.gov

Isotopic labeling of plants provides a unique opportunity for understanding metabolic processes both in the plants themselves and in people or animals fed labeled plant material. A significant challenge of isotopic labeling during plant growth is that isotopes must be administered without disrupting plant development and at sufficient levels for mass spectral analysis. We describe a system for isotopic labeling of leafy vegetables with ^{13}C and demonstrate successful incorporation of ^{13}C into anthocyanins of preheading red cabbage (*Brassica oleracea* L var. *capitata*). ‘Super Red’ red cabbage seedlings were grown for 34 days in an airtight acrylic labeling chamber supplied with $^{13}\text{CO}_2$ to maintain 400 ppm. Nutrient solution was delivered hydroponically without allowing infusion of ambient unlabeled CO_2 into the labeling chamber. Plants were initially grown at $22 \pm 1^\circ\text{C}$ in constant light at $228 \mu\text{mol m}^{-2} \text{s}^{-1}$. Upon canopy closure, anthocyanin development was promoted by reducing nutrient solution concentration and reducing temperature to $10.5 \pm 1.5^\circ\text{C}$. Total shoot fresh weight (FW) was 1565 g and root FW was 491 g at harvest. Analysis of red cabbage shoot tissue by high performance liquid chromatography/tandem mass spectrometry (HPLC-MS/MS) indicated the presence of 37 anthocyanins, of which fourteen have not previously been described. Mass shifts representing ^{13}C incorporation into anthocyanins were evident in mass spectra of anthocyanins from labeled tissue and demonstrate successful isotopic labeling into nearly 100% of all carbons. Major anthocyanins differing in glycosylation and acylation will be isolated and fed to human subjects to study the impact of substituents on anthocyanin uptake and metabolism.

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Effect of Elevated CO₂ and Harvest Schedule on *Allium* Biomass and Sensory Quality of *Allium fistulosum*

Amanda Broome^{1*}, Ellen Peffley¹, Leslie Thompson² and, David Wester³

¹ Department of Plant and Soil Sciences, Box 42122,

² Department of Animal and Food Sciences, Box 42121,

³ Department of Natural Resources Management, Box 42125,

Texas Tech University Lubbock, TX 79409, USA

* Email address: amanda.broome@ttu.edu

Allium has a unique accumulation of edible biomass in leaves and bulb making it a versatile candidate for fresh consumption on long-term space missions. Green shoots can be harvested repeatedly over time providing fresh edible biomass for extended periods. To better investigate *Allium* species and harvest strategies that produce maximum edible biomass and plant quality while minimizing crew-time handling of plant material, shoot biomass of three *Allium* species were examined at three harvest schedules and two CO₂ levels.

Plants of *A. fistulosum*, Japanese bunching onion (JBO); *A. cepa*, bulbing onion; and *A. schoenoprasum*, chive were sown in Oasis® media and grown hydroponically in Environmental Growth Chambers at 400 ppm and 1200 ppm CO₂. Plants were placed on a poly plastic covered stainless steel plant tray and irrigated with recirculating Hydro-sol® nutrient solution using poly pipe tubing. Shoots of plants were harvested weekly, bi-monthly, or one time at 70 days after planting (DAP). Shoots were removed 50-mm from media surface and weight (g) recorded. Experimental design was a completely randomized block with repeated measures; data was analyzed using SAS 9.1. Overall, JBO and bulbing onion had the greatest shoot biomass regardless of harvest schedule. Shoots of plants harvested at 70 DAP weighed more than the cumulative weight of shoots harvested weekly or bi-monthly. The effect of CO₂ on shoot weight depended upon harvest schedule. Shoots from plants left undisturbed and harvested at 70 DAP weighed more when grown in 400 ppm than those grown in 1200 ppm CO₂.

In a companion study, JBO satisfied criteria required for a sensory study, *i.e.*, it produces a large amount of shoot biomass when harvested bi-monthly at both 400 ppm and 1200 ppm CO₂, has an upright growth habit facilitating ease of harvest, and the shoots have a common onion flavor. JBO was grown at 400, 1200 and 2000 ppm CO₂. A consumer panel was assembled (n = 25) and samples of JBO shoots grown under each of the three CO₂ levels were ranked for visual appeal. Panelists ranked the visual appeal of JBO on a scale of 1 to 6, with 1 being dislike very much, and with 6 being like very much. The panel ranked sensory quality of JBO grown at 1200 ppm and 2000 ppm CO₂ as more visually appealing at 28 DAP; JBO grown at 400 ppm CO₂ was ranked as the most visually appealing at 70 DAP.

2008 International Meeting on Controlled Environment Agriculture
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How to Measure and Report Growing Conditions for Experiments in Plant Tissue Culture Facilities

International Committee for Controlled Environment Guidelines

Poster presenter: M.P. Fuller*, The University of Plymouth, Plymouth, Devon, PL4 8AA, UK

*Email address: mfuller@plymouth.ac.uk

It is important that conditions in controlled environment tissue culture facilities are reported accurately, to allow replication of experiments and comparison of results among facilities and to avoid experimental artefacts from uncontrolled variables. This poster and its accompanying guidelines brochure (entitled '*Guidelines for measuring and reporting environmental parameters for experiments in plant tissue culture facilities*' and published by the International Committee for Controlled Environment Guidelines in March 2008) provide a recommended minimum for the amount, type and format of information that should be measured and reported in publications to meet these aims.

The guidelines are the fruit of effort by an international sub-committee with members from the UK, France, USA, Australia and Japan (see <http://www.ceug.ac.uk/ICCEG.htm> for details of the committee's membership) appointed by the International Committee for Controlled Environment Guidelines (ICCEG). The guidelines are the result of an initiative emanating from the second international Controlled Environment meeting in 2004 at Brisbane, Australia, under the auspices of the North American Committee on Controlled Environment Technology and Use (NCERA-101), the UK Controlled Environment Users' Group (UK CEUG), and the Australasian Controlled Environment Working Group (ACEWG).

All delegates are encouraged to review the poster and take additional copies of the guidelines for dissemination in their institutions and to colleagues elsewhere. The poster and further copies of the guidelines will also be available from the three user groups to take to other regional, national and international meetings.

For additional information, please visit:

<http://www.ceug.ac.uk/TC-guidelines.htm>

<http://ncr101.montana.edu/Guidelines.htm>

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Maintaining and Quantifying Drought Stress in Containers

Julie Chard and Bruce Bugbee *

Crop Physiology Laboratory, Dept. of Plants Soils, Biometeorology, Utah State University
Logan, UT, 84322-4820, USA

* Email address: bruce.bugbee@usu.edu

It has always been difficult to study drought stress in containers because the root-zone water potential changes rapidly. Here we describe techniques for maintaining drought stress in both soil columns and pots of soil-less media. Containers are typically filled with a soil-less media mixture such as peat/perlite to facilitate drainage. Growing plants in soil better approximates field conditions, but it is difficult to avoid flooding and reduced air-filled porosity. Soil columns facilitate drainage and increased porosity. In soil columns, gravimetric measurements of soil water content were compared to measurements of soil water potential made by Watermark sensors. In pots with soil-less media, plants were subjected to steady-state, low root-zone water contents (or negative water potentials). Real-time changes in transpiration rate of plants in soil-less media were gravimetrically quantified at 10-minute intervals using digital balances. See Chard & Bugbee online (www.usu.edu/cpl/research.htm) for additional details.

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Energy Saving Measures in Controlled Environments at Rothamsted Research

Ian Pearman, Julian Franklin* and George Waimann

Rothamsted Research, Harpenden, Herts. AL5 2JQ, UK

* Email address: julian.franklin@bbsrc.ac.uk

The energy costs of running the Plant Growth Facilities at Rothamsted Research are currently in excess of £500,000 (\$1 million) per year. With energy costs increasing at over 10% per year over the past few years and little prospect of a significant slow down in such costs measures have been taken to reduce these costs. Some of these are described.

Rothamsted Research benefits from being a large user of energy and can find competitive rates for its energy. In the past such competition has kept costs down. Currently Rothamsted Research pays from 5.5 pence (11 cents) to 17 pence (34 cents) per kWh of electricity dependant on the time of day. Lighting strategies exist to optimise the use of cheaper rates of energy. A combined heat and power unit (CHP) providing 1 MW helps reduce these costs as well as ensuring continuity of supply.

Recent replacement/upgrade of two large plant growth rooms (55 m² growing area) dedicated to providing cereal donor plants for GM studies saw these rooms divided into six, the fitting of inverter driven compressors, improved room insulation, air make up fans inverter driven and improved control systems. Energy savings of at least 20% appear to have been achieved.

There are currently 45 air conditioned glasshouses used primarily for quarantine studies. These compartments are sealed for quarantine purposes with appropriate filtration installed as required. The compartments are cooled and heated via a heat pump. The current replacement strategy for these heat pumps optimises the use of free cooling within the unit to reduce energy costs whilst maintaining the integrity of containment.

Rothamsted Research routinely specifies energy efficient lighting, working with suppliers to reduce energy costs of installed Controlled Environments. The recent construction of a Containment Level 3 facility incorporated several energy efficient features including, insulation of building, lighting, efficient refrigeration systems, flexible 'intelligent' control systems.

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Containment of Quarantined Insects

Richard Natt

Experimental Glasshouses and Plots Team, Central Science Laboratory (CSL), Sand Hutton, York, UK, YO41 LZ

* Email address: r.natt@csl.gov.uk

The Central Science Laboratory (CSL) provides scientific support to the Department for Environment Food and Rural Affairs (Defra), Plant Health Division, facilitating international trade in plants and planting material and protecting the UK industry and environment, notably through the diagnosis of exotic pests and diseases. A strong research base with international expertise in diagnostics and quarantine pest and disease biology engenders links with other academic, government and commercial organisations both within the UK and internationally.

CSL carries out a wide range of work on non-indigenous plant pests and diseases many of these are subject to statutory controls under both UK and European legislation and must be held under 'Licensed Quarantine Facilities'. The move to the site at Sand Hutton, York, eleven years ago allowed CSL to build a state of the art facility for working on such organisms.

The plant pest section operates under strict licensed conditions as it holds insect and other organisms that actively move and must be contained. The whole area is within a sealed unit entered through a double door system, only one door can be opened at a time, all internal doors being fitted with alarms to prevent any two adjacent doors being opened at the same time. The plant growth rooms open onto a cold corridor, which is held at -15°C , so should any insect escape they will be immobilised and killed.

All staff working in the area have to wear dedicated clothing at all times while in the facilities. Disposable coveralls are worn when handling any insects. This clothing is removed and placed in a -20°C freezer for 24 hours before disposal.

The facility consists of five plant growth rooms and five plant growth cabinets, which can work at positive or negative pressure. Air exchange is through fine filters to prevent organisms being carried out (or in).

Specially designed methyl methacrylate (Perspex) cages keep the insects contained even when changing food plants. This is achieved by being able to fit a second smaller cage holding a new plant into place before lifting the sliding door. Then by using an integral glove the plant is moved into the main cage. The door is then slid back into position before removing the second cage. Thrip-proof cages are constructed from electrical switchgear boxes, manufactured to IP68 standard with all ventilation openings being fitted with filters with a pore size of $10\mu\text{m}$. All waste including insect pots and plants is frozen at -20°C for at least 48 hours before being autoclaved.

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Growth Chamber Maintenance Costs and Factors Influencing Equipment Longevity, Reliability and Operating Quality.

Mark Romer^{*}, Claire Cooney, Frank Scopelleti, Glenn Orr

McGill University Phytotron, 1205 Dr Penfield avenue, Montreal, Quebec, Canada H3A 1B1

* Email address: mark.romer@mcgill.ca

The McGill University Phytotron was inaugurated in March 1988 and has now been operational for 20 years. The Phytotron mandate defined the facility as “a diverse collection of controlled environment equipment managed and operated by a central staff of specialists who support research users and projects”. At McGill, a comprehensive set of operational protocols were developed and implemented to maintain the facility’s equipment. Growth chambers and major mechanical equipment undergo routine verification, calibration and service before experiments are initiated, and periodically during the year. Major mechanical equipment is also serviced routinely to ensure a uniform and optimal operating environment for the growth chambers and experimental organisms.

Service records have also been maintained for each individual unit including associated costs. A summary of 10 walk-in high performance chambers and 5 smaller reach-In chambers is presented. Replacement parts for the walk-in chambers averaged \$6,210 over 20 years or \$ 310/year. Smaller reach-in chambers averaged \$2,700 over 20 years or \$135/year. A breakdown by subsystem reveals that lighting components represent the most significant cost in high-light, walk-in chambers (46%) and refrigeration components in the smaller reach-in chambers (29%). An evaluation of chamber component reliability suggests that performance is strongly tied to the correct initial design and consistent operation of facility support equipment such as the cooling tower, HVAC and R/O water production systems.

The successful facility should have in place well defined and effective procedures for maintaining equipment; a user fee structure and institutional support for upgrading and repairing systems; ancillary equipment for monitoring and verifying experimental conditions and resulting products. A core group of experienced and dedicated support staff are essential to overseeing and executing the myriad of tasks involved in maintaining such programs. In recent years, huge investments in CE infrastructure have been made without corresponding investments for management, maintenance and operations staff. This imbalance is likely to have an adverse impact on the longevity of the new facilities as well as the quality of their research products.

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[A Risk Analysis of the Production of Hydroponic Babyleaf Spinach with respect to *Pythium aphanidermatum*](#)

T.J. Shelford*, L.D. Albright

Cornell University, 164 Riley-Robb Hall, Cornell University, Ithaca, NY, 14853, USA

* Email address: tjs47@cornell.edu

Pythium aphanidermatum has previously been identified as the major hurdle to hydroponic production of babyleaf spinach. This water mold reproduces and spreads quickly through the nutrient solution and can quickly destroy the roots of an entire crop. Currently commercial production systems in Japan replace the nutrient solution after every harvest, however this is a considerable cost for the producer both in terms of water and nutrients, and in environmentally sound disposal.

Previous work at Cornell has identified alternative production strategies that allow reuse of the nutrient solution, however there are varying costs associated with these techniques. Through a simulation model this paper quantifies the risk of damage/loss of the crop due to *Pythium*, which will allow informed production technique decisions to be made by a grower.

The production strategies compared include: Continuous multiple crop production with continuous use of untreated nutrient solution, batch crop production with one time use of solution, batch crop production with the nutrient solution treated between crops, continuous multiple crop production in a single pond with nutrient solution temperature control, continuous multiple crop production in a two pond system (7 days of the 14 day crop cycle spent in each pond) with and without temperature control.

The simulation model incorporates both a greenhouse temperature simulation model developed from an energy balance, a spinach growth model, and a disease model developed from previously collected data on *Pythium* infections. A Monte-Carlo type simulation was then conducted with varying climatic conditions, equipment reliability and disease parameters, to provide a distribution of expected production losses under the different production strategies.