The Fourth International Meeting of UK CEUG, NCERA-101 and ACEWG

Controlled Environments: Technology and Practice

ACEWG
Australasian Controlled Environment Working Group

United Kingdom Controlled Environment Users' Group
UK CEUG

USDA
NCERA-101
NCR-101
Committee on Controlled Environment Technology and Use

9th -12th September 2012
at Downing College
Cambridge UK

2012 International Meeting on Controlled Environment Agriculture

SCIENTIFIC PROGRAMME

	SUNDAY 9 SEPTEMBER 2012: EVENING
13.00-19.00	Registration at the Howard Room Downing College
19:00	Cafeteria style meal in Dining Room.
20.00	Welcome Reception at the Howard Room

	MONDAY 10 SEPTEMBER 2012: MORNING
08.30-08.45	Opening of Conference: Prof. David Baulcombe
SESSION 1	LIGHT IN CONTROLLED ENVIRONMENTS (Chair: B.Bugbee)
08.45-09-15	C. Humphreys (University of Cambridge, UK) *The Science of LEDs*
09.15-09.45	E. van Echtelt (Philips Lighting, Eindhoven, The Netherlands) *Growing Value With Application of LED Technology In Horticulture*
09.45-10.15	C. A. Mitchell (Horticulture, Purdue University, USA) *LEDs from a Plant Scientist's Point of View*
10.15-10.45	Morning Coffee
SESSION 2	LIGHT IN CONTROLLED ENVIRONMENTS (Chair: B.Bugbee)
10.45-11.15	J. Sager (Kennedy Space Center, Florida, USA) R. Wheeler (Kennedy Space Center, Florida, USA) *Plasma Lighting For Crop Production*
11.15-11.45	J. Bijl (Vitroplus, The Netherlands) *Commercial Application of Lighting*
11.45-12.15	F. van der Meij (SpectraPartners, The Netherlands) *Challenges of Comparative Light Measurement with New Technology*
12.15-12.45	Panel-led Discussion on Sessions 1 & 2 Above seven speakers
12.45-13.45	Lunch
	MONDAY 10 SEPTEMBER 2012: AFTERNOON and EVENING
13.45-17. 00	Tour of University of Cambridge & Sainsbury Laboratory Plant Growth Facilities, Cambridge Botanic Gardens, Poster Session and Trade Displays
18.30	Dinner
21.00	Business Meetings

	UK CEUG in Howard Lecture Theatre NCERA-101 Music room and concurrent Bar
	TUESDAY 11 SEPTEMBER 2012: MORNING
SESSION 3	SUSTAINABILITY OF CONTROLLED ENVIRONMENTS (Chair: T.Agostino)
08.45-09.15	A. Padfield (Unigro, UK)) *The Concept of Free Cooling and Coolth and use in energy conservation*
09.15-09.45	M. Bucholz (Watergy, Berlin, Germany) *Innovative Structures and methods for operating closed system at high ambient temperatures*
09.45-10.15	C. Procter (ADAS, UK) *Application of Alternative Energy sources in CEs*
10.15-10.45	Morning Coffee
SESSION 4	SUSTAINABILITY OF CONTROLLED ENVIRONMENTS (Chair: T.Agostino)
10.45-11.15	S. Goodhew (University of Plymouth, UK) *Environmental Impacts 1 : Sustainable Building Materials*
11.15-11.45	L. Marcelis (Wageningen, The Netherlands) *Environmental Impacts 2 : The road to environment friendly production in greenhouses*
11.45-12.15	J. Franklin (Rothamsted Research, UK) *Legislative Impacts on Agrochemical Use in Controlled Environments*
12.15-12.45	Panel-led Discussion on Sessions 3 & 4 Above six speakers
12.45-13.45	Lunch

	TUESDAY 11 SEPTEMBER 2012: AFTERNOON and EVENING
SESSION 5	TECHNOLOGY AND PRACTICE (Chair: G.Taylor)
13.45-14.15	L. Albright (Cornell University, USA) *Vertical Farming*
14.15-14.45	G. Giacomelli (University of Arizona, USA) *Novel Application of Controlled Environments*
14.45-15.15	T. Agostino (CSIRO, Australia) *The Australian Plant Phenomics Facility: Application of Modern Digital Imaging Technologies in the Plant Sciences*
15.15-15.45	Afternoon Tea

SESSION 6	TECHNOLOGY & PRACTISE (Chair: G.Taylor)
15.45-16.15	G. Holroyd (University of Lancaster, UK) *Defence Priming & Integrated Management Practice*
16.15-16.45	N. Bragg (Horticultural development Company, UK) *The Science of Growing Media*
16.45-17.15	Panel-Led Discussion on Sessions 5 & 6 Above five speakers
19.00	Conference Dinner

	WEDNESDAY 12 SEPTEMBER 2001: MORNING
SESSION 7	CONSERVATION & CLIMATE CHANGE (Chair: J. Franklin)
08.45-09.15	S. Redstone (Royal Botanic Garden Kew, UK) *Controlled Environment Quarantine Facilities For The Conservation Of Plant Genetic Resources*
09.15-09.45	C. Elliott-Kingston (University of Dublin, Eire) *Climate Change Research In The Programme For Experimental Atmospheres And Climate (PÉAC)*
09-45-10.15	A. Milcu (CNRS Ecotron, France) *Controlled Environments in Ecosystem Research*
10.15-10.45	Panel-Led Discussion on Session 7 Above three speakers
10.45-11.00	Morning Coffee
SESSION 8	
11.00-11.30	A. J. Both (Rutgers University, USA) *Greenhouse Guidelines*
11.30-12.00	B.Bugbee (Utah State University, USA) *Theory & Observation in CE Research: the Zig-Zag path to knowledge*
12.00-14.00	Lunch before departure. Start of Post-Conference Tour

Sessions 1 and 2

LIGHT IN CONTROLLED ENVIRONMENTS (Chair: B.Bugbee)

Session 1

The Science Of LEDs

C.J. Humphreys

Department of Materials Science and Metallurgy, University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, UK (colin.humphreys@msm.cam.ac.uk)

In the world of lighting, the past 130 years have been the age of the incandescent light bulb. However, major changes in the world of lighting are occurring. Fluorescent tubes and compact fluorescent lamps are rapidly replacing incandescent light bulbs in order to save energy. But these are likely to be only a stop-gap measure until light-emitting diode (LED) lighting becomes available at a reasonable cost. LED lighting is, of course, already starting to be used in a wide range of applications. There are good reasons to believe that LED lighting will dominate the future of lighting.

This talk will describe the science of LEDs, which can, in principle, be 100% efficient in converting electricity into light. We will describe how LEDs work, the importance of gallium nitride (GaN), the efficiency of LEDs, the production of white light using LED chips plus phosphors, the production of white light using red plus yellow plus green plus blue LEDs, high power LED packages, thermal management, lifetime and cost. The talk will also discuss limitations of LEDs, for example "efficiency droop" and the "green gap" problem. Finally, we will discuss some applications of LEDs.

References

Humphreys, C.J. (2008). Solid-State Lighting. MRS Bulletin. 33:459-470.

Zhu, D. & Humphreys, C.J. (2012). Lighting. In Fundamentals of Materials for Energy and Environmental Sustainability (Eds. D.S. Ginley and D. Cahen). Cambridge University Press, 474-490.

Session 1

Growing Value With Application Of LED Technology In Horticulture

E.m. Hogeveen – Van Echtelt

Philips Lighting
Boschdijk 525, 5621 JG, Eindhoven, The Netherlands
P.O. Box 90500, 5600 PB, Eindhoven, The Netherlands
[Email: esther.van.echtelt@philips.com]

LED technology is one of the technologies that can help in producing crops and flowers in a more effective and sustainable way around the world. The benefits of LEDs are clear: you can choose and/or adjust spectrum and intensity, the energy efficiency is higher than most conventional light sources, there is freedom of product design because of the small size of separate LEDs, there is lack of infra red radiation, and they have a long lifetime. With these characteristics they offer loads of (new) opportunities to use them in horticultural applications.

Key in the successful and sustainable use of LEDs in horticulture is combining the knowledge of the technology with knowledge about plant and crop physiology and being able to apply this knowledge to local circumstances and needs from growers in usable light recipes. This leads to value for the user. The following examples indicate achievements of LED- recipes that have been developed by Philips with growers and researchers and which are currently operational around the world.

- Increased production capacities of growers by 40% without building new greenhouses via multilayer cultivation (tulips, ferns);
- Savings up to 90% of energy in control of flowering with photoperiodic lighting in crops like strawberry, dahlia, chrysanthemum;
- Production of young lettuce plants with a constant production period and quality (21 days instead of 25-90 days) in a controlled multilayer cultivation system;
- Increasing production (efficiency) of tomatoes and cut roses via use of LED interlighting in the crop together with energy savings compared to conventional lighting.
- Shortening of production cycle up to 4 days of kalanchoe because of less use of growth regulator by lighting with LEDs during internal transport and shortening of cycle by 20% because of growing young plants in multilayer.
- Increased survival rate of rooted cuttings in the greenhouse
- Performing good research on heat tolerance of tomatoes in climate cabinets with perfectly controlled climate conditions.

Session 1

LEDs From A Plant Scientist’s Point Of View

C. A. Mitchell

Department of Horticulture and Landscape Architecture
Purdue University, 625 Agriculture Mall Drive, West Lafayette, Indiana 47907-2010 USA
[Email: cmitchel@purdue.edu]

Light-emitting diodes (LEDs) can provide waveband-selectable, monochromatic light to elicit photosynthetic, photomorphogenic, phototropic, and/or photonastic plant responses free of cumbersome technology that has complicated studies of plant photoresponses to broad-band radiation requiring cutoff filters. Thus, plants may display higher quantum efficiencies and “cleaner” photo-responses to actinic light generated by LEDs than by “less pure” light sources. The relative ease of working with LEDs will promote future discovery and characterization of plant physiological and developmental responses to light. Because waste heat from LEDs is removed remotely from photon-emitting surfaces, such emitters can be placed much closer to plant tissues than can other light sources, without need for water barriers to remove long-wave radiation. Use of LEDs for sole-source plant lighting will help reveal the nature of interacting photosystems in complex photoresponses such as growth and flowering. Ability to blend output from different color LEDs and to control irradiance independently allows precise control of wavelength ratios. Development of high-intensity LEDs allows plants to be grown for entire life cycles at tunable light qualities and at high irradiances not previously possible using low-output LEDs. Growing plants under narrow-spectrum light will reveal precisely which wavelengths are required for a given photoresponse and which are not. As LEDs emitting far-red and ultraviolet radiation improve in luminous efficacy, it will become clear which and how much of such wavelengths are needed to prevent physiological disorders such as intumescence from forming on shoots of certain species growing under narrow-spectrum light. Roles of red, blue, and green light in stem elongation, leaf expansion, and canopy photosynthetic productivity will be elucidated for many different species using emergent LED tools! Plant scientists likely will develop new appreciation for the broad-band “white light” that plants evolved under using narrow-spectrum LEDS as research tools for sole-source lighting. The relative “coolness” of LED photon-emitting surfaces allows novel placement of LED light emitters within crop foliar canopies in controlled environments, thereby enhancing capability for enhancement of crop quantum efficiency and crop-stand productivity. The unique properties of LEDs also allow them to be to be used for photoperiodic control of flowering in greenhouses, to promote propagation and production of transplants, and for supplemental greenhouse crop-production lighting during times of the year when solar light is limiting.

Session 2

Plasma Lighting For Crop Production

J.C. Sager and R.M. Wheeler

NASA (retired), Exploration Life Support Project, Kennedy Space Center, Florida 32899 USA (Email: sager1590@aol.com)
NASA, Surface Systems Office (NE-S1), Kennedy Space Center, Florida 32899 USA (Email: raymond.m.wheeler@nasa.gov)

Plasma lamps are part of the family of electrodeless lamps first demonstrated by Nicola Tesla ca 1894. A plasma lamp system contains an electrodeless design and an excitation source such as a magnetron (microwave generator – 2.45 GHz) or other radio frequency (RF) generator. Unlike another member of this family, fluorescent induction lamps with mercury (Hg) and a phosphor coating, a plasma lamp generates a continuous spectrum by exciting the sulfur or halide molecules in the lamp. The radiative efficiency is high, up to 70% of power coupled into the plasma is emitted as visible light, resulting in efficacy from 50 to 100 lm/W.

The sulfur plasma lamp was developed by Michael Ury and Chuck Wood of Fusion Lighting Systems, Inc. in 1980 and they commercialized several versions from 1995 to 1999. The application of the sulfur plasma lamp to crop production was investigated around the world. In the United States, development of the lamp was supported by a NASA Small Business Innovative Research (SBIR) Phase 1 and Phase 2 contracts from 1992 to 1995. In 1997 Fusion Lighting was awarded a NASA SBIR Phase 1 contract for development of an RF excited plasma lamp, but the company went bankrupt due to failure of the magnetron circuitry in the sulfur plasma lamps before completion of the contract. Sulfur plasma lamps are usually in the range of 700 to 3000 W and have a photon efficacy of ~1.3 µmol/J or ~100 lm/W. The RF excited plasma lamps containing halides are in the 250 to 500 W range and have a photon efficacy of ~1.0 µmol/J or ~55 lm/W. The latest ceramic metal halide lamps yield ~1.9 µmol/J and LEDs have reached 2.0 µmol/J. Currently there are at least three manufacturers of sulfur plasma lamps (magnetron-based) and at least the same number of RF excited plasma lamp manufacturers in the world.

Crop production research under the sulfur plasma lamps was initiated as soon as the lamps were available and included testing with cucumber, lettuce, radish, and rice. For example, cucumber growth showed the most dramatic increase, 30% at 500 µmol/(m^2 s), and increased to 64% at 100 µmol/(m^2 s) with the addition of a green filter and added far red. There is much less data on crop production under the RF excited plasma lamps. Visual comparisons with a like number of crops as above have shown a petiole elongation similar to that seen with a green weighted spectrum or a high far red spectral component. Both plasma lamps are extremely high irradiance sources that require very sophisticated reflector/luminaires, and are very hot (~900 C) requiring cooling and separation from the crop canopy.

Session 2

A New Business Model For Producing Plants Arose From The New Way Of Growing Ferns Under Led In Innovative Packaging

J.J. Bijl & C.F.T. Visser

ViVi B.V. Head Office: Mijlweg 18, 3295 KH ’s-Gravendeel The Netherlands[Email:info@vivi.nu]
Laboratory & Supplies: De Roterij 26, 4328 BA Burgh-Haamstede
The Netherlands [E-mail: supplies@vivi.nu]

Introduction

The production of young plant starter material for the production of ornamentals and vegetables normally takes place in greenhouses. The source of this material can be tissue culture, seeds or cuttings. This material is planted or seeded on trays. In the case of seeds this process is frequently automated, but in the case of tissue culture and cuttings it still contains mainly hand labour. After the plants are fully grown and rooted, they are potted at the same location or they are packed and shipped by truck or plane to the final customer. This illustrates the existing business model.

The practice

Vitro Plus is a fern company specialized in the micro-propagation and hardening of fern starter material. Vitro Plus has automated the complete process of fern tissue culture production and the way in offering her products to the customers. The growth of Vitro Plus tissue culture products take place in multi-layer growth chambers under LED in such innovative way that fern growers are able to plant their starter material direct from the growth chambers instead of using rooted liners from the greenhouse. This has changed the business model for fern sales world-wide in the last 6 years, 80% of the clientele of Vitro Plus are now end customers.

The automation in the Vitro Plus laboratory was built by Visser International Trade & Engineering, a company specialized in the development and production of horticulture automation solutions.

The future

Since now it has been proved that besides ferns a wide range of tissue culture and seed products can be processed with the same technology as ferns. A lot of businesses showed interest to purchase the technology. Through this a new company was born named 'ViVi', a joint venture between Visser International Trade & Engineering and Vitro Plus. ViVi offers plant growers the possibility to use the technology that has proven to save costs, improve plant quality and creates a complete new business model.

Session 2

Challenges of Comparative Light Measurement with New Technology

F Van de Mei

Spectra Partners The Netherlands

Sessions 3 and 4

Sustainability of Controlled Environments (Chair:T. Agostino)

Session 3

The Concept Of Free Cooling And Coolth And Use In Energy Conservation

A. Padfield (Unigro UK)

Session 3

Innovative Structures And Methods For Operating Closed Systems At High Ambient Temperatures

Martin Buchholz, Watergy GmbH, Berlin, Germany

Hygroscopic salt solutions (desiccants) can be used for climate control in closed greenhouse environments. The whole daily load of vapour evaporated by plants can be absorbed by a liquid desiccant. The thermal energy, released by the phase change to water can be used in two directions: A first part, removed by the desiccant solution is accumulated in a thermal storage. A second part is removed by the dried greenhouse air, which allows thermal conduction through the greenhouse roof cover, as being shifted to above ambient temperatures. For desiccant regeneration, thermal energy from the storage is used during night for evaporation of water to the greenhouse air with condensation of water on the cold greenhouse cover. Air with low vapour content can be provided due to cold night temperatures. For areas with low day/night temperature amplitude, an additional heat source (e.g. waste heat from solar power generation) has to be used to create sufficient temperature amplitudes.

Closed ecosystems may consist of a combination of producer and consumer organisms to reach a balanced exchange of CO_2 and Oxygen. In some cases additional synergism can be generated by the humid air provided by the vegetation, especially for a combination with fungus / solid state fermentation cultures. For higher organisms (animals, humans), a further zone with lower temperature and humidity has to be created. For this case, a secondary evaporator is introduced, that uses exhaust air from the colder/dryer cabinet for production of additional cool. This is used to cool down the greenhouse air after being dried in the absorber and cooled down near to ambient temperatures by passing the greenhouse cover. In this way, a cascade between the two zones with different temperatures is created. For regeneration, absorbed water vapour from vegetation and secondary evaporator has to be removed and condensed at the greenhouse cover. In this way, evaporative cooling can be used, while through a day/night period, water is captured within a closed cycle in the enclosure.

Two projects, for a horticultural greenhouse in Cairo, Egypt and a greenhouse/building module in Berlin, Germany (both in state of planning) will be presented.

Session 3

Application Of Alternative Energy Sources in CEs

C. Procter (ADAS UK)

Session 4

Environmental Impacts 1 : Sustainable Building Materials

Steve Goodhew, Environmental Building Group University Of Plymouth

Buildings that provide plants with an appropriate environment in which they can thrive require the building's façade to be able to perform the task of separating the internal and external spaces whilst still providing other expected functional requirements. The list of those functional requirements has lengthened with the inclusion of sustainability related obligations leading to the possible choice of a number of organic based construction materials. This presentation focuses upon the moisture related performance of straw based materials and the range of methodologies that can be used to judge the condition of organic materials used in the walls of buildings. Different building technologies, locations and environments are related to the moisture performance of a number of straw bale walls.

Session 4

Environmental Impacts 2: The Road To Environmental Friendly Production In Greenhouses

L.F.M. Marcelis

Wageningen UR, P.O. Box 644, 6700 AP Wageningen, The Netherlands (Email: Leo.Marcelis@wur.nl)

Greenhouse production systems are characterised by high production levels as well as high levels of inputs such as energy and nutrients on a small area of land. In the Netherlands the annual production per m^2 has doubled the last 25 years. The horticultural sector and government have set targets for energy use, emissions of N and P, use and emission of pesticides, light emission. Besides, limiting water use and waste are important when minimizing environmental impact.

The energy use efficiency (production per unit of energy) increased by about 70% between 1980 and 2008. In particular the widespread introduction of cogeneration of heat and power has contributed to these savings. However, the greenhouse industry still has a large demand for fossil fuel. Geothermal heat is one of the options to save energy. Next generation cultivation systems have been developed to save 30-50% energy, while maintaining the same yield and product quality. The Next Generation Greenhouse Cultivation is based on the intensified use of thermal screens combined with control of humidity, maximizing the use of the integration capacity of the crop, growing with high humidity, improved efficiency of CO_2 dosing. In the near future LED lamps, insulating greenhouse covers with high light transmittance may lead to substantial energy saving. In the long term electricity producing greenhouses may open new ways of saving energy.

In greenhouses water use efficiency (unit product per m^3 of water) is much higher than in the open field. In particular when crops are grown on substrate with recirculating the irrigation water. For instance tomato production in the Mediterranean requires about 60 litre water per kg tomato when grown in the open field, while about 30 litre in greenhouses. In the Netherlands with recirculating systems this is only 15 litre. Even with recirculating systems there is some discharge of water with N, P and pesticides, polluting ground and surface water. Methods are being developed to have no discharge at all. Most of the pests and diseases are nowadays controlled by biological control. To further minimize the use of pesticides, research is focusing on improving the resilience of the production system.

If a grower wants to use assimilation light at night, he needs blackout screens to prevent environmental pollution. It is challenging for researchers to close these screens without creating unfavourable conditions for the plants.

It is expected that greenhouse production systems will continue to reduce their environmental impact. This requires precise control and monitoring of all processes in the crop production system.

Session 4

Legislative Impacts On Agrochemical Use In Controlled Environments

Julian Franklin

Horticulture and Controlled Environments
Rothamsted Research
West Common, Harpenden, Herts. UK. AL5 2JQ
[Email: julian.franklin@rothamsted.ac.uk]

Pest and disease problems occur within Controlled Environments and often may need to be managed with the use of Agrochemicals. Increasingly uses of such chemicals, including biocides, are being controlled by legislation imposed by governments. Legislators wish to improve the Health and Safety of operators and the general public, as well as ensuring no environmental damage is caused by such chemicals.

Legislation increasingly is limiting the availability of agrochemicals/biocides, as well as how they are used and require operator training or certification. Some of the impacts of recent European and UK legislation are discussed as well as possible future impacts on Controlled Environment usage.

An unintended consequence of the introduction of new legislation includes the non-availability of suitable agrochemicals for the control of certain pests and diseases following the decision to ban certain products due to safety or environmental concerns.

SESSIONS 5 AND 6

TECHNOLOGY AND PRACTICE (Chair: G. Taylor)

Session 5

Vertical Farming

L. D. Albright

Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, 14853, United States (Email: albright@cornell.edu)

Urban (local) food production is a concept that has generated a great deal of public and commercial interest. Two of the more controversial methods proposed to grow food within the urban environment are vertical greenhouses and plant factories. In both cases, food crops are grown indoors, with little or no access to natural (sun) light. Instead, all or nearly all of the photosynthetic lighting is provided electrically. Moreover, the more enthusiastic proponents have suggested that nearly all agronomic crops can be grown in vertical greenhouses in quantities sufficient to feed the surrounding metropolis, including commodity crops such as wheat, soybeans, and corn. If this were achievable, the claim is made that much of today’s farmland could be returned to its primordial state, whether forest or grassland. These claims are often challenged based on the large amount of supplemental lighting that would be needed, and its cost. The challenges are refuted by claiming that mirrors, renewable energy sources, and much more efficient plant lighting can be invented for specific use in vertical greenhouses. This presentation explores and quantifies several of the claims supporting vertical greenhouses and plant factories, covering productivity and the possible income from commodity crops, the amount of electricity used for food crop production, and the (rather large) carbon footprint arising from using only electrically-generated light in closed systems. Additionally, issues are discussed related to transport difficulties within a city, possible use of mirrors, incorporating renewable technologies (primarily photovoltaic), and possible LED applications. An alternative, termed “peri-urban” farming, is suggested as an alternative.

Session 5

Novel Application of Controlled Environments

G. Giacomelli (University of Arizona USA)

Session 5

The Australian Plant Phenomics Facility: Application of Modern Digital Imaging Technologies in the Plant Sciences.

Tony Agostino[1], Mark Tester[2] and Robert T. Furbank[1]

[1]CSIRO Division of Plant Industry Black Mountain Laboratories PO Box 1600
Canberra, Australian Capital Territory, 2601 AUSTRALIA
(email: tony.agostin@csiro.au, robert.furbank@csiro.au)

[2] University of Adelaide, School of Agriculture, Food & Wine PMB1, Glen Osmond
Adelaide, South Australia AUSTRALIA (email: mark.tester@acpfg.com.au)

The Australian Plant Phenomics Facility (APPF) is a two-node publicly funded research facility that has realised the incorporation of new digital imaging technologies into modern high throughput plant controlled environment facilities.

The *Plant Accelerator*, located at the Waite Campus in Adelaide, provides over 2300m2 of glasshouse facilities incorporating four specialised “Smarthouses”. These have the capability to grow plants on an automated, high-throughput, platform linked to imaging stations for the non-destructive measurement of plant growth, development and physiology. The facility is capable of processing over 100,000 plants annually and is tailored for the rapid selection and analysis of plant traits that are of interest in basic plant research and plant breeding programs.

The *High Resolution Plant Phenomics Centre* (HRPPC), based at CSIRO’s Black Mountain Laboratories in Canberra, has focused on the development and application of new sensor tools based on chlorophyll fluorescence, Lidar, thermal and RGB imaging - capable of providing full 3-D reconstruction of plants on a continuous, non-destructive, platform. Tools have been developed to study a range of plant growth parameters and responses in controlled environment cabinets, glasshouses and in field environments.

This talk will provide an overview of the two nodes of the APPF, their structure, capabilities and achievements.

Session 6

Defence Priming And Integrated Management Practice

G. Holroyd, D. Worrall, M. Roberts

Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK

Technology and practice in commercial horticulture has developed rapidly in recent years with ever increasing levels of sophistication. Effective integration of procedures employed must be achieved to produce reliable, workable management plans aimed at maximising yield, quality, efficiency and productivity. Driving these improvements are social, economic and political pressures. Consumers demand quality, healthy produce at a low price, whilst producers look to improve resource use efficiency and productivity at reduced labour costs. Politic pressure is also driving improvements on energy use and agrochemical reduction whilst aiming to maintain food security for an ever increasing global population.

The spiralling costs of agrochemicals, the ever increasing loss of long standing proprietary pesticides through legislation and the growing consumer lead pressure to minimise their use is a significant area impacting on the challenges in developing crop management approaches.

It is now common practice to deploy biological controls in protected crop environments. These have the advantage of reducing the high cost of chemicals and minimise risk of residues in the product. However, biological controls of all types, whether sterile insect, parasite, predator or pathogen carry inherent problems in that the problem must be present before they are effective. The balance between cost, to monitor the crop, and the economic losses from allowing a level of damage to occur is a difficult call and one which comes with significant potential impact.

We have developed a seed treatment technology (Worrall *et al* 2012) which allows plants derived from them to respond more rapidly and more effectively when a pest or pathogen is subsequently encountered. This has comparisons with immunisation in mammalian biology since plant endogenous defence systems are targeted and enhanced rather than directly induced. The methodology, effectiveness and current and potential application of this technology as a component of crop management practice will be presented.

Reference

Worrall D, Holroyd GH, Moore JP, Glowacz M, Croft P, Taylor JE, Paul ND, Roberts MR (2012). Treating seeds with activators of plant defence generates long lasting priming of resistance to pests and pathogens. *New Phytologist* 193:770-778

Session 6

The Science of Growing Media

N. C. Bragg,

Chairman, Horticultural Development Company, Stoneleigh Park, Kenilworth, Warwickshire, Cv8 2TL (neilbragg@btinternet.com)

The challenge faced by the plant breeders at the John Innes Institute in the 1930's (1) is the same one facing all users of substrates for research purposes now- an array of non-uniform mixes made from a whole series of materials which are in no way standardised.

In 1990 when the HDC reviewed the use of 'Peat and its alternatives' (2) there were at least 30 potential ingredients identified as possible physical additives to mixes. Peats alone might easily produce at least ten different materials having been formed under varying conditions in different locations- sedges to young sphagnum mixes are all 'peats' but are all different in their physical, chemical and biological properties. (3)

Therefore in using substrates in the CE the problem the researcher is trying to understand or elucidate may easily be confounded by the fact the Growing media used in the experiment was poorly defined or of such a variable nature that it introduced a separate set of conditions.

In 2011 the UK Government produced a white paper on the natural environment, with ambitious target for the replacement of the horticultural use of 'peats' in England. One of the outputs of the 'Task Force' set up to examine the ways of moving towards the governments aims clearly recognises that at present performance standards for substrates have been lacking. There is now a move towards the establishment of a basic performance standard for Multi-Purpose composts, but I would suggest that all those responsible for work in CE units should actually adopt a simple and straight forward mix standard that they all work with and hence reduce the risks of confounding their experiments.

References

Lawrence W.J.C and Newell J, 1939, Seed and Potting Composts, G Allen and Unwin Ltd

1) Bragg N,C, 1990, Peat and its alternatives, Horticultural Development Council Contract no C900419
2) Bunt A,C, 1976 Modern Potting Composts, G Allen and Unwin Ltd

Sessions 7 and 8

CONSERVATION AND CLIMATE CHANGE (Chair: J. Franklin)

Session 7

Controlled Environment Quarantine Facilities For The Conservation Of Plant Genetic Resources

Sara Redstone

Plant Health & Quarantine Officer, Plant Reception & Quarantine Unit, Royal Botanic Gardens Kew, Kew, Richmond, Surrey, TW9 3AF
(Email: s.redstone@kew.org)

The Royal Botanic Gardens Kew (RBG Kew), a UNESCO World Heritage site, has been involved in the propagation, cultivation and movement of plant material around the globe for more than 250 years. For at least half of that time it has operated a variety of quarantine facilities, often on behalf of government and linked to the UK's changing priorities, so that plant material could be moved safely between countries.

In more recent times, whilst still delivering many services to government, RBG Kew has become a non-departmental public body, working to support and facilitate global plant conservation, taxonomy and research. This work is underpinned by a number of critical controlled environments – most notably the new plant reception and quarantine unit, the Millennium Seed Bank and the Jodrell laboratories insectary. These three facilities include quarantine areas that are licensed by FERA (Food and Environment Research Agency) and the Forestry Commission to handle a range of controlled and prohibited biological materials.

The IUCN (**International Union for Conservation of Nature) has determined that the impact of both climate change and** invasive **n**on-native species are major factors leading to biodiversity loss and habitat destruction. The economic and environmental costs associated with outbreaks of new pests and diseases or with the effects of other types of invasive organisms can be substantial – to individuals, businesses and even nations. In 2010, in a report for Defra (Department of Environment Food and Rural Affairs), CABI estimated the cost of invasive non-native species to the UK economy to be in the region of £1.7 billion per annum.

As a leading plant conservation organisation, and in line with its statutory obligations under the Heritage Act 1983 – Kew Trustees have a duty to maintain and develop the living collections in line with scientific and research needs and to provide a quarantine service. Whilst training, risk assessment, safe practises and procedures can mitigate risks, a system of inspection and quarantine is required to ensure material entering Kew's collections is safe. RBG Kew have developed a new plant reception and quarantine unit, opened in 2011, to replace the former quarantine house which was becoming uneconomic to operate and maintain. The new unit acts as a single point of entry for live plant material and an overview of the development, features and various roles of the new facility in support of Kew's work in plant conservation, research and education.

Session 7

Climate Change Research In The Programme For Experimental Atmospheres And Climate (PÉAC)

C. Elliott-Kingston, A. Holohan and J.C. McElwain

School of Biology and Environmental Science, Science Centre West, University College Dublin, Belfield, Dublin 4, Ireland.
(caroline.elliottkingston@ucd.ie) (aidan.holohan@ucd.ie) (jennifer.mcelwain@ucd.ie)

The Programme for Experimental Atmospheres and Climate (PÉAC) at University College Dublin was established in 2007. It is a unique facility, consisting of 8 CONVIRON BDW40 walk-in growth rooms with capacity to simultaneously monitor and control sulphur dioxide (SO2), carbon dioxide (CO2), and atmospheric O2. Research to date has focused primarily on three major avenues: (a) improving understanding of atmospheric evolution over the past 400 million years through plant-atmosphere and combustion experiments, (2) investigating the evolution of stomatal function in land plants and (3) interpreting fossil plant biodiversity responses to past climate change through controlled environment experiments with modern taxa. The challenges associated with past and ongoing experiments include (a) high running costs, (b) development of an appropriate costing structure for internal and external users, (c) maintaining lamp loft temperature within a reasonable range when working at high light intensities (>1000μm), (d) minimizing damage and precipitation of sulphate salts while working with elevated SO2 (up to 2000ppb), (e) development of appropriate safety protocols for sub-ambient O2 research (in the range of 7 to 15% O2). Perhaps the greatest challenge associated with growth chamber research is the perception amongst some members of the plant sciences community that pot-based experiments in artificial conditions are a poor representation of nature. Our wish list for future development in growth chamber technology includes individual within-chamber plant sensors for light, temperature and humidity; an ability to programme stochasticity in controlled variables at a temporal resolution of minutes; large volume soil modules with in-built sensor technology and in-built thermal imaging and chlorophyll fluorescent imaging. The research focus, challenges and aspirations of PÉAC will be discussed.

Session 7

Controlled Environments in Ecosystem Research

A. Milcu.

CNRS Ecotron,1 Chemin du Rioux, Campus Baillarguet, 34980, Montferrier sur-Lez

Controlled environment facilities for ecosystem research (Ecotrons) are unique tools in ecology particularly well suited for understanding the functioning of ecosystems. Here I present two innovative experimental approaches involving the CNRS Ecotron (Montpellier, France) and Imperial College Ecotron (Silwood Park, UK).

Session 8

Greenhouse Guidelines

A.J. Both (Rutgers University USA)

The latest pre-publication version of the guidelines will be presented and discussed

Session 8

Theory and Observation in Controlled Environment Research: The Zig-Zag Path to Knowledge

Bruce Bugbee Crop Physiology Laboratory Utah State University
bruce.bugbee@usu.edu

Theory: Fundamental principles that form the basis for interpreting new observations.
Observations: Measurements of plant response to environment from individual studies.

Abstracts: Poster Presentations

Poster 1

An Introduction to the Facilities and Research at the Limerick Institute of Technology

C. O’Keeffe [1], G.W. Stutte[2] and M. Bennett[1]

[1]CELLS Research Group, Shannon Applied Biotechnology Centre, Limerick Institute of Technology, Limerick, Ireland. (Email: Catherina.okeeffe@lit.ie)
[2]QinetiQ, Space Life Sciences Laboratory, Kennedy Space Center, Florida 32899, U.S.A.

The Controlled Environment Laboratory for Life Sciences (CELLS) Research Group was established in 2010 as a dedicated research group within the Department of Applied Sciences at the Limerick Institute of Technology. CELLS builds upon a previously established link with the Space Life Science Laboratory at NASA’s Kennedy Space Centre, Florida, with its research efforts focus on utilising state-of-the-art environmental growth chambers for plant growth and development with potential applications in the food and nutraceutical industries. CELLS aims to utilise the skills the graduates developed to establish a Centre of Excellence for the enhancement of bioactive compounds in plants using controlled environments, with outcome pertinent to both terrestrial and extraterrestrial applications. The group focuses primarily on the generation of high-end bioactive molecules from plant sources through forced adaptation under controlled environmental conditions with applications to nutraceutical and functional food industries, and herbal supplement development. However, research within the group also makes use of hydroponic techniques, originating from previous space research, for investigation into areas such as agricultural crop growth, bio-fuel enhancement, and bioflavonoid enhancement, all through non-genetic manipulation, for added nutraceutical value in every day salad crops.

CELLS is one research group within Shannon Applied Biotechnology Centre. Shannon ABC is a commercially focussed, state of the art, research centre. It evolved from a merger between the Natural Products Research Centre (NPRC) based at the Institute of Technology, Tralee and the Nutraceuticals Research Centre (NRC) at the Limerick Institute of Technology. The merger between these two centres was facilitated through the development of the Applied Research Enhancement (ARE) Centre Program, established by Enterprise Ireland and supported by EU structural funds. Shannon ABC focuses on developing, enhancing and commercialising biotechnology in the Shannon region, and beyond, by confidentially collaborating with industry to promote product diversification and enhancement, increasing market growth and aiding competitiveness. Shannon ABC offers expertise in bio-processing, extraction, purification and screening of products derived from a wide variety of natural products and waste streams, with a view to identifying bioactive substances of value to a wide spectrum of industries.

Poster 2

Design, Development and Management of a Large Scale Controlled Environmental Plant Production Facility at: Tamagawa University.

E. Ono, H. Usami, K’ Ohashi-Kaneko’ M’ Fuse’ and H’ Watanabe*

Biosystems & Biofunctions Research center, Tamagawa University Research
Institute,6-1-lTamagawaGakuen,Machida,Tokyo,Japan194-8610
*Department of Life science, Faculty of Agriculture’ Tamagawa University’
6-1-1 Tamagawa Gakuen’ Machid’a’ Tokyo’ Japan 194-8610
(Email: eiichi@lab.tamagawa.ac.jp)

A large scale controlled environmental plant production research centre is under operation at Tamagawa University in Tokyo, Japan. The full research facility, named Future Sci Tech(FST) Lab,has been in operation since May 2010. The main focus of this facility is to explore the possibility of an enclosed

Artificial lighting type plant production facility.The total construction area of the research centre is 801 m2, which includes 115’6m2 for the main cultivation room, the nursery room, the air shower booth, the genetic transformation laboratory with bio safety level2 (P2) the plant photophysiology laboratory, the cold storage room, and the Space agriculture laboratory, which equips a hypobaric chamber and a clinostat. The facility utilizes multiple lighting sources, such as water-cooled high power Chip on Board (COB) Light-emitting Diodes (LEDs),Hybrid Electrode Fluorescent Lamps (HEFLs), and HF fluorescent lamps for plant production

In this facility, leafy vegetables such as lettuce. Herbs (rocket, Japanese basil) were successfully produced. In addition to the variety of leafy vegetables and herbs, medicinal plants such as periwinkie were cultivated. Further, fruit vegetables such as strawberries and potatoes weresuccessfully produced using LED lighting system. Studies on utilization of lnformation and Communication Technology (ICT)for the controlled environmental plant production facility are also being conducted.

Poster 3

Variation in Responses of Arabidopsis Thaliana Accessions to Low Proportions of Far Red in LED Emitted Light

G. Bochenek, T. Pocock

Heliospectra AB, Frans Perssons väg 6, Delsjömotet, Göteborg 412 76 Sweden (Email: tessa@heliospectra.com)

In most cases laboratory plants are grown under fluorescent or mixture of fluorescent and incandescent light. In some cases metal halide or HPS lamps are also employed. Recently, the increasing number of researchers uses LEDs as a light source. The main advantage of LED lamps is efficiency of energy conversion, low temperature of light beam and plasticity allowing selecting specific wavelengths and easily modifying a light regime for a targeted plant response.

The effect of different red to far-red ratios (R/FR) on Arabidopsis morphology is well described in the literature, and includes flowering time, number of rosette leaves and development of axillary buds. Yet the optimal level of FR for vegetative growth is not known. Additionally, it has to be taken into account that responses to R/FR ratio are ecotype dependent. Photomorphological responses depend on the photoequilibrium of Pr and Pfr forms of phytochrome, which is defined not only by R/FR but by the whole spectral composition of incident light. Phytochrome signalling is also linked with activity of other photoreceptors.

The purpose of our study was to characterise growth of the most popular background accessions (wild types) of Arabidopsis thaliana under LED light regimes with decreasing R/FR ratio, and to compare it with plant performance under traditional light sources. The original Landsberg ecotype (La-0), Landsbeg erecta (Ler-1), Columbia (Col -1) and Wassilewskija (Ws-0) were grown under HPS, fluorescent light and three LED light regimes: the Helio basic LED regime (BR) which provides a PAR spectrum minus FR, and BR altered by adjusting the amount of far-red light to achieve 8:1 and 3.5:1 R/FR ratios. Seedlings with two first true leaves were placed in growth units in a temperature-controlled room. They were grown in in long day photoperiod in 25/15°C and 120µE PAR. We recorded the date of flowering start, number of primary and secondary rosette lives and the number of secondary rosettes. We also measured chlorophyll content and chlorophyll fluorescence.

Shade avoidance responses seam to be proportional to FR level, however might be accelerated by high proportion of green and/or long blue in a spectrum. The FR level had little effect on flowering time particularly in Landsberg erecta ecotype. In the LED regime without FR, plants had almost all rosette buds activated, producing multiple secondary rosettes and flowering stems. The total number of leaves, particularly in the Col accessions was similar to those reported in the literature for plants grown in short day photoperiod. In result, the plants had large vegetative growth as well as high reproductive output.

Poster 4

Short-Duration Blue Light from Light-Emitting Diodes Impacts Important Glucosinolates and Mineral Elements in Sprouting Broccoli (Brassica oleracea L.)

Carl E. Sams* and Dean A. Kopsell

Plant Sciences Department, The University of Tennessee, Knoxville, TN 37996 USA

Microgreens are a specialty leafy green harvested shortly after the first true leaves have emerged. They are harvested just above the roots and consumed fresh as salad greens. Microgreens have a quick production cycle (two to three weeks) and occupy very little space in controlled environment production. Broccoli (Brassica oleacea L.) microgreens can accumulate significant concentrations on cancer-fighting glucosinolates. Light-emitting diodes (LEDs) offer the ability to measure impacts of specific wavelengths of light on seedling physiology. The objective of this study was to measure the impact of short-duration blue light on the nutritional quality of broccoli microgreens. Broccoli microgreens were grown in a modified environment under LEDs using Sure to Grow□pads. Seeds were cultured under a 24 h photoperiod under red (627 nm)/blue (470 nm) LEDs (350 μmol□m2□sec1) at 23 °C. Upon emergence of the first true leaf, a nutrient solution of 42 mg nitrogen per L was used to submerge the growing pads. At 13 days after sowing, broccoli microgreens were grown under either: 1) red/blue LEDs (350 μmol□m2□sec1); or 2) blue LEDs only (41 μmol□m2□se c1). Microgreens were harvested after 5 days of the LED treatments. Shoot tissues were freeze dried and measured for glucosinolates and mineral elements. The pre-harvest blue LED treatment significantly increased shoot tissue glucoraphanin (P = 0.03); aliphatic glucosinolates (P = 0.04); essential micronutrients of B, Cu, Fe, Mn, Zn (P□ 0.01), and the essential macronutrients of Ca, P, K, Mg, S (P □0.001). Management of LED lighting technology in controlled environments may be a way to increase the nutritional value of broccoli microgreens.

Poster 5

Nutritionally Important Pigments in Sprouting Broccoli (Brassica oleracea L.) Respond to Short-Duration Blue Light from Light-Emitting Diodes

Dean A. Kopsell* and Carl E. Sams

Plant Sciences Department, The University of Tennessee, Knoxville, TN 37996

Microgreens are specialty leafy crops harvested just above the roots after the first true leaves have emerged and consumed fresh. Broccoli (Brassica oleacea L.) microgreens can be a rich source of anti-oxidant phytochemicals, such as carotenoids. Carotenoid pigment concentrations will respond to changes in the light environment, and zeaxanthin carotenoids are hypothesized to be blue-light receptors in plant physiology. Light-emitting diodes (LEDs) now provide the ability to measure impacts of specific wavelengths of light on seedling morphology and physiology. The objective of this study was to measure the impact of short-duration blue light on nutritionally important pigments in sprouting broccoli microgreens. Broccoli microgreens were grown in a modified environment under LEDs using Sure to Gro□ pads. Seeds were cultured on the pads and grown under a 24 h photoperiod under red (627 nm)/blue (470 nm) LEDs (350 µmo□m2□sec1) at 23 °C. Upon emergence of the first true leaf, a nutrient solution of 42 mg nitrogen per L (20% Hoagland's #2 solution) was used to submerge the growing pads. At 13 days after sowing, broccoli plantlets were grown under either: 1) red/blue LEDs (350 µmol□m2□sec1); or 2) blue LEDs only (41 µmol□m2□sec1). Microgreens were harvested after 5 days of the LED treatments. Shoot tissues were freeze dried and measured for chlorophyll and carotenoid pigments. Comparison of the two LED light treatments revealed the pre-harvest blue LED treatment significantly increased shoot tissue β-carotene ($P = 0.04$); violaxanthin ($P = 0.006$); and total xanthophyll cycle pigments ($P = 0.03$). However, shoot tissue chlorophyll b was higher under red/blue LED light ($P=0.04$). Results demonstrate management of LED lighting technologies through pre-harvest, short-duration blue light

Poster 6

Spectral Characteristics of Lamp Types for Plant Biology

Bruce Bugbee
Crop Physiology Laboratory
Utah State University

The study of the effects of light on biological organisms became a highly respected science in 1903 when Niels Ryberg Fisen was awarded the Nobel prize in Physiology and Medicine for his pioneering contributions to the therapeutic use of light. His work led to the widespread belief that significant exposure to sunlight was an essential component of health and well-being. Plant photobiologists have worked to elucidate the complex interactions of radiation quality on plant growth and development since Emerson and Arnold first developed an action spectra for photosynthesis in the 1930's.

Two recent developments warrant a comprehensive characterization of the radiation from electric lamps:

1) Spectroradiometers capable of accurately measuring radiation below 300 nm are now more widely available.
2) Advances in technology have provided an increased range of options for plant lighting.

Poster 7

A Method for Estimating Somatal Conductance with Combination of Temperature Measurements on Intact and Imitation Leaves

Yoshiaki KITAYA, Kazuha KAYANO, Noboru IKEDA, Toshio SHIBUYA and Ryosuke ENDO
Graduate Graduate School of Life and Environmental Sciences, Osaka Prefecture University Sakai, Osaka 599-8531, Japan

1. Introduction

Stomatal aperture of leaves is lowered and transpiration and photosynthesis are suppressed, when plants suffer from water stress. Monitoring of stomatal behavior, therefore, is important to control plant growth. In this study, a method for simply monitoring stomatal aperture in plant production sites was developed, which is based on the heat balance method.

2. Materials and methods

An index of stomatal aperture (SAI, hereafter) was derived from heat balance equations on intact, wet reference and dry reference leaves as followings; The heat balance of the leaf is generally shown by the following equation.

$$R - H - \lambda E = R - c_p g_{Ha} (T_L - T_a) - \lambda g_{vL} (e_s(T_L) - e_a)/p_a = 0 \quad (1)$$

Temperatures of intact (TL), wet reference (TW) and dry reference (TD) leaves are obtained from equation (1) as shown bellow.

$$T_L = T_a + \frac{R - \lambda g_{vL} \frac{e_s(T_L) - e_a}{p_a}}{c_p \cdot g_{Ha}} \quad (2), \qquad T_W = T_a + \frac{R - \lambda g_{vW} \frac{e_s(T_W) - e_a}{p_a}}{c_p \cdot g_{Ha}} \quad (3), \qquad T_D = T_a + \frac{R}{c_p \cdot g_{Ha}} \quad (4)$$

Then, following equations are derived.

$$\frac{T_D - T_L}{T_D - T_W} = \frac{g_{vL}}{g_{vW}} \times \frac{e_s(T_L) - e_a}{e_s(T_W) - e_a} \quad (5), \qquad \frac{e_s(T_W) - e_a}{e_s(T_L) - e_a} \simeq \frac{T_W - T_X}{T_L - T_X} \quad (6), \qquad \frac{T_D - T_L}{T_D - T_W} \times \frac{T_W - T_X}{T_L - T_X} \simeq \frac{g_{vL}}{g_{vW}} = \mathrm{SAI} \quad (7)$$

The method for getting SAI was verified experimentally with tomato plants grown hydroponically in a greenhouse. The wet reference leaf made of a paper sheet and the dry reference leaf made of an aluminum plate were placed near a intact tomato leaf. Leaf temperatures were measured with thermocouples. The experiment was conducted at air temperatures of 22-45°C and water vapor pressure deficits of 5-60 hPa on fine and cloudy days.

3. Results and discussion

The SAI estimated in this method was consistent with the leaf conductance measured with the porometer method that is a standard method for evaluating the leaf conductance that mainly consists of the stomatal conductance.

This method can be used for continuously monitoring stomatal behavior of plants in greenhouses and fields. The monitored data will be useful not only for studies on interactions between plants and environment but also for management of watering.

Poster 8

At 50 the Canberra Phytotron joins the digital age!

Tony Agostino
CSIRO Division of Plant Industry
Black Mountain Laboratories
PO Box 1600
Canberra, Australian Capital Territory, 2601
Australia
(tony.agostino@csiro.au**)**

In September 2012, the Canberra Phytotron celebrates its 50 anniversary. On of the worlds first large scale phytotrons it features an impressive collection of refrigerated glasshouses, artificially-lit controlled environment cabinets, photo-period cabinets and support laboratories.
Over five decades the Phytotron has been host to successive waves of plant research activity ranging from plant physiology, agronomy, ecology, plant breeding, molecular biology and genomics, and more recently plant phenomics.
With each wave of new activity, the facility has adapted to incorporate new technologies, work practices and an ever changing regulatory compliance environment.

Whilst the Phytotron has undergone a number of building modernisation programs to maintain its integrity and capabilities, these have been particularly significant in the last 5 years. Notably, these include the re-development of the lower level of the building into the *High Resolution Plant Phenomics Centre* and the current upgrade of main controlled environment facilities that will see the installation of 70 new growth cabinets and a full refurbishment of laboratories and support facilities.

This poster provides an overview of the Canberra Phytotron’s journey over the last 50 years and outlines some of the current upgrades that place it at the forefront of the new digital phenomics revolution.

Poster 9

Spectral Errors from Three Commercial Quantum Sensors Under LEDs and Other Electric Lights

J. Mark Blonquist Jr.[1], B. Bugbee[2]

[1]Apogee Instruments, Inc., Logan, Utah
(mark.blonquist@apogeeinstruments.com)
[2]Dept. of Plants, Soils, and Climate, Utah State University, Logan, Utah
(bruce.bugbee@usu.edu)

Light emitting diode (LED) technology has advanced rapidly in recent years and LEDs are increasingly being used in plant growth chambers. Measurement of photosynthetic photon flux (PPF; □mol m^{-2} s^{-1}) using quantum sensors can be associated with significant errors because of the unique spectral output of LEDs (e.g. narrowband output). A spectroradiometer with accurate cosine correction is the preferred instrument to measure PPF of electric lights, particularly LEDs. Although the cost and ease of use of spectroradiometers has improved significantly over the past decade, they are still an order of magnitude more expensive than quantum sensors. As a result, quantum sensors and/or meters are often used to measure PPF from LEDs. However, use of quantum sensors introduces spectral error because no commercially available quantum sensors perfectly match the defined plant quantum response for PPF measurement: equal weighting of all wavelengths between 400 and 700 nm. Spectral errors for three commercially available quantum sensors (LI-COR, Kipp & Zonen, and Apogee) were determined for eight common narrowband (specific color), broadband (white), and mixed color LEDs, as well as other common electric lights used in growth chambers (cool white fluorescent, metal halide, high pressure sodium). Under LEDs, spectral errors were less than 3 % for Kipp & Zonen sensors (new PQS 1 model), less than 7 % for LI-COR sensors (LI-190 model), and less than 11 % for Apogee sensors (SQ-120 model). Spectral errors are dependent on the spectral response of the specific quantum sensor and were typically smaller for the broadband LEDs than for the narrowband LEDs. Under the other electric lights, spectral errors were less than 4 % for all quantum sensor models. Quantum sensors can be a practical means of measuring PPF from electric lights, including LEDs, but spectral error should be considered when making measurements.

Poster 10

Mini-Lysimeters to Monitor Transpiration and Conductance and to Control Drought Stress

J. Chard[1], M. van Iersel[2,*], and B. Bugbee[1]

[1] Department of Plants, Soils and Climate, Utah State University, Logan, Utah, 84322, USA
[2] Department of Horticulture, University of Georgia, Athens, Georgia 30602, USA (Email: mvanier@uga.edu)

Methods for the precise control of drought stress have been a holy grail of plant biology research. We have developed a mini-lysimeter system, using balances or load cells to monitor and control the mass of a soil/plant system. Data collection and control functions are fully automated using a datalogger. These mini-lysimeter systems are easily scalable to different applications. Because short-term weight changes are normally small compared to the overall mass of the plant/pot, averaging of multiple measurements is needed to remove excessive noise in the data.

The system can be programmed to maintain a steady-state reduction in transpiration compared to well-watered control plants, and can continuously monitor whole-plant stomatal conductance. Conversely, the system can be used to monitor transpiration and conductance as drought becomes gradually more severe. Mini-lysimeters are also useful for quantifying water use efficiency, whole-plant stomatal oscillations, and plant-available water in the root-zone.

Poster 11

Spectral Characteristics Of Lamp Types Of Plant Biology

Bruce Bugbee

Utah State University

The study of the effects of light on biological organisms became a highly respected science in 1903 when Niels Ryberg Fisen was awarded the Nobel Prize in Physiology and Medicine for his pioneering contributions to the therapeutic use of light. His work led to the widespread belief that significant exposure to sunlight was an essential component of health and well-being. Plant photobiologists have worked to elucidate the complex interactions of radiation quality on plant growth and development since Emerson and Arnold first developed an action spectra for photosynthesis in the 1930’s. Compared to sunlight, all lamps are deficient in UV radiation. Measurement of the weighted UV is recommended to quantify the UV effects. Blue light is generally deficient in electric lamps, and most new lamps have a lower fraction of blue light then the lamps they are replacing. Most new lamps also have significantly less UV than older lamps. The ratio of YPF to PPF ranges from 0.89 to 0.91 for sunlight and for most of the lamps in this study. Higher values for this ratio (0.95; HPS lamps) indicate that plant growth might be slightly better than the PPF as measured by a standard quantum sensor. The red/far-red ratio varies widely because there are only trace amounts of far-red radiation from many lamps. The measurement of Phytochrome Photoequlibria (PPE) may provide a more comprehensive measurement of the effects of phytochrome on plant development, but PPE still underestimates blue light effects. According to the PPE, the radiation from all common lamps would be perceived as bright sunlight, since the PPE is greater than 0.72.

Poster 12

Short-Duration Blue Light from Light-Emitting Diodes Impacts Important Glucosinolates and Mineral Elements in Sprouting Broccoli (Brassica oleracea L.)

Carl E. Sams* and Dean A. Kopsell

Plant Sciences Department, The University of Tennessee, Knoxville, TN 37996 USA

Microgreens are a specialty leafy green harvested shortly after the first true leaves have emerged. They are harvested just above the roots and consumed fresh as salad greens. Microgreens have a quick production cycle (two to three weeks) and occupy very little space in controlled environment production. Broccoli (Brassica oleacea L.) microgreens can accumulate significant concentrations on cancer-fighting glucosinolates. Light-emitting diodes (LEDs) offer the ability to measure impacts of specific wavelengths of light on seedling physiology. The objective of this study was to measure the impact of short-duration blue light on the nutritional quality of broccoli microgreens. Broccoli microgreens were grown in a modified environment under LEDs using Sure to Grow? pads. Seeds were cultured under a 24 h photoperiod under red (627 nm)/blue (470 nm) LEDs (350 µmol?m2?sec1) at 23 °C. Upon emergence of the first true leaf, a nutrient solution of 42 mg nitrogen per L was used to submerge the growing pads. At 13 days after sowing, broccoli microgreens were grown under either: 1) red/blue LEDs (350 µmol?m2?sec1); or 2) blue LEDs only (41 µmol?m2?sec1). Microgreens were harvested after 5 days of the LED treatments. Shoot tissues were freeze dried and measured for glucosinolates and mineral elements. The pre-harvest blue LED treatment significantly increased shoot tissue glucoraphanin ($P = 0.03$); aliphatic glucosinolates ($P = 0.04$); essential micronutrients of B, Cu, Fe, Mn, Zn (P ? 0.01), and the essential macronutrients of Ca, P, K, Mg, S (P ? 0.001). Management of LED lighting technology in controlled environments may be a way to increase the nutritional value of broccoli microgreens.

USDA NCERA-101
NCR-101
Committee on Controlled Environment Technology and Use

ACEWG
Australasian
Controlled
Environment
Working Group

United Kingdom Controlled Environment Users' Group
UK
CEUG

Attendees

Trade Stands

Apogee Instruments Inc. {Apogeeinstruments.Com}
Argus Control Systems {Arguscontrols.Com}
Biochambers Inc. {Biochambers.Com}
Bridge Greenhouses Ltd {Bridgegreenhouses.Co.Uk}
Cambridge Hok Glasshouse Co {Cambridgehok.Co.Uk}
Clf Plantclimatics {Plantclimatics.De}
Conviron {Conviron.Com}
Cycloptics Technologies Llc {Cycloptics.Com}
Gavita As {Gavita.Com}
Illumitex {Illumitex.Com}
Lemnatec Gmbh {Lemnatec.Com}
Li-Cor Biosciences {Licor.Com}
Percival Scientific {Percival-Scientific.Com}
Philips Lighting {Philips.Com}
Rotronic Instruments Ltd {Rotronic.Co.Uk}
Skye Instruments {Skyeinstruments.Com}
Unigro {Unigro.Co.Uk}
Vaisala {Vaisala.Com}
Weiss-Gallenkamp {weiss-gallenkamp.com}

Attendees

NAME	COMPANY	COUNTRY
Adamson George	Ontario Scientific	Canada
Agostino Tony	CSIRO	Australia
Albright Lou	Cornell University	USA
Alger Damian	John Innes Centre	UK
Alexander Paul	Royal Horticultural Society	UK
Allen John	University of St Andrews	UK
Andrews Stephen	Sainsbury Lab Cambridge	UK
Barauskas Rimantas	Syngenta	UK
Benjamin Laurence	Rothamsted research	UK
Bijl John	Vitroplus	Netherland
Blonquist Mark	Apogee Instruments	UK
Bochenek Grazyna	HelioSpectra	Sweden
Booth Liz	Weiss-Gallenkamp	UK
Both A.J.	Rutgers University	USA
Bouchard Keri	Conviron	Canada
Buchhoiz Martin	Watergy GmbH	Germany
Bragg Neil	HDC	UK
Brault David	Quebec	Canada
Brett Rob	Sainsbury Lab Cambridge	UK
Bugbee Bruce	Utah State University	USA
Butsele Jan Van	Bayer Crop Science	Belgium
Cabrera-Poch Hector L.	HSE	UK
Cleland Tracey	Vaisala, Birmingham	UK
Connole Lisa	Limerick Institute of Technology	Ireland
Cookson Alan	IBERS, Aberystwyth University	UK
Cordy Rebecca	John Innes Centre	UK
Creasy Robert	University of Western Australia	Australia
Cromphout Peter	Bayer Crop Science	Belgium
Daff Jason	Syngenta	UK
Darby Robert	Aberystwyth University	UK

Denston Colin	University of Cambridge	UK
Elliott-Kingston Caroline	University College, Dublin	Ireland
Fatten Jason	Ball Horticultural Co.	USA
Ferguson Marc	Illumitex Inc.	USA
Fox Chris	Rotronic	UK
Franklin Julian	Rothamsted research	UK
Fryars Christopher	CLF Plant Climatics GmbH	Germany
Fryars Eva	CLF Plant Climatics GmbH	Germany
Fuller Mick	Plymouth University	UK
Gardner Gary	University of Minnesota	USA
Giacomelli Gene	University of Arizona	USA
Gill Peter	Scottish Crop Research (Retired)	UK
Gilroy Matthew	Conviron Europe Ltd.	UK
Gilzean Fiona	Rothamsted Research	UK
Goodhew Steve	Plymouth University	UK
Glanfield Peter	Jealott's International Research	UK
Gray Paul	Illumitex Inc.	USA
Greer Dennis	Charles Sturt University, NSW	Australia
Griffin Anthony	Rothamsted Research	UK
Guy Steven	Norwich Bioscience Inst.	UK
Hansen Laurence	University of Reading	UK
Hart Simon	Writtle College	UK
Haupt Sophie	University of Edinburgh	UK
Healy William	Ball Horticultural Co.	USA
Herrick Xander	Stanford University	USA
Hillberg Staffan	HelioSpectra	Sweden
Holmes-Henderson Guy	Syngenta	UK
Holroyd Geoff	Lancaster University	UK
Hughes Martin	Weiss-Gallenkamp	UK
Hummel Lynn	University of Wisconsin	USA
Humphreys Colin	University of Cambridge	UK
Imberti Henry	Percival Scientific Inc.	USA
Incoll David	Guest	UK
Jansen Erik	Philips Lighting	Netherland
Kanwar Rameshwar	Iowa State University	USA
Karlsson Bjorn	University of Wisconsin	USA

Kerslake Janeane	Kerslake Associates	Australia
Kerslake Rob	Kerslake Associates	Australia
Kettner Bruce	Biochambers	USA
Kitaya Yoshiak	Osaka University	Japan
Klaver Monique	Spectra Partners	Belgium
Kroft Steve	Conviron	Canada
Langley Paul	University of Cambridge	UK
Lefsrud Mark	McGill University	Canada
Ling Peter	Ohio State University	USA
Mackenzie Alec	Argus Controls	Canada
Mackenzie Marlene	Argus Controls	Canada
Marcelis Leo	Wageningen University	Netherlands
Massa Gioia	NASA -Kennedy Space Centre	USA
Mc Donnell Geoffrey	University of NSW	Australia
Milcu Alex	CNRS Ecotron	France
Mitchell Cary	Purdue University	USA
Mitchell Letty	Purdue University	USA
Morgan Alan		UK
Mukanik Bill	Conviron	Canada
Mulder Jan	Gavita	Netherland
Natt Richard	FERA	UK
Newman Lisa	Pioneer	USA
O Keeffe Catherine	Limerick Institute of Technology	Ireland
Ono Eiichi	Tamagawa University	Japan
Oosterhuis Derrick	University of Arkansas	USA
Overly Devin	Apogee Instruments	UK
Padfield Angus	Unigro Ltd.	UK
Paul Alexander	RHS-Wisley	UK
Peekstock Thijs	Monsanto	Holland
Pelletier Nicolas	Quebec	Canada
Penketh Lance	University of Leeds	UK
Perkins Lionel	John Innes Centre	UK
Pitkin Graham	James Hutton Institute	UK
Pocock Tessa	HelioSpectra	Sweden
Procter Chris	ADAS UK Ltd	UK
Quiring Reg	Conviron	Canada

Redstone Sarah	Royal Botanic Gardens Kew	UK
Reid Sharon	Conviron.	Canada
Robertson Barry	John Innes Centre	UK
Romer Mark	McGill University	Canada
Runkle Eric	Michigan State University	USA
Ryheul Bernard	Bayer Crop Science	Belgium
Sager John	NASA (Retired)	USA
Samworth Beccy	Norwich Bioscience Institute	UK
Saravitz Carole	North Carolina State University	USA
Sheridan Flip	Cycloptics Technologies	USA
Steven Guy	Norwich Bioscience Institute	UK
Stutte Gary	QinetiQ-NA	USA
Taylor Garry	Weiss-Gallenkamp	UK
Theroux Marc	Biochambers	USA
Timbol Thomas	Texas A&M University	USA
Van Butsele Jan	Bayer Crop Science	Belgium
Van der Meij	Spectra Partners B.V	Netherlands
Van Echtelt Esther	Philips Lighting	Netherland
Van Lersel Marc	University of Georgia	USA
Visser Cees	Visser International	Netherland
Walker Tony	Bridge Greenhouses	UK
Waterland Nicole	West Virginia University	USA
West Diana	Utah State University	USA
Wierzchowski John	EGC Aurora	USA
Wilson Dave	Stanford University	USA
Wilson Sheryl	Stanford University	USA
Wingate Jeremy	Rotronic	UK
Wood Frazer	Weiss-Gallenkamp	UK
Xander Herrick	Stanford University	USA
Zheng Youbin	University of Guelph	Canada