The Power to Control

Summaries of talks given at the International Controlled Environment Conference, Brisbane, March 2004

Edited by

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Please note that it is not intended to submit this manuscript in its present form to the *New Phytologist* or any other journal. It is simply an edited form of the summaries submitted by the following delegates to the conference who were all bursary holders. A paper suitable for submission to *New Phytologist* will follow.

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Introduction:
Plant scientists worldwide have sought to control environments to grow plants since Greek and Roman times (Enoch & Enoch 1999). However, first attempts at testing the idea that growing sensitive plants in heated courtyards could improve growth and survival can only be classed as scientific in a loose sense. Things have moved on over 2,000 years and we now have international conferences on how we grow plants in controlled environments, and perhaps more importantly, why. We (Earth dwellers) are now exploring systems to grow plants on the Moon and Mars. The International Controlled Environment Meeting in Brisbane (Australia) during March 2004 included about 100 delegates from around the world who gave some 40 presentations on their areas of interest and responsibility. The talks varied from Mark Roehrs of Queensland, who gave the opening address, describing how to build a plant research unit where adaptability was the key, with principles such as sustainability, affordability, efficiency and availability being major factors. We heard from Neil Yorio from Florida how light emitting diodes may be the key to growing lettuces (*Lactuca sativa*) in space and from Kevin Sawford of England how controlled vernalisation in sugar beet (*Beta vulgaris)* is the key to quick plant-to-seed turn around. The variety of talks was startling, but common ground was the need to control plant growth to discover more about the phytosphere and how best it can serve both mankind and environment.

Showcasing technology, Australia/Pacific Rim. **Monday 15 March**

Controlled Environment Facility (CEF) in Brisbane. Rob Kerslake. (Australia) 9:30.
An overview was given of the CEF at CSIRO Plant Industry at Queensland Bioscience Precinct in Brisbane. The facility was built in 1993 for the Division of Tropical Crops and Pastures, for work on stress physiology and plant nutrition. There are 14 rooms of which, six standard units are 3m high with a 9m^2 floor area, four tall units are up to 8m high with a 9m^2 floor area and four small units that are 3m high with a 4.5m^2 floor area. Temperature, humidity, light and CO2 can be precisely controlled. Lighting is via up to 6 x 1kW metal halide and 6 x 1kW tungsten lamps, screened with a water barrier, providing up to 500 µmol m^2 s^{-1}. Currently work is concentrating on barley, soybean, mungbean, wheat, *Macadamia* and *Arabidopsis* whereas in the past the emphasis was on sugarcane. The facility is a certified PC2 (Planthouse) containment facility for work with transgenic plants.
Reporter: Julian Franklin

The Canberra Phytotron. Tony Agostino. (Australia) 09:45.
An overview was given of the range of controlled environment facilities at CSIRO's Plant Industry Division in Canberra. There are around 6,000m^2 of plant growth facilities supporting 550 research staff working in plant breeding, molecular biology, agronomy, ecology, biochemistry and plant physiology. Increasingly the emphasis of work has shifted towards molecular biology and growing of *Arabidopsis*. The Canberra Phytotron, containing 15 air conditioned (heat pumps) glasshouses (605m^2), 60 reach in cabinets and a variety of walk in rooms was commissioned in 1962 and recently refurbished in 2000 costing AUS $2million. The facility is registered as a PC2 (Planthouse) containment facility for working with transgenic plants. Also, there are 55 individual glasshouses with a total area of 3850m^2 and Biosafe facility (PC2

Planthouse) of five 200m^2 glasshouses. There are also six Conviron "walk in" Cabinets.
Reporter: Julian Franklin

The Adelaide CE Facility. Lance Hoare. (Australia) 10:15.
The speaker started by telling the audience that Adelaide was the capital city of South Australia and despite only housing 5% (1.5 million people) of the nation's population it accounted for a larger share of the country's primary produce, for example 42% of its wine, 33% of barley, 13% of wheat, 20% of fish and 11% of sheep. The speaker then went on to describe how the South Australian Research & Development Institute (SARDI) was organised and the areas of research that it was involved with. Then he described the facilities of their main Plant Research Centre at the Waite Research Precinct at Urrbrae showing examples of the different CE and glasshouse facilities and the capabilities that these facilities could perform to including rooms that have ultra high PAR lighting and frost rooms that had a temperature range of -20°C to + 30°C. In concluding he mentioned how the Research centres worked to their standards but with energy efficiency as a major factor.
Reporter: Kevin Sawford

The Tasmanian Facility. Ian Cummings. (Australia) 11:00.
In the introduction the speaker stated that the facilities were built in the 1960s and with renovation much needed how A$1 million had been gained. He then went on to describe how this money had been spent and showed examples of the facilities that had been constructed. These consisted of an upgrade to their phytotron glasshouse including new fogging system, shade screens and some air conditioning. Continuing on the speaker's main focus was to describe their new ecophysiology and photomorphogenesis facilities showing examples of the way the environmental factors were controlled, the units that controlled these and how it was all monitored and managed. The speaker finished off the talk by describing how they had developed a narrow band monochromatic LED lighting system showing how the users were able to use this set up to avoid light contamination.
Reporter: Kevin Sawford

The New Zealand CE Laboratory. C. Norling. (New Zealand) 11:15.
The NZCEL in Palmerston North Research Centre under the control of HortResearch was renamed in 2000, and in 2001 a transgenic containment facility was added. It comprises 24 3m x3m x3m chambers which are microprocessor controlled and lit by metal halide and tungsten light supplying 0-1500μmol m^{-2} s^{-1} 5min to 24h photoperiod, R/FR ratio 0.8-4.6, temperature 5-45°C, RH 30-100%. A convective freezing capability is available to -25°C capable of delivering white or black frosting events with snow options. The five new containment rooms are licensed to PC2 regulation levels with upgrade to PC3 possible. Media possibilities include composts, rockwool, hydroponics and aeroponics and includes root temperature control. Some rooms are networked by camera with reports by web teleconferencing for direct viewing of contents remotely. This modern facility needs to recover full costs to remain viable. Users are charged full economic cost for their use. More recently, usage of the facility has altered with uptake by Sports Scientists and other non-plant scientists. At present there is about 75% external client usage.
Reporter: Mick Fuller

The New Phytotron at the Kennedy Space Centre. Neil Yorio. (USA) 11:45.
The new Space Life Sciences (SLS) Laboratory at Kennedy Space Centre is designed to research bio-generative life support systems for use in space. There are 15 CE units totalling 43m^2 controlling temperature, humidity, light quality/quantity and CO_2 concentration. SLS laboratory is managed by the Dynamic Corporation & includes staff from NASA and the University of Florida. Core capabilities include flight operations, mission support, animal care, aseptic operations, molecular biology, analytical chemistry and a phytotron. There is also an Orbitor Environmental Simulator (OES). Past research includes using LEDs with salad crops using green light in conjunction with blue and red to improve appearance and penetration. There have been some unique responses including leaf oedema possibly due to lack of UV light. Also, reduced anthocyanins in red lettuce. Other results include stomata closing when CO_2 levels reach 2000ppm (v/v) in sealed chambers and pollination is inhibited at 1000ppm (v/v). Problems include ethene contamination of CO_2.
Reporter: Martyn Stenning

Summary and general discussion of Session 1.
Neil Yorio was asked a question on the oedema resulting on leaves of peppers under fluorescent lights. Although this was usually UV related it was noted that others had experienced oedemas in peppers. There was a discussion centred around the CO_2 used in the Space Life Sciences Phytotron at the Kennedy Space Centre, in terms of the concentrations (+30,000 ppm, v/v), the need to scrub CO_2 to prevent 'contamination' of other ambient rooms, CO2 scrubbing systems, contamination of CO_2 supplies. Comments from B. Bugbee, G. Taylor, R. Wheeler, and M. Romer, all endorsed the need to filter CO_2 with potassium permanganate as well as the need to source the CO_2 carefully. Ethylene glycol was also noted as another contamination source in CE facilities with plants such as marigolds being sensitive. C. Mitchell and I.Cummings noted the need for fresh air exchange to prevent any build up of gaseous contaminants. It was confirmed that the new CE facilities at ANU in Canberra delivered light levels exceeding 2,400µmol m^2 s^{-1}.
Reporter: Julian Franklin

What Controlled Environments can/can't do technically

Lighting Systems. R. Kerslake. (Australia) 16:00.
Queried what was necessary in controlled environments in modern controlled environment facilities. Most Phytotron facilities were constructed to conduct realistic plant/crop physiological studies but is this still necessary? Increasingly, users of the CE facilities are molecular biologists often requiring basic facilities for growing *Arabidopsis*. Who now decides what is necessary to give meaningful physiological data with respect to Arabidopsis, the molecular biologists, the physiologist or the engineer? Reducing the lighting specification in growth rooms does not appear to affect Arabidopsis and lower specificationss can reduce running costs by two thirds. There is definitely a possibility that the responses observed in crude CEs are interacting with the genetics being studied which could create false observations. There is a risk that CE facilities could be de-commissioned or down-graded to provide adequate facilities now which later, when transgenics moves more into crop plants, prove inadequate to give true physiological responses.
Reporter: Mick Fuller

RH/VPD Control. Reg Quiring. (Canada) 16:20.
Relative humidity (RH) describes the moisture content of air, and affects plant growth. This presentation addressed controlled environment capabilities to achieve a range of RH conditions. Most plants require RH control of between 40% and 80%. However, some experiments require higher or lower RH. Many factors affect RH in glasshouses. Temperature is important, but the RH is also affected by lighting (on or off), plant load, irrigation systems and air changes. Relationships between RH, temperature (dry and wet bulb), VPD and dew point are illustrated by use of a psychometric chart, showing how changes in one parameter affects others. The amount to which desired RH deviates from ambient conditions is directly related to energy required, complexity and cost of equipment needed to maintain this. Large deviations from ambient conditions require higher capital and recurrent expenditure. Critically, selection of mechanical systems and accurate controls should be carefully considered if desired RH deviates significantly from ambient. Generally, increasing RH by adding moisture is easier and cheaper than removing moisture to reduce RH. Raising RH can be achieved by reducing air changes or adding moisture (e.g. steam injection, atomising liquid water, etc). Lowering RH is achievable by increasing air changes, using cooling coils, chemical dryers or desiccant dehumidifiers.
Reporter: Joe Aldous

CO_2 Control. Mark Romer. (Canada) 16:40.
There has been considerable development of carbon dioxide sensors in recent times but comparatively little integration of these sensors into controlled environment facilities. Only 5-15% of chambers and 20-25% of research glasshouses are equipped to control CO_2 at some level. Small changes in CO_2 levels in CEs can dramatically change a plant's growth rate hence control may become much more important. Multiplex systems exist that draw samples from different controlled environment compartments to a single analyser using a system of tubes. An integrated controller can then control additive CO_2 levels to the range of 350 to 3000$\mu mol.mol^{-1}$ to a degree of accuracy of 5-20% from bottled carbon dioxide supplies. Reduced CO_2 levels in CEs can be achieved by using scrubbing agents such as sodalime. On attempting to control carbon dioxide in controlled environments for experimentation purposes, it is important to calibrate the sensors frequently, verify non-compensating sensors and use the same type of sensors when replicating or repeating work.
Reporter: Graham Pitkin

Temperature Control. Paul Austin. (New Zealand) 17:00.
Temperature control in CE facilities is important, and technology for measuring and manipulating the temperature is generally well understood. Most CE regimes require either constant or two-stage diurnally varying temperatures that produce artificially stable environments. However, more complex temperature patterns are required to reveal the effects of response dynamics or metabolic control under fluctuating environments. Recent work at NZCEL has used a complex system of pseudo-random ternary temperature sequences to study room thermodynamics and plant responses under fluctuating environments. To achieve rapid rates of temperature changes (typically between 15°C, 22.5°C and 30°C) requires very accurate control systems with fast response times to avoid conflicts between heating and cooling systems. Initial trials have been encouraging and the CE rooms are being upgraded to allow faster response times to frequent temperature changes. Condensation has been a big

problem due to slow response time of the humidification system. Improved insulation of the CE is also required to reduce under and over-shoot of temperature. This will provide better conditions for further trials studying effects of fluctuating environmental on plant response dynamics (e.g. bud break, stress responses, etc).
Reporter: Joe Aldous

Air Movement for Promoting Gas and Heat Exchange. Yoshiaki Kitaya. (Japan) 17:20.
Precise control of air movement within a crop canopy is difficult, especially if there are large numbers of plants. This causes air current, light level and CO_2 concentration to be very low, air temperature and water vapour to be high, relative to the conditions above the plant canopy, and reduces transpiration and net photosynthetic rate. The reduction of the transpiration and net photosynthetic rates were closely related to an increase in boundary layer resistance, which is proportional to the thickness of the layer. Increased airflow (above $0.2 m.s^{1}$) within the plant canopy (by increasing airflow above it) reduces the boundary layer thickness and hence reduces the variations within the canopy. In tissue culture vessels, increasing airflow over the containers also increases air movement within the vessel, but the presence of plant material reduces airflow relative to an empty container.
Reporter: Ian Pearman

Enhancing Controlled Environments Capabilities to Assist Plant Science.
Tuesday 16 March

Using Controlled Low Root-Zone Temperatures with Airoponic's to Reduce Expression of Heat Stress in Arabidopsis. Paul T Austin. (New Zealand) 09:00.
Paul Austin described work carried out to investigate if growing *Arabidopsis* under tropical conditions was possible in the tropics. *Arabidopsis* grows across a wide range of climatic conditions and low light levels. He found that it was possible to grow Brassica and lettuce and hypothesised that it may be possible to grow *Arabidopsis* too. The work was carried out at the National Institute of Education in Singapore. A new aeroponic unit was made available, where chilled nutrient solution is used to cool the root-zone to ensure normal plant development. Wild type *Arabidopsis* was first germinated in vermiculite ($20/23^{\circ}C$) and transplanted to wetted foam blocks at the two-leaf stage. Three lines containing the GFP (green fluorescent protein) marker under tropical glasshouse conditions with high temperatures ($28/38^{\circ}C$). Their development and photosynthesis was monitored. Level of uniformity of expression of GFP was measured using fluorescence microscopy. The technique highlighted the need for minimal root disturbance for successful transfer to aeroponic troughs. However once established cool root zone conditions ensured vigorous root growth that allowed shoots and rosettes to grow normally, and recover turgor despite repeated and significant wilting of leaves and bolts in the middle of the day.
Reporter: Barry Robertson

Continuous Gas Exchange Measurements in Controlled Environments.
A.J.Both. (United States Of America) 09:15
One way of measuring daily crop growth and transpiration rates non-destructively is to measure whole canopy gas exchange. This removes variation between individual leaves, captures diurnal changes and includes the effect of plant respiration. Two long-term experiments of about 90 days were carried out in four acrylic boxes in an

‘open system’ in a walk in growth room, CO_2 concentration was controlled in the growth room and used to supply a vertical airflow through the photosynthesis boxes. Measurements of air in, air out, flow rate and light at top of the plant canopy enabled calculation of photosynthetic rates. Short-term step changes in conditions were made for three periods of two days each. The results were compared with those from a destructive final harvest. At high CO_2 the correlation between destructive and non-destructive carbon gain measurements was not very good (overestimated by 130-180%), but was better at low CO_2 (64-128%). This was probably due to instability of calibration with this type of system. The results do give ratios, which can be used as a correction factor in modelling data.
Reporter: Ian Pearman

Manipulating Whole Tree Root Temperatures in Controlled Environments Affects Budbreak in Apple. Dennis Greer. (Australia) 09:30.
Root zone temperature reduction from 25°C to 7°C delayed bud break in apples by at least six days. Temperature control of ±1°C was achieved using water circulating around heating and cooling elements. Clonal trees were grown for 70days in controlled air temperature of 25/18°C at each of three experimental root zone temperatures, namely 7, 15 and 25°C. Other effects of low root zone temperature were shorter & fatter shoots, delayed flowering and decreased soil respiration rate and reduced photosynthesis. Also, leaf gas exchange rates varied with root-zone temperatures, which may relate to source-sink demands between root and shoot.
Reporter: Martyn Stenning

Session 5
General discussion
After a good session that overran, there was only time for a short discussion session. Paul Austin was asked if during his work he had encountered problems with algae? He responded by stating that algae were not a problem he had come across. Dennis Greer was asked how long were the apple trees in their pots? Three years was the answer. AJ Both was asked a number of questions including the % of Carbon that was recorded during his work? 46% was his answer. Also, was root respiration a factor? And in the chamber did the temperatures of the leaf and air differ? He answered yes and advised anyone interested to see his recent publications.
Reporter: Mick Fuller

Controlled Environment Studies for NASA’s Space-Flight Research. Gary Stutte & Ray Wheeler. (United States Of America) 10:00.
Research into effects of micro-gravity on growth of plants has been progressing for many years. Initially, experimentation in space was difficult due to shortage of time in the space shuttle and biosatellite programmes and inadequate environmental control. Recent development of manned space stations has enabled longer duration experiments under better environmental conditions. As constraints of micro-gravity (e.g. different gas/fluid dynamics, lack of convective currents, etc) have become better understood, various methods have been developed to improve the growing environment. These have enabled many plants to be grown in space that are comparable to ground control plants when similar environmental conditions are applied. As manned flights go deeper into space, it will be necessary to grow food to sustain human life over long periods. Problems such as watering and providing adequate lighting are still being investigated. Much is yet to be done, but experiments

with potatoes, wheat and soybeans are already encouraging and many cultivars and some GMOs are being developed to produce dwarf plants producing high yields.
Reporter: Joe Aldous.

Science Showcasing Manipulating Environments and Plant Processes

Temperature Control of Tuber Formation. Ted Tibbitts. (United States Of America) 11.00.
Research at the University of Wisconsin Biotron was undertaken to establish the potential of potatoes as food and life support in long-term space programmes. Using disease free micro-propagated potato cultivars, it was shown that control of tuber formation is temperature, variety and photoperiod specific. Temperature has a controlling influence over growth, 18°C being optimum for tuber formation, 16°C for total biomass. Evidence was given of the difference in growth shown by different c.v.s grown in different temperature and photoperiodic conditions. Early varieties and varieties bred in northern latitudes could tolerate 24 hours of lighting and constant 18°C; others require the dark period and lower night temperatures.
Reporter: Graham Pitkin

Controlled Environments to Elucidate Temperature Related Phenomena in Sugarcane Growth and Development. Graham Bonnett. (Australia) 11:15.
There are productivity problems associated with growing sugar cane at the extremes of its range towards 30°S in New South Wales and 16°S in Queensland and Western Australia. Sugar cane is perennial and exposed to extremes of temperature at some time during development at the margins of its range. Using tall greenhouses at Brisbane, experiments studied genotypic variation for resistance to frost and photosynthetic rate during cooling. Wild types perform better than cultivars at low temperatures but not high temperatures with or without acclimation of $20/12^{0}$C compared with control (30/25°C). No differences in frost tolerance were found.
Reporter: Martyn Stenning

Role of Far Red Light in Flowering and Stem Extension of Plants. Erik Runkle. (United States of America) 11.45.
The speaker began by talking about how light quality had a profound effect on long-day plants and the importance of red/far-red light ratio in promoting plant growth. He also explained how red and far-red was absorbed by phytochrome photoreceptors, which in many plants regulate growth and development. The speaker showed how he set up experiments with the objective of determining if far-red light could be added at various light and dark periods to a far-red deficient environment to facilitate flowering with minimal extension growth. Using plastic sheeting that selectively reduces the transmission of far-red light (700 to 800nm) and neutral sheeting, a number of greenhouse experiments were set up containing long-day plants to determine that as red to far red ratio increased (i.e. less far-red) stem extension decreased and flowering was delayed. He concluded that his experiments indicated that exposure of plants to far-red light can partially, but not completely, promote flowering.
Reporter: Malcolm Pratt

Environmental Control for Quality Preservation of Transplants. C. Kubota. (United States of America) 12:00.

Presentation emphasised the need for quality transplants both from in-vitro culture and from module raisers (plant propagators). Data were presented to emphasise that both types of transplants must have good levels of starch/sugar in order to grow away well in the glasshouse or field. Light was found to be important during rooting and transport of modules long distances. Only low light level (approx 9 to 18μmol m^{-2} s^{-1}) was necessary to significantly improve plant take. Where light cannot be supplied during transport, then the use of chilling to 10-12°C reduces respiration losses, maintains starch levels and improves plant take on transplanting.
Reporter: Mick Fuller

Tequila, Tomatoes and Insectivorous Plants with Rice, Some Challenges Met by the Plant Stress Unit at Sussex. Martyn Stenning. (United Kingdom) 14:00.
Plant Stress research started at Sussex with searching for salt tolerant rice and tomato strains. Stress is manifested in the plant's response to different soil salinity. Objectives include developing strains that grow in high soil salinity, and improved crop yield. *Agave tequilana* is also grown, attempting to replicate, in greenhouses, the semi-arid neo-tropical habitat they come from. *Agave* research is yielding possible treatments for diabetes. Sussex also researches mechanisms by which insectivorous plants capture prey. These plants grow in low soil fertility, and light, and source insects for nutrients, they are kept in growth rigs under low light. Most work is on micro-propagation and prey securing mechanisms made visible using electron microscopes. The talk showcased controlled environment facilities at Sussex used to study exotic plants of marginal habitats, and how crop plants, that normally grow in non-marginal habitats can be adapted to poor soil often farmed by poor people.
Reporter: Martyn Stenning

Vernalisation of Sugar Beets in Controlled Environments. Kevin Sawford (United Kingdom.) 11:30.
The speaker briefly described the location and role of Broom's Barn Research Station and went on to give examples of the sugar beet crop and why vernalisation was required to promote flowering. The ways used to vernalise plants were demonstrated along with facilities used to carry out these procedures. The speaker then detailed in his role of manager of these facilities some important points that were essential to the smooth running of the facilities when working with low temperatures required to vernalise sugar beet. He then went on to outline a number of experiments that had taken place to attempt to accelerate the vernalisation period showing how different environmental conditions or photoperiods were used. The results of this work were shown and the talk was rounded up with a summary of all of the work that showed how different genotypes required differing vernalisation periods.
Reporter: Kevin Sawford

Use of CEs For Developing Crop Models. Dave Fleisher. (United States Of America) 14:30.
Two methods are being evaluated for quantifying potato canopy leaf appearance rate as a function of air temperature. The first method uses a thermal time approach and the second uses a non-linear temperature response function. Data for the models was obtained from SPAR (soil-plant-atmosphere research) chambers at USDA-ARS, Beltsville, MD where potatoes (Solanum tuberosum L. cv. Kennebec) were grown in one of six temperature treatments ranging from 14/10°C to 34/29°C. Main stem leaf number increased linearly with accumulated thermal time which supports use of the first method. However, significantly different phyllochrons were obtained for each

treatment (9.3, 11.9, 14.4, 17.9, 21.4, and 32.7 GDD leaf-1 at 14/10°C, 17/12, 20/15, 24/19, 28/23, and 34/29°C respectively with a base temperature of 8°C). These findings indicate that the use of a constant phyllochron will lead to errors when estimating foliar development in environments with fluctuating temperatures. In the second method, a beta-distribution function, which has been shown to be superior to thermal time methods with other crops, was fit (r^2=0.996) to the relationship between leaf appearance rate and daily average temperature. The suitability for using these models for the field will also be tested using field data obtained during the summer of 2004 at USDA-ARS, Belstville, MD.
Reporter: Joe Aldous

Two New Techniques and Three New Instruments for Real-Time Measurement of Plant Growth. Bruce Bugbee. (United States Of America) 14:45.
Spectral images of plant canopies, using a low cost (c. $4000 as against c. $18000 for the old rotating prism models) multi-element array spectroradiometer, are highly correlated with radiation capture and growth rate. They could also be used to provide spectral signatures for major plant nutrients, enabling early identification of deficiencies (e.g. nitrogen deficiency shows as increased green reflectance). New low-cost line quantum sensors and digital cameras allow real-time measurements of radiation capture and ground cover %. These measurements are easier to make than canopy photosynthesis and because biomass yield directly correlates to intercepted radiation (in the absence of stress) are a very good guide to growth rate prior to canopy closure.
Reporter: Ian Pearman

Elevated Carbon Dioxide Canopy Architecture and Disease Interaction. Sukumar Chakraborty. (Australia) 15:00.
Since the beginning of the industrial revolution ambient carbon dioxide levels have risen by 31% to 367ppm (v/v). Doubling the availability of carbon dioxide increases biomass of plants by 30%, but the resultant enlarged canopy offers a micro-climate that encourages disease. Using anthracnose disease of tropical legumes and a rust disease of woody weed rubber vine and the CSIRO controlled environment facility, it was shown that the fecundity of rust disease increases, and rust pustules increase spore production by up to 112%, at twice ambient carbon dioxide levels. However, the doubling of carbon dioxide levels can increase a plant's ability to resist disease infection initially. The severity of the infection increases due to increased disease pressure after several initial cycles, as the pathogen overcomes host resistance. This is a dynamic system that should be tested in the field but by using controlled environments, hypotheses can be formed before expensive field trials are begun.
Reporter: Graham Pitkin

Summary & general discussion. **15.15 pm**
Conference discussed temperature responses of crops including root zone temperatures, control of which is impractical in the field. Use of controlled environments can be made to provide models of field situations, and a comparison of models was discussed. The domination of rice studies in controlled environments was declining, and ecological studies were increasing. The model for temperature integration to achieve a reduction in energy spent on lighting was discussed. There is already some commercial application for this.
There was a debate concerning whether different sensors should be used to measure light from different sources. For example, LEDs emit no green light (which is not

used by plants anyway) therefore careful thought is required when choosing a light sensor to measure light energy. It was felt that hardware has improved over the last two years especially in incorporating co-sine correction into spectro-radiometers.
Reporter: Graham Pitkin

Manipulating Genes in Controlled Environments

Controlled Environments for Gene Expression. Julian Franklin. (United Kingdom) 16:00.
The speaker discussed the value of controlled environments in Genomics, Proteomics and Metabalomics. The need of this type of research for controlled environments with uniformity, repeatability, as well as specificity and extremity in temperature, humidity and light was highlighted. Factors such as air movement, watering and CO_2 were not to be ignored especially when uniformity and repeatability were considered. The need to grow large numbers of plants, some of which may be quite small, under standard conditions underpinned much of the work on genomics and metabalomics. When considering the acquisition of controlled environments for such work many factors, including optimum size, uniformity of conditions, sophistication of control, range of control and, importantly, reliability should be considered. Quality control was seen as of being of increased importance, and increasing dependence of funding on good quality control processes was stressed. New NCR-101/UKCEUG/ACEWG reporting guidelines were cited as an aid to the quality control process.
Reporter: Julian Franklin

Environment and the Expression of Genes for Flowering. Rod King. (Australia) 16.15.
The speaker began by explaining how light quality, intensity, day-length and temperature relate to seasonal control of flowering. Using *Lolium temulentum* grass in a long-day environment, he showed that certain gibberelic acids increased in leaf and later in shoot tissue to induce flowering, and this was more pronounced when low intensity incandescent lamps were incorporated. He continued by speaking about vernalisation responsive genes and, unlike day-length, how these responses are localized in the shoot apex. Cold treatment promotes early flowering by suppressing flowering locus C gene in the shoot. Whereas without cold treatment (vernalisation), the flowering locus C gene is present in the shoot, and late flowering occurs.
Reporter: Malcolm Pratt

Manipulating Genes Involved in Phosphate Nutrition of Plants. Frank Smith. (Australia) 16:30.
Although there is usually plenty of P in soil, in many places it may not be available for plant growth as it is strongly absorbed onto iron and aluminium, leaving soil solution concentrations of less than 1 micromolar. The Dilute Flow Culture Facility in Brisbane was used to measure uptake of ^{32}P labelled phosphate in hydroponically grown Arabidopsis and cereals. Phosphate co-transporter proteins form pores in cell membranes to enable the proton pump to drive the mechanism transporting P against the concentration gradient. This is regulated by environmental, chemical and developmental signals stimulating production of transcription factors. Reporter genes link the promoter gene to a coding region which produces a product which can be visualised e.g. Green Fluorescence Protein. In high P there is little expression but in low P there is high expression and an increase in numbers of root hairs, which aid

uptake by releasing organic anions to complex with iron and aluminium thus releasing P for plant uptake.
Reporter: Ian Pearman

Large Scale Gene Expression Analyses under Controlled Environments
Kemal Kazan. (Australia) 16:45.
All organisms must cope with external conditions in order to continue existing. To produce an appropriate response, changes in extra-cellular environment must be integrated in a specific manner from outside the cell to the inside. Evidence indicates that extensive changes in gene expression pattern underlie plant responses to environmental signals. Important steps controlling the process appear to be initiation of signal transduction of genes. By using a functional genomic strategy. The aim is to identify molecular events involved in the regulatory network connecting plant responses to biotic stimuli such as pathogen infection in model plant *Arabidopsis* genes. The large-scale expression analysis of *Arabidopsis* genes using DNA microarray technology is an integral first step in this functional genomic strategy. It is evident from microarray analyses that special emphasis should be given to the reproducibility of microarray experiments. Reproducibility in gene expression can be achieved by reducing variation due to differences unrelated to the actual treatment. Controlled environment facilities where environmental variation in gene expression observed between the repeated experiments can be reduced by strictly adhering to the identical plant growing conditions.
Reporter: Barry Robertson.

The use of the New Zealand Controlled Environment for Gene Function Discovery in *Arabidopsis*. Andrew Allan. (New Zealand) 17.05.
Using this facility the authors have introduced genes of apple, kiwi fruit and blueberry into *Arabidopsis* using agrobacteria to study chosen fruit genes e.g. dwarfing, cold tolerance and branching. 90% of genes do not express in the *Arabidopsis* phenotype. However, because *Arabidopsis* is so easy to grow, poorly controlled or variable environments are often used in research. This masks or falsely enhances true expression of the trans-gene. The author described experiments of New Zealand facility that characterised small changes in the *Arabidopsis* genotypes. Expression of branching, fruiting and stress in the phenotype demonstrated that precisely controlled environments are required in order to avoid ambiguous or meaningless results.
Reporter: Graham Pitkin

The Photometric System a New Answer to the Challenge of Measuring Radiation for Plant Application. Gilberto da Costa. (United States of America) 09:00.
Although the photon-based quantum system of light measurement for plants has been around for over three decades its dissemination and use outside circles of plant scientists and agricultural/biosystems engineers remains very limited. Hindered by the quantum system being not quite intuitive and by the difficulty of linking it to the universally adopted photometric system developed for human vision applications. They looked at comparing the response curves for human eye and that of a photosynthesising plant curve. A mathematical formula was proposed which brought together the different response curves to allow one measurement system called Photometric. The photometric system allows for conversion of units to quantum system, radiometric system, and photometric system. Quite simply, the photometric system is more versatile, comprehensive and compatible with existing standard

measuring of light than the quantum system.
Reporter: Barry Robertson

Controlled Environment Technologies to Assist Plant Science.
Wednesday 17th March

Testing for Radiation Freezing in Controlled Environments. Mick Fuller. (United Kingdom.) 09:15.
Radiation freezing is a very damaging event in temperate climates in spring and in sub-tropical climates in mid-winter. No radiation freezing cabinets are available on the open market so these must be custom built like the one at University of Plymouth. Radiation freezing also requires ice nucleation before damage occurs and this is temperamental. In controlled freezing experiments the ice nucleating bacteria Pseudomonas syringae Cit 7 is used and ice nucleation and ice spread monitored using Infrared Thermography. These techniques and the radiation chamber are enabling a fuller understanding of the process of radiation freezing damage to non-hardy plant tissues. Intervention strategies to avoid radiation freezing damage using a hydrophobic particle film were showing promise in potatoes and grapevine. The technique reduces the risk of freezing by encouraging the shedding of dew drops from the leaf surfaces which are implicated in ice nucleation in the field.
Reporter: Mick Fuller

New Perspective on Air Conditioning Research Glasshouse Compartments.
Alex Turkewitsch. (Canada) 09:30.
Air conditioning for research glasshouses compartments has traditionally been coupled with the building a glasshouse is attached to. This involves the use of the building system and ducting air to and from building to glasshouse. With an increased expense of ducting the air to and from the building and competition for priority of cooling. The isolation of compartments for biological containment requirements is difficult to achieve and demonstrate with this building system. The system described involved the air-handling units being wholly contained within the glasshouse compartments they serve. This minimises mechanical ducting, disturbance to adjoining buildings and improves containment. The units are contained within the glasshouse space. But in order not to ingress in to the growing space the units are held under the benches where the plants would be grown. This frees up access and growing areas for personnel and plants. The air is moved across the glasshouse to maximise temperature control while maintaining adequate humidity. It also provides adequate velocity through the plant canopy to ensure sturdy plant growth.
Reporter: Barry Robertson

Optimizing LED Lighting Strategies for ALS-Related Crops. Cary Mitchell. (United States of America) 9:45.
The speaker began by addressing the problems that future space colonists will face on Mars and elsewhere in space in growing enough food to eat without using up all the resources to do it. He spoke of his research using overhead crop lighting systems using fluorescent tubes and how inefficient they were (75% loss of light under the leaf canopy as the plants grew taller). He showed how he had used intra-canopy fluorescent lighting both horizontally and vertically to improve growth, but this tended to overheat the area and scorch the plants. He went on to say how he was currently investigating energy saving ways to light food crops in space using light-

emitting diodes (LEDs) to maximize crop production, and that two types of LED arrays had been designed. Firstly, a close canopy horizontal crop lighting system which consists of clusters of red, blue, and green LEDs mounted on a panel can be automatically maintained in close proximity to the top of plants as they grow. Secondly, using intracanopy lighting that consists of LED strips which hang vertically within the crop canopy with plants growing all around them. The LEDs are cool enough for the plants to even touch them as the power output is low and the LED clusters can be regulated independently as required by altering the input voltage, thus saving energy. He concluded by anticipating that these new LED arrays would be manufactured and ready for use by April 2004.
Reporter: Malcolm Pratt

Non-Contact Water Stress Detection Techniques. Peter Ling. (United States of America) 10.00.
The speaker began by explaining how important reliable detection of plant water stress is for proper water management in plant production. He went on to talk about the comparison of three non-contact water stress detection techniques based on plant canopy temperature, plant motion and plant water content. His research suggested that the detection of plant stress with the application of infrared thermometry using a crop water stress index formula was the best early indicator. Monitoring plant growth and movement in the top canopy area using a digital camera was the least efficient. He spoke of the use of multi-spectral sensing devices being risky and that more research work was required. The speaker ran out of time, and did not complete his talk.
Reporter: Malcolm Pratt

Closing Address - Cary Mitchell (United States of America)
Cary Mitchell's closing address covered a wide range of controlled environment (CE) issues raised in conference. In recognising CE skills were not typical, covering plant process to physical processes with knowledge of engineering along with horticulture and computing, it was accepted that the global CE community was limited. The CE community awaited the discovery by biotechnologists of a need for facilities to study gene interaction with the environment. This is an opportunity for CE staff to stress the value of its skills, offering solutions and overcoming preconceived or ill-conceived perceptions. The poor perception of our institutions on the value of CE as well as under investment was highlighted. The need for leadership as well as involvement of CE professionals in writing proposals was stressed. Successful models for managing CE facilities as part of clusters or centralised facilities, the way they were funded and recharged were areas discussed. Light, temperature, water, nutrients and atmosphere were cardinal factors affecting plant growth, but physical forces of wind, vibration, touch and gravity have to be considered also. The 'added value' of CE in terms of increased yield per unit area, both in terms of crop yield as well as crop cycles is recognised. The value of producing consistent reliable crops, with high value components reliably to high quality standards was also being exploited commercially. The 'pharma' plant defined in part by genetic modification plus modification of the environment to produce nutraceuticals and pharmaceuticals was an exciting opportunity for CE researchers. Space applications, especially regenerative support will enable man to reach into the solar system. These were the ultimate controlled environments and opportunities for ground-breaking developments were likely to occur. New technologies are evolving more applications for CE in terms of scope of research as well as in improvements to CE facilities themselves. Aquaponics, bio-

derived sources of energy, gene environment optimisation, and reclamation technologies are examples of areas where CE will be involved.
Reporter: Julian Franklin

Reference: Enoch, H.Z. & Enoch, Y. (1999). The History and Geography of the Greenhouse. Chapter 1 in: Ecosystems Of The World. Stanhill & Enoch (Eds.). Elsevier Science B.V.