CONTROLLED ENVIRONMENTS IN THE NEW MILLENNIUM

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ABSTRACTS

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Abstracts are arranged alphabetically by first author in each section

INVITED PAPERS

Note: There is no abstract for the following invited paper:

Session 1: P. Logan (Health & Safety Executive, Bootle, UK) *Legislation for GMOs in the UK and Europe*

LEGISLATION FOR GMOs IN NORTH AMERICA: DESIGN OF CONTAINMENT FACILITIES

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Regulation of GMOs in North America is primarily targeted to field release, food, and feed applications. Under the Coordinated Framework for Regulation of Biotechnology, three US governmental agencies regulate GMOs: the Department of Agriculture, the Environmental Protection Agency, and the Food and Drug Administration (FDA). In Canada, the Canadian Food Inspection Agency (CFIA) is responsible for the regulation of importation, environmental release, and feed use of plants with novel traits which include transgenic plants. Health Canada has jurisdiction over novel foods, including food products derived from transgenic plants. Mexico regulates field experimentation with non-maize transgenic plants. Regulation governing transgenic plants and related organisms in greenhouses and other controlled environments, however, is relatively sparse. All US agencies defer to and accept the National Institutes of Health's Guidelines for Research Involving Recombinant DNA Molecules (NIH Guidelines). Appendix P of the NIH Guidelines was added in 1994 to specifically address plant and plant-related organism containment.

The NIH Guidelines describe methods for conducting transgenic research in laboratory and other controlled environment settings but they stop short of offering design detail for containment facilities. Design for transgenic research borrows from containment principles found in phytosanitary and other biosafety applications. There may be a broad range of guesses and opinions among scientists and facility managers regarding what is needed. Some may harbour a misunderstanding that all GMOs must be grown in a highly contained 'clean-room,' while others may be completely unaware that certain cases require specific containment measures in order to protect the surrounding environment.

The primary goal of containment is preventing the dissemination of propagules. Designing or renovating containment facilities to meet most transgenic research programs can require little more than establishing management protocols and offering reasonable facility accoutrements. On the other hand, if the escape of research organisms poses a serious environmental, agricultural, or health threat, then engineering controls that resemble the 'clean-room' approach would be indicated.

The most qualified individuals to assess the risks are the investigators themselves acting in concert with regulators, institutional biosafety committees, and facility staff. The most qualified designers are experienced engineers and architects operating as a team with users and facility staff.

PANELLIST'S STATEMENT FOR SESSION 7:

USING CE FACILITIES TO DESCRIBE DYNAMIC RESPONSES TO THE ENVIRONMENT

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CE facilities are well suited to studying the dynamics of responses to natural environmental fluctuation, and wide range of time-series oriented methods exists to assist this objective. Such information would assist development of quantitative models of plant systems and provide useful insights concerning processes and interactions that may not be investigated easily using more conventional experimental techniques. The capability of CE facilities to arbitrarily control the temporal aspect of environmental variability also offers potential to enhance the efficiency with which information about environmental responses is generated, if coupled with more temporally-intensive measurement approaches.

However, successful application of more explicitly temporally oriented approaches to CE experiment design depends on a sound quantitative understanding of CE control performance. This objective highlights a number of issues, including:

- Physical and statistical description of CE performance capability, especially with respect to expected spatial and temporal variability at various time scales, and when conditions change in unusual ways. This issue becomes particularly significant if the experimental design precludes conventional randomisation approaches to dealing with spatial variability.

- A need for a comprehensive CE regime specification format that can describe complex time-series oriented designs, and includes explicit information about environmental reporting parameters.

WORKING WITH DESIGNERS ON THE GREAT GLASSHOUSE

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The Great Glasshouse is part of a Millennium Project to create a National Botanic Gardens for Wales that will be dedicated to the sustainability and protection of threatened plant species. Opened in May 2000, it is located in the centre of the Botanic Garden. A temple of architecture and engineering, it contains a specialist collection of plants from mediterranean habitats of the world.

Considering the structure from a horticultural viewpoint, we will discuss some of the difficulties and challenges the building presents as a result of being a plant growing space. From the requirement of ventilating windows that promised to spoil the beauty of the design, via a granite-lined guttering that can render a rainwater irrigation system unusable to the differences of using limestone against sandstone cladding in the landscape, have provided the entire team with endless hours of material for discussion.

IN SUPPORT OF SIMPLE ENVIRONMENTS

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Horticulturists are keen observers of plant/environment responses in the real environment of the field. Plant physiologists use purified enzymes in simple glass test tubes. Both approaches advance the discipline, but I believe that scientists should work at as simple a level as their training allows.

Plant Scientists should think more and measure less. Measurements are real - thinking is simple. The most simplified tests of hypotheses are done using theory or models. Einstein used the simplest possible laboratory apparatus - he never made a measurement. His laboratory was chalk, a blackboard, and his mind. Young scientists would do well to heed his advice, “Everything should be as simple as possible, but no simpler.”

In our quest for big research budgets, we forget that simple environments are low cost environments - and this facilitates replication. Smaller is often simpler. With the same research budget, one could buy and operate a hundred small, simple growth chambers - or one chamber the size of Biosphere2.

We have passed on a legacy of empirical techniques to young plant scientists, and we often deserve the “spray and pray” label for our research. Too often we add sensors and blinking lights to our growth chambers without thinking about how the additional measurements will help us better test our hypotheses.

Our approach to research seems to follow our approach to writing. Our sentences are adorned with clutter. We are a society strangling in unnecessary words and pompous jargon. We should strive to make our research, like our writing, concise, simple, and elegant.

GROUND-BASED DEMONSTRATION CHAMBERS IN NASA'S ADVANCED LIFE SUPPORT PROJECT

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In order to more fully explore and develop space, the National Aeronautics and Space Administration (NASA) is conducting research and technology development of advanced life support (ALS) systems. These regenerative life support systems will reduce the risk and cost of long-duration space missions. The ALS Project encompasses both flight (microgravity) and planetary surface (hypogravity) life support systems, with associated flight- and ground-based testing. This paper will cover the ground-based chambers used by NASA for integrating and testing advanced life support systems.

A complete life support system is composed of several different technologies. Air revitalization, water recovery, solid waste processing, biomass production, food processing, thermal control, human accommodation and integrated computer monitoring and control are all integrated into one complete advanced life support system. Both biological and physicochemical processes are used in these systems. Development work has primarily occurred at three NASA Field Centers: the Ames Research Center (ARC) in California, the Kennedy Space Center (KSC) in Florida, and the Johnson Space Center (JSC) in Texas. JSC is responsible for the complete integration and testing of these systems, including testing with humans.

A combination of commercial plant growth chambers and custom-built chambers is used throughout all three NASA centres involved in the ALS Project. ARC focuses on physicochemical processes for air, water, and solid waste recovery. KSC focuses on biological processes for plant growth, and air, water, and solid waste recovery. JSC, in addition to managing the ALS Program, focuses on implementing the individual technologies for specific flight purposes, plus integrating all the technologies into regenerative systems.

At JSC, a series of tests were conducted between 1995-1997 on a combination of physicochemical and biological processes to recycle air and water. Currently, a new facility is being built that will expand on the lessons learned from this test sequence, and will aim to close more completely the mass loop required for human life support. The Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex) will start testing later in this decade.

CONTROLLED ENVIRONMENTS: PAST ACHIEVEMENTS AND FUTURE DIRECTIONS

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A brief history of controlled environments will be reviewed, from the earliest attempts to grow plants in controlled conditions. It is generally recognised that the first true controlled environment facility was the Earhart Plant Research Laboratory in Pasadena, California, which opened in 1949 under Dr F. Went. The two key technological achievements that bought about this achievement were the development of air conditioning for temperature control and the fluorescent lamp for artificial lighting.

Technological changes in lamps, control system hardware and software will undoubtedly continue to occur, especially with the drive for greater efficiency, improvements in performance and specification. However, in the new millennium, scientific opportunities will provide the demand for controlled environment capabilities, rather than technology drive, given the rapid expansion in gene technology research.

Controlled environments can be described as having five characteristic features that enable study of environmental impacts on biological systems. These include an ability to *isolate* the system for study under a *simulated* environment, an ability to *manipulate* the parameters of that environment, an ability to *replicate* a standard environment for research purposes, an ability to *quantify* responses to changes in those parameters and an ability to *integrate* results with knowledge of the natural environment.

Probably, the majority of past controlled environment research used the characteristics of isolation and simulation, replication and manipulation for the research. Such research was usually characterised by *static* conditions, that is, where environmental parameters were all held constant. Less common were controlled environment uses where the characteristics of quantification and integration of research results were emphasised. Such research is characterised more by use of *dynamic* conditions, that is, where one or more environmental parameters are changed over time. Use of controlled environments will increasingly underpin development of decision-support tools.

A new paradigm in controlled environments arises with the sequencing of plant genomes and the increasing interest in functional genomics. The five controlled environment characteristics will all be of use in gene expression and genotype - environment interaction studies. Development of contained controlled environments will thus be a necessity.

ENERGY POLICY AND PRACTICE - A EUROPEAN VIEW

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Energy Policy - Formulation

As the Energy Efficiency Engineer of the UK's Biotechnology and Biological Sciences Research Council (BBSRC) from 1994 to 2000, I was involved in the formulation of BBSRC's current Energy Efficiency Policy. There was considerable debate as to what should or should not be included. The statement of policy objective that resulted is deliberately short, simple and 'to the point': "To reduce the BBSRC's energy bill to the lowest practical level commensurate with the needs of the research programme".

The policy objective reflects two important points:

1. Cost saving is the driver of BBSRC's Energy Efficiency activities.
2. BBSRC's Energy Efficiency Measures should not have an adverse impact on the core business of the organisation.

Energy Policy - Support

The BBSRC supports its policy by funding the BBSRC Energy Office. Activities of the Energy Office include co-ordination & promotion of energy efficiency initiatives and providing financial support for energy efficiency measures taken at research sites within the BBSRC group. It also collates a group-wide energy cost and consumption database, which is used to monitor performance against targets, provide an annual report to senior management and facilitate 'Energy Trading'.

Energy Policy in Practice

As Head of Facilities of a BBSRC supported institution, I am involved in putting the policy into practice. IACR have considered of a number of efficiency measures concerning Controlled Environments. These have included: energy efficient lighting units, siting ballast units remote from the conditioned space, operation of CE daytime cycles during off peak electricity times, use of Combined Heat and Power with absorption chilling, use of roller benching to make more efficient use of space, electronic control of electric motors, recycling heat by use of heat pumps/energy packs.

Electricity represents our greatest energy cost and we tend to favour measures that save electricity.

ENERGY, CONSERVATION AND RECYCLING. POSITION STATEMENTS ON ENERGY POLICIES AND PRACTICE. THE AUSTRALIAN POSITION

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Should we take old designs into the new millennium?

Australian organisations are facing recent developments, which have serious impact on the usage and cost of electric energy. These are a commitment by the government to reduce greenhouse gas emissions in Australia in line with the Kyoto protocol and moves to privatise electric power generation and supply in most Australian States, a development that so far has substantially increased the cost of electric power.

As a result many Australian organisations using controlled environments have now formulated policies which focus on the environmental and economic objectives of reducing energy usage particularly that obtained from fossil-fuelled generation and of making maximum use of energy recycling as a strategy for reducing operating costs. In doing so the scientific function of the controlled environment must of course be preserved.

The SA Research and Development Institute was formed by the SA Government in 1992 to adopt a co-ordinated and holistic approach, incorporating excellence, innovation and cutting edge methodologies, to its research operations. When planning its new $AU 35 million Plant Research Centre in Adelaide, South Australia, the Institute decided to search the tender market for consultants and contractors capable of providing innovative and cutting edge input to the design of its new controlled environments in order to meet these environmental and economic objectives. In conjunction with its controlled environment consultant, Phoenix Research, SARDI succeeded in building units that feature:

- Co-generation
- Storing and recycling of hot water
- Making of ice and recycling ice melt
- Capturing and recycling naturally conditioned air
- Utilising variable speed fan technology
- Using precise computer based control of environmental conditions

So our planning for new or upgraded controlled environments in the new millennium should offer designs which achieve their scientific objectives but which are kind to the environment and energy efficient.

REPORTING GUIDELINES IN PRACTICE: A GOOD IDEA, BUT DOES ANYONE TAKE ANY NOTICE?

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The standardisation of the reporting of environmental parameters in experiments in which plants are grown is essential if meaningful comparisons are to be made between experiments. To this end guidelines developed by the American Society for Horticultural Sciences for scientists reporting research on plants grown in controlled environment chambers have been incorporated into key reference works (ASAE 1992; Salisbury 1996). However, these guidelines are only of any use if journal editors insist on their use and then ensure that they are adhered to.

Fifteen major botanical journals from around the world were surveyed. Papers about plants grown in controlled environment chambers were scored for correct reporting of environmental parameters in thirteen categories as laid down in the guidelines. Whilst the air temperature in which plants are grown is usually well reported, other parameters are listed more variably. Substrate temperature and air velocity in growth chambers are very poorly reported, whilst atmospheric carbon dioxide concentrations, electrical conductivity and pH of nutrient solutions are also poorly covered.

One reason for this non-adherence to the guidelines could be that their use is not stipulated for authors submitting manuscripts. The instructions to authors of 29 botanical journals were examined, and only those for *Plant Physiology* made reference to the guidelines. An additional two journals stated that growth conditions should be reported and four listed some parameters required.

The findings are discussed in relation to the need for standardisation of reporting of plant growth conditions.

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CURRENT AND PROSPECTIVE TECHNOLOGIES FOR CONSERVING AND RECYCLING ENERGY IN RELATION TO CONTROLLED ENVIRONMENT PLANT GROWTH FACILITIES IN JAPAN

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To solve issues such as shortages of food and energy and damage to the global environment, plants play an important role through providing materials for food, energy sources and environmental conservation. Therefore the demand for environmentally controlled growing facilities is increasing in fields as diverse as applied studies on genetic improvement of plants, production of huge numbers of high quality nursery plants, and fundamental studies on interactions between plants and environment. Users of such facilities hope to grow the plants at minimum energy input not only to reduce cost but also to prevent causing environmental problems themselves.

I will introduce the technological status and prospects for conserving and recycling energy in plant growth facilities in Japan. Improvement of structural thermal characteristics, operation of the heating and cooling systems and effective lighting systems are focused on as fundamental to energy saving in environmentally controlled facilities. I will also introduce several current facilities for growing plants such as plant factory systems, nursery plant production systems and closed plant production systems used for space research in Japan.

REPORTING AND MONITORING FOR DIAGNOSTIC PURPOSES

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In order to conduct meaningful studies in controlled environments, it is important that researchers and facility managers have a clear idea as to the cultural conditions to be utilised, the environmental parameters to be monitored and controlled, the type and location of sensors, and the frequency of measurements to be made. Previously published guidelines should be consulted for guidance in standardising the type and location of environmental sensors in the growth chamber.

Ideally, a checklist of cultural and environmental conditions and a log book should be kept and careful notes recorded whenever problems are observed or adjustments in set points are made. Careful records of environmental conditions provide a valuable diagnostic tool in deciding when to make adjustments in control settings and in interpreting any unexpected results in plant response.

To minimise soil moisture stress, root restriction, and other limiting factors, it is important that careful consideration be given to choice of substrate, container volume, and water and nutrient regime and that these be thoroughly described.

For most studies, the most critical parameters to control and record are photosynthetic photon flux, air temperature (°C), and atmospheric moisture. In many cases, carbon dioxide concentration (μmol mol^{-1}, Pa, or mol m^{-3}), spectral distribution (μmol m^{-2} s^{-1} nm^{-1} or W m^{-2} nm^{-1}), and soil temperature are also essential. For experiments conducted in solution culture, where periodic adjustments in pH and nutrient composition must be made, it is important to have good records of hydrogen ion concentration (pH), electrical conductivity (mS m^{-1}), and dissolved oxygen (mg L^{-1}).

Ideally, measurements of photon flux (μmol m^{-2} s^{-1}) or energy flux (W m^{-2}) and temperature should be taken at the top of the plant canopy. For long-term studies, it may be impractical to adjust shelf height and thereby maintain uniform PPF levels at the top of the canopy but at least the PPF range can be described. To ensure accuracy, researchers should have access to within-laboratory calibrators and reference calibrators. To facilitate comparisons of data with those from other facilities, measurements should be reported in SI units.

THE MELISSA PROJECT: WASTE RECYCLING FOR PLANT PRODUCTION

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MELISSA (Micro-Ecological Life Support System Alternative) has been conceived as a micro-organisms- and higher plants-based ecosystem intended as a tool to gain understanding of the behaviour of artificial ecosystems, and for the development of the technology for a future life support system for long-term manned space missions, e.g. a lunar base or a mission to Mars. The collaboration was established through a Memorandum of Understanding and is managed by ESA/ESTEC. It involves several independent organisations: CNRS/IBP Gif sur Yvette/Orsay (France), University of Ghent (Belgique), University of Clermont Ferrand (France), VITO Mol (Belgique), ADERSA (France), University “Autonoma” of Barcelona (España), University of Guelph (Canada).

The driving element of MELISSA is the recovering of edible biomass from waste (faeces, urea), carbon dioxide and minerals. Based on the principle of an “aquatic” ecosystem, MELISSA comprises 5 compartments from the anoxygenic fermenter up to the photosynthetic one (algae and higher plants). In this presentation, we will present in detail the structure of the project, present the main results obtained over the last 10 years and outline the current areas of the research activity.

THE MICROTURBINE: WHY A GAS ENGINE MAY AT LAST BE OF BENEFIT TO THE HORTICULTURE INDUSTRY

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The microturbine, or small gas turbine, has only been commercially available since the late nineteen nineties. In its short life, it has struggled to shrug off the stigma attached to reciprocating gas engines, which were initially installed as the cost-effective technology of the day. Experience with reciprocating gas engines, particularly in the horticulture sector, has not been an overwhelming success leading to an understandable reluctance of the industry to embrace yet another ‘ leading edge’ technology.

Our paper discusses the basic microturbine technology, highlighting the features that make this gas engine have potentially wide applicability in the horticulture industry. The paper highlights the desirable performance characteristics that can benefit the end user without compromising product quality and site operation while the operational flexibility of the technology allows users to control and maximise their particular energy needs.

IN SUPPORT OF REAL ENVIRONMENTS

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Organisms have evolved in environments in which changes in physical, chemical and biotic factors create huge complexity in time and in space. While the “real world” may not be the most attractive stage on which to perform experimental science, we cannot hope to understand the multiplicity of factors which regulate fundamental processes if we reach conclusions based **solely** on simple manipulations of variables. Examples will be cited to point out the kinds of misunderstandings that can occur as a result of “simple” experimentation which neglects the complexity encountered in an uncontrolled, or partially controlled, environment. The German word “gestalt”, defined in Webster’s dictionary as “a structure, configuration, or pattern of physical, biological, or psychological phenomena so integrated as to constitute a functional unit with properties not derivable by summation of its parts”, points clearly to the perils that may be associated with “simple” approaches which are, in effect, “shallow”. On the other hand, there are sound and robust reasons for employing experimental methods in which the term “simple” is synonymous with “manageable”.

GENETICALLY MODIFIED ORGANISMS (GMOs) IN CONTROLLED ENVIRONMENTS - WORKING WITHIN THE LEGISLATION.

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In recent years GM research in plants and other organisms has been the focus of a great deal of scientific endeavour. Developmental advances in gene transfer technology have enabled the rapid generation of large populations of GM plants conferring a wide range of modified traits. In addition, the use of alternative GM vectors, such as viruses, as a means of gene transfer in plants has also increased. Though reports are limited, several GM fungi species have also been generated, with particular containment problems of their own.

The rapid-scale up that has occurred in this period, from the early experiments where a limited number of experimental plants were generated and monitored *in vitro*, to the recent production of many thousands of plants for field scale assessments, has presented a number of technical, as well as legislative, problems.

Undoubtedly, for rapid, accurate and repeatable data on the performance, effects and safety of GM organisms, the importance of reliable growth conditions and containment cannot be over-emphasised. The provision of facilities to enable such research was initially the adaptation of existing growth room/glasshouse amenities, but in recent years custom designed and built complexes have been constructed. However, the rapidly changing scientific base necessitates that maximum flexibility of design and operation be built-in at an early stage.

Using, as a background, the design, construction and operating procedures of a new glasshouse/controlled environment/ laboratory facility at SCRI, progress and problems associated with working within GMO legislation will be outlined.

LIGHTING CHOICES FOR PLANT GROWTH IN HORTICULTURE

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For many years artificial light has been used in Dutch greenhouses. This started with the use of incandescent lamps for controlling photoperiodic reactions in ornamental crops. Nowadays the use of HID lamps is very common for the improvement of CO_2-assimilation of greenhouse crops. This supplementary light gives an increase in crop production and quality, but also gives the grower the opportunity to produce during the whole year.

In recent years more and more controlled environments have been used for tissue culture, production in more than one layer, and rooting and production of seedlings. The advantage of such systems is a better control of the production process, compared with production in a greenhouse. Disadvantages are the energy consumption and, in most cases, the exclusion of natural daylight. The choice of light source in a closed environment is very important, not only for efficiency reasons, but also for its spectral composition. Many studies have been done on the effect of radiation on plant development (photomorphogenesis). The importance of the red/far-red ratio on plant growth is widely acknowledged, but also the blue component is important.

The most common lamps used in growth chambers are the high-pressure sodium (HPS), the metal halide and the fluorescent tubes. The photosynthetic active radiation (PAR) efficiency of the HPS lamps is very high. However for some plants, the HPS lamps lack blue wavelength emission. This can be supplemented with metal halide or fluorescent light. The use of fluorescent lamps ('TL' D and 'TL' 5, colour 840) for plant growth is, in general, very satisfactory. The spectrum generally matches the requirements of most plants. The spatial distance between lamp and plants can be low, which makes it possible to grow plants in more than one layer. The new generation fluorescent tubes of Philips™ have an improved maintenance. In normal use, the lamps still emit 90% of their original irradiance after 10 000 hours. Metal halide lamps are probably most suitable for growth chambers, especially when high irradiance is required. The efficiency is comparable with the fluorescent lamps, but slightly lower than HPS. Metal halide lamps are available in 250 to 2000 W (HPI and MHN). Philips™ has introduced a new metal halide lamp, which is called the CDM. This is a ceramic metal halide lamp with a warmer white colour (3000 K). The effect of this light source on plant growth is not yet known.

CHOICES FOR TEMPERATURE AND HUMIDITY: CONTROL SYSTEMS

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This presentation will focus on the energy impact of different choices for controlling temperature and relative humidity in controlled environments.

Controlled environment chambers and rooms for plant growth require considerable energy for electrical and mechanical functions to provide close control over a wide range of temperature and humidity program conditions. Whether the chamber has self-contained refrigeration or is connected to a central chiller system, a mechanical cooling process takes place.

In phytotrons, careful planning of the entire building heating, cooling and ventilation infrastructure can result in significant energy efficiencies. For a small number of chambers, dedicated central cooling plants may not be practical. Consideration will be given to self-contained air-cooled, water cooled and remote air-cooled refrigeration for these circumstances. Examples of different systems and operating circumstances will shed light on energy considerations when planning a plant growth facility.

Similarly, control of relative humidity involves the use of energy. Generally, removing moisture has a greater impact on energy consumption than adding moisture. In fact, adding moisture by common evaporative methods reduces energy consumption. Options to remove moisture are usually based on chemical desiccants or chilled heat exchangers, which take process air below saturation to condense water vapour out. Examples of each type, operating at several conditions, will illustrate the energy impact.

Ideal designs not withstanding, operating a facility in the real world with a mix of commercial equipment of different vintages presents a vast range of challenges. Furthermore, research programs can take abrupt changes in direction depending on funding, corporate re-alignment, government policy and changes in scientific staff. Planning and operating a facility with an eye on energy efficiency may be lost from time to time. However, since the energy costs for controlled environments constitute one of the single highest costs after purchase, it is worth understanding the basics of elements impacting energy consumption.

ENERGY POLICIES AND PRACTICE IN RELATION TO CONTROLLED ENVIRONMENTS. THE NORTH AMERICAN POSITION: LIGHTING TECHNOLOGIES FOR ENERGY LIMITED ENVIRONMENTS

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Controlled environment agriculture is, by its nature, energy limited. An extreme example of this limitation is the use of controlled environments for life support in space or on planetary surfaces. In the United States, the National Aeronautics and Space Administration (NASA) has identified lighting as a critical technology. The critical elements in crop lighting systems are the electrical conversion, the spectral quality, and the distribution. The electrical conversion of common sources ranges from 15% for light emitting diodes (LEDs) to 35% for high-pressure sodium lamps. New technologies such as plasma sources, microwave/sulphur lamps, may reach 50% in the near future. The spectral quality of these sources, however, must be tailored to the crop to maximise productivity. The low electrical conversion efficiency of LEDs when combined with their ability to produce highly efficient photosynthetic wavelengths, blue and red, increases the overall efficiency of LED systems. In addition, the longer wavelength red LEDs are more electrically efficient and have been shown to have greater productivity in crop production due to the early elongation and higher light interception. The ability to provide an area source with LEDs and to dissipate the waste heat from that large area is an added benefit to their application in closed systems. High pressure sodium lamps, although the most electrically efficient source currently available, are difficult to manage in a closed system due to the large thermal load, a spectrum deficient in blue, and the complicated luminaire required for uniform distribution. New sources such as the microwave/sulphur lamp offer unique capabilities in electrical conversion efficiency, highly efficient spectral quality, and “point” source configuration for simplified luminaire design. The transport and distribution from high intensity sources can be efficiently designed using optical fibres or light pipes with high transmission efficiencies. Uniform distribution can be effected using holographic diffusers, developed for the computer industry, to provide an efficient coupling to the closed environment. The application to life support and space experiments of these critical elements will be briefly presented during the panel discussion.

REFRIGERATORS AND REFRIGERANTS – THE FUTURE

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After the Montreal Protocol a large discussion has started concerning the alternatives for the different CFCs. A lot of different points have to be considered carefully. These are e.g. ozone depletion, global warming, flammability and toxicity. Because there will be no fluid with positive results at all four points, we must be aware of at least one risk. The development goes in two directions, on the one hand towards fluorinated hydrocarbons and on the other, towards natural fluids like ammonia, propane, butane, CO_2 and water.

This paper shows the main impact of the refrigerants on the environment and the technical demands for refrigerants in refrigeration systems. Comparisons between the different refrigerants are done also on the basis of the Total Equivalent Warming Impact, TEWI.

The alternatives also demand several changes in the hardware equipment of the compression systems. Another possibility is the switch to other systems like Absorption and Stirling-Refrigeration plants. These systems have special temperature ranges and different part-load behaviour. This must be considered in all comparisons.

REPORTING AND MONITORING FOR USER RECORDS

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Carefully documented environmental conditions are essential for the duplication of research studies by oneself and by other researchers. However, it is difficult to document the conditions so that they can be effectively and constantly repeated, even by oneself and especially by others. This problem is complicated by the fact that as research scientists, we do not agree on how thoroughly, and in some cases, what environmental parameters need to be monitored. This has led to the development of guidelines that have been jointly agreed on by concerned scientists and include both the conditions to be monitored and procedures required for this monitoring.

Of initial importance in the development of guidelines, is the assurance that instruments are readily available to make the measurements. Next in importance in guidelines is detailing monitoring procedures that represent the entire growth period of the plant, not just the start of growth. This requirement poses considerable difficulty in minimising the data reporting to meet journal requirements yet accurately documenting the changing levels that affect plant response. Finally the guidelines should, if possible, document conditions to which the separate plants in each experiment are subjected.

The guidelines developed by the North American Controlled Environment Technology and Use Committee will be reviewed and discussed in relation to these needs and concerns.

THE EDEN PROJECT - THE HUMID TROPIC AND WARM TEMPERATE BIOMES

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The Eden Project is located at Bodelva, St Austell, Cornwall, PL24 2SG, (http://www.edenproject.com/). To deliver our twin message on man's dependence on plants and his responsibility for the stewardship of nature throughout the world, The Eden Project required space to reproduce environmental conditions indusive to the growth of plants from the tropics, sub-tropics and warm temperate regions. To date, two such environments have been established, the Humid Tropic Biome covering 1.5 ha and the Warm Temperate Biome of 0.6 ha, their respective maximum heights are 55 m and 25 m.

Both Biomes use the same blown hot air heating system and side louvre and dome top ventilation system. These structures were commissioned in October 2000 so to date, performance data is provisional. Our findings to date indicate that the heating system is satisfactory, however the ventilation leaves much to be desired and the retention of a high relative humidity is not reached when the structures are ventilated.

Long standing experience of botanic gardens around the temperate world indicates how tolerant most species of higher plant are to very crude approximations to the climate of their natural environments. Present indications are that Eden's massive Biomes are still dependent on this natural adaptation together with the skills of the horticultural staff. The huge advantage presented by the height of these structures appears to have been bought at the expense of the ability to fine-tune the required temperatures and humidity. It is intended that efforts will be made to develop localised conditions within the structures.

MODIFICATIONS AND UPGRADES FOR THE BIOSPHERE 2 LABORATORY

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The Biosphere 2 Laboratory (B2L) consists of medium scale synthetic communities of plants and soils (mesocosms) encased in a gas-tight glass and metal shell. The B2L includes ocean, rainforest, intensive forestry and desert areas that can be (or soon will be) studied as isolated whole systems. Since mid 1996, Columbia University has managed the facility and has made a host of renovations designed to optimise the use of B2L for the experimental studies of global change impact on Earth systems. Lightweight curtains allow reversible closure of the rainforest and three intensive forestry sections currently operated at three different CO_2 concentrations. These and other modifications provide unique research opportunities to study “system-level” responses to elevated CO_2 and climate change, yielding data that are needed to validate models that scale up from leaf to canopy to ecosystem. Lessons learned in B2L will lead to new approaches in research and complement less well-controlled experiments such as long-term ecological reserves (LTER) and free atmosphere carbon dioxide enrichment (FACE).

Each biome is a large controlled environment chamber in which fluxes of water, carbon and other compounds can be monitored precisely for measurements of the whole system mass balance and response to changing CO_2 and/or other climatic factors (e.g. net ecosystem carbon exchange (NEE), transpiration, trace gas production and isotopic balances). Each isolated terrestrial mesocosm is equipped with CO_2 injection and extraction systems so that the CO_2 partial pressure can be controlled in the range of 400 μmol mol^{-1} (close to present level) to 1200 μmol mol^{-1}. Fans installed inside each mesocosm prevent temperature stratification, and water supply and drainage systems have been modified so the rainforest, desert and intensive forestry biomes have a single-pass water system. Water balances are calculated by metering and reporting all water fluxes occurring in the system. Arrays of research instrumentation in each biome measure temperature, light, PAR, humidity, soil temperature and soil moisture. A separate data network of data loggers acquires data from sensor matrices in each biome and makes the data available remotely in real time. Analytical grade IRGAs monitor CO2 values from multiple sample points in each biome while industrial grade IRGAs work in concert with mass flow controllers for the maintenance of prescribed CO_2 levels. Portable instrumentation is used throughout the facility for measurements on leaves.

DEVELOPMENT OF THE COMMERCIAL PLANT BIOTECHNOLOGY FACILITY FOR THE INTERNATIONAL SPACE STATION

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A Commercial Plant Biotechnology Facility (CPBF) has been developed by the Wisconsin Center of Space Automation and Robotics (WCSAR) at the University of Wisconsin-Madison. The purpose of the CPBF is to support long-term commercial and scientific plant research in a microgravity environment on board the International Space Station (ISS). CPBF provides an enclosed, environmentally controlled plant growth chamber with controlled parameters of temperature, humidity, light intensity, and atmospheric composition, and with fluid nutrient delivery.

CPBF is configured as a quad single Middeck Locker payload to be mounted in an EXPRESS rack that will be installed in the U.S. Lab Module. Since the CPBF is envisaged to remain on board ISS for extended periods of time, its design is based on an open-architecture concept i.e. the subsystems are removable and replaceable on board ISS. CPBF consists of seven major subsystems: a rack interface structure; an environmental chamber; a light module; an ASTROPORE™ unit; active fluid and nutrient delivery; atmosphere composition control; and computer control and data management.

The rack interface structure serves as a chassis to house the CPBF payload and is attached to the Payload Mounting Panel of the EXPRESS Rack. The environmental chamber provides an airtight volume to prevent the chamber air from being contaminated by the ISS cabin atmosphere, which usually contains high levels of CO_2 and trace organic compounds that may affect plant growth. The ASTROPORE™ unit provides the features of self-priming, humidification, dehumidification, and recovery of condensate from the dehumidification process. The light module offers a choice of two configurations, an LED light module using high-efficiency, low-heat red and blue light emitting diodes at wavelengths of 670 nm and 450 nm, respectively, and a fluorescent light module using high output bi-axial tubes. Fluids and nutrients are delivered to the plants through porous tubes buried in the rooting material. The nutrient solution is confined within the porous tubes with a slightly negative pressure so that it is supplied to plants by capillary transfer through the pores into the rooting material. The atmosphere composition control system maintains chamber CO_2 concentration at a desired level and continuously removes the ethylene released by the plants. The computer control and data management system integrates the advanced control, fault detection, and telescience technologies together to increase overall system robustness and user friendliness.

TEMPERATURE MEASUREMENT: A REVIEW OF THE ADVANTAGES AND DISADVANTAGES OFTHE 4 MOST COMMON TYPES OF THERMOCOUPLE WIRE.

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I will review and discuss the criteria for selecting appropriate thermocouple wire for temperature measurement in controlled environments. Appropriate data acquisition equipment, coupled with correct measurement procedures, allows gradients of 0.01 °C to be accurately measured. An absolute accuracy of 0.1 °C is also possible.

HYBRID SOLAR AND ELECTRIC LIGHTING TO ALLEVIATE POWER CRUNCH FOR BIOREGENERATIVE ADVANCED LIFE SUPPORT

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Hybrid solar and electric lighting (HYSEL) systems constitute the latest generation of lighting systems for advanced life support, exhibiting continued potential for reducing the significant electrical power demand of current bioregenerative life support systems (BLSS). Two experimental HYSEL systems were developed: one employing xenon-metal halide (XMH) lamps and the other adopting light-emitting diodes (LEDs) as the electric-lighting components, and both using a mirror-based, fiber-optic-based solar collection system. The results showed that both the XMH and LED HYSEL systems effected reduced effective plant growing volume, indicating a potential for a compact plant hardware design. The apparent electrical conversion efficiency of the LED HYSEL system exceeded that of the XMH HYSEL system by five-fold. Both the XMH and LED HYSEL systems provided reasonably acceptable spectral quality and lighting uniformity. So far, LEDs appear to be the most competent artificial light source for a HYSEL system. Also, preliminary studies suggested that HYSEL systems show promise of BLSS application both on the Martian surface and on a Sun synchronous orbit around Mars.

INTRACANOPY LIGHTING AS A SOLE SOURCE OF PAR AND PHAR FOR PLANOPHILE CROP CANOPIES IN CONTROLLED ENVIRONMENTS

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Mutual shading attenuates PPF below the light-compensation point within closed canopies of overhead-lighted crop stands, causing loss of productivity and premature senescence of lower leaves in dense stands of planophile crops (leaves aligned perpendicular to the plane of incident light) growing in controlled environments. Deployment of low-intensity light sources within foliar canopies permits developing leaves to adapt physiologically for more efficient conversion of photon energy to the energy content of photosynthate. The usual attenuation of blue and red wavelengths in the understorey of overhead-lighted canopies is absent in intracanopy-lighted canopies. A significant delay in senescence of lower leaves occurred within cowpea (*Vigna unquiculata* L. Walp) crop stands lighted by 15-W fluorescent lamps arrayed within the canopy remote from their ballasts and switches. Lamina and petioles re-oriented so that adaxial leaf surfaces faced the nearest tubular lamp. Intracanopy lighting with low-PPF PAR yielded half as much crop biomass as did overhead lighting with high-PPF PAR, but did so consuming only 10% as much electrical energy for lighting. The heat load associated with low-irradiance intracanopy lighting raised leaf temperature no more than 2°C above ambient air temperature without activating the air-conditioning/heat-rejection system, which ran constantly with high-irradiance overhead lighting. Intracanopy lighting with relatively cool light sources that are low in mass, volume, and power requirement and which have an emission spectrum that matches absorption maxima of major pigment systems have a promising future for controlled environment agriculture on Earth and in space.

J.M. Frantz - Winner: UK CEUG / NCR-101 Graduate/Postgraduate Travel Award

DESIGN AND OPERATION OF A MULTIPLE-CHAMBER GAS-EXCHANGE SYSTEM FOR PLANT COMMUNITIES

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Measuring whole-plant CO_2 gas exchange is a powerful technique, but cost and lack of commercially available chambers for whole plants often limit its use. We developed a 10-chamber gas-exchange system and it continues to evolve as a tool to investigate plant-environment interactions. Each chamber, constructed of clear acrylic plastic (Lexan™), is 0.5 m x 0.4 m x 0.9 m (L x W x H) permitting plant canopies to be studied. The chambers are housed within a larger walk-in growth chamber lit with six pairs of 1000 W HPS lamps providing up to 750 $\mu mol\ m^{-2}\ s^{-1}$ at bench height. Within each of the ten chambers, cooling coils positioned in front of a small fan further cool the chamber air and control humidity. A 75 W resistance heater within a given chamber interfaced with a data logger maintain temperature set points to ±0.2°C. Furthermore, root-zone temperature is controlled separately to maintain a root-zone temperature set point for each chamber. Individual deep-batch, aerated hydroponic systems positioned within the chambers are typically used and can be managed (pH and refill) without the need to open the chambers. Air flow to each chamber is controlled by separate mass flow meters positioned outside the walk-in unit. CO_2 is controlled on the main air line feeding into the chambers with a mass flow controller. A single pump is connected to a solenoid manifold and samples air from each chamber for one minute every ten minutes. Air samples are passed through a set of gas analysers and, with the flow rate, photosynthetic or respiration rates can be calculated to give a total of 144 measurements for each chamber every 24-h period. Current studies focus on how temperature and light influence respiration and carbon use efficiency of crop plants (ratio of daily growth to gross photosynthesis). The use of small chambers permits multiple, *replicate* canopies to be evaluated in a range of temperatures (range of 20°C with separate root-shoot control), light (0 to 750 $\mu mol\ m^{-2}\ s^{-1}$), relative humidity (~30% to 100%), and nutrition in a single study. The total cost of materials required for this system, including sensors for gas exchange, is about US$35,000.

LIGHT INTERCEPTION AND CANOPY COVERAGE OF LETTUCE AND RADISH GROWN UNDER DIFFERENT WAVELENGTHS OF RED LIGHT-EMITTING DIODES (LEDs)

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Light-emitting diodes (LEDs) represent an innovative artificial lighting source with several appealing features specific for supporting plants, whether on space-based transit vehicles or planetary life support systems. Appropriate combinations of red and blue LEDs have great potential for use as a light source to drive photosynthesis due to the ability to tailor irradiance output near the peak absorption regions of chlorophyll. This paper describes the importance of far-red radiation and blue light associated with narrow-spectrum LED light emission. In instances where radish and lettuce were grown under lighting sources in which the ratio of blue light (400-500 nm) relative to far-red light (700-800 nm) was low, there was a distinct leaf stretching or broadening response. This photomorphogenic response sanctioned those canopies as a whole to reach earlier critical leaf area indexes (LAI) as opposed to plants grown under lighting regimes with higher blue:far-red ratios. In many instances, the salad crops grown under LEDs were just as productive as crops grown under broad-spectrum light, largely as a consequence of more efficient light interception during early growth.

CALIBRATION STANDARDS FOR CONTROLLED ENVIRONMENTS: HISTORY AND USE OF THE NCR-101 INSTRUMENT PACKAGE

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In response to a need for uniform standards for controlled environment research, the NCR-101 group began assembling a set of reference instruments over 20 years ago. Of particular interest and emphasis has been the accurate measurement of radiation including photosynthetic, short wave, long wave, and most recently ultraviolet radiation. Radiation sensors in the package include:

1. Pyranometer (Eppley Lab Inc., model PSP, 285-2800 nm),
2. Pyranometer (Eppley Lab Inc., model PSP RG 715, 700-2800 nm),
3. Pyrgeometer (Eppley Lab Inc., model PIR, 4-50 μm),
4. Red/far red sensor (Skye Instruments, 660/730 nm),
5. UV sensor (Apogee Instruments, 250-400 nm), and
6. Three quantum sensors (LI-COR, 400-700 nm).

The package also contains an anemometer (TSI) and a data logger (Apogee Instruments) programmed for use with all the sensors. A spectrometer (StellarNet) was recently purchased and we are currently testing its performance.

The package serves two functions:

1. to provide a set of standards that can be used to check the calibration of members own instruments thus improving uniformity among studies in different controlled environment facilities, and
2. to provide members with unique instruments for characterising greenhouse and growth chamber environments.

The package is circulated by mail among the members for a fee of $300 (US). The fee helps to cover costs associated with managing the package including annual recalibration of the instruments. This paper will discuss the philosophy of the need for the package and provide an overview of the instruments and their use.

USING LEDs TO MANIPULATE RED:FAR-RED RATIO AND PHOTOMORPHOGENESIS IN CONTROLLED ENVIRONMENTS

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Light signals play a crucial role in determining the architecture of individual plants and canopies. In dense stands of plants, reflected far-red light (wavelengths in the range 700-750 nm) signals lead to reductions in red:far-red ratio (R:FR ratio), which are perceived by the phytochromes, a family of photochromic regulatory photoreceptors. Reductions in R:FR ratio trigger shade avoidance reactions, resulting in increased elongation of internodes and petioles with a concomitant reduction in allocation of resources to harvestable components such as seeds, roots or tubers.

Our understanding of the perception of R:FR ratio signals and the roles of individual members of the phytochrome family, as well as efforts to experimentally eliminate shade avoidance responses in crop plants, has been dependent on the construction of controlled environments in which R:FR ratio can be manipulated. The conventional approach to manipulating R:FR ratio has been to create polychromatic light sources where white light is supplemented with high photon irradiances of far-red light, generated by filtering the output of high-energy incandescent lamps through appropriate filters. The use of high-energy incandescent lamps consumes significant amounts of energy and generates massive amounts of heat. The greatest challenge in constructing low R:FR ratio controlled environments has been the dissipation of excess heat, usually involving windows of flowing refrigerated water.

Recently, we have created a new generation of low R:FR ratio controlled environments using optoelectronics. By manufacturing arrays of LEDs (light emitting diodes) with emission maxima at 735 nm, we have been able to produce low R:FR ratio sources by a simple modification of existing controlled environment growth rooms or cabinets. The LEDs generate virtually no heat, have very low energy consumption and estimated lifetimes of several years.

CARBON DIOXIDE WITHIN CONTROLLED ENVIRONMENTS; THE COMMONLY NEGLECTED VARIABLE

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The option to measure and control carbon dioxide levels within controlled environment chambers has been commercially available for over a decade. Despite this fact, relatively few controlled environment users choose to purchase or even utilise this option when it is available on their equipment.

Routine measurements taken at the McGill University Phytotron have shown pronounced fluctuations and significant variability of CO_2 levels between replicate growth chambers, between plant developmental stages and over the course of diurnal and seasonal cycles. Since elevated and below-ambient CO_2 levels have well documented effects on physiological, morphological and developmental aspects of plant growth, poor control of this variable must influence experimental results and the validity of research findings. At the McGill University Phytotron, chamber-mounted Infra-Red Gas Analysers are utilised in combination with simple scrubbers and injected CO_2 gas to control and stabilise ambient CO_2 levels. Typical long-term results demonstrate consistent CO_2 control at a level of ± 10 µmol mol^{-1}. A description of the materials, maintenance requirements and costs associated with routine control of this variable will be presented.

MODERNISATION OF THE CANBERRA PHYTOTRON: RECENT MAJOR MODIFICATIONS ALLOWING THE FACILITY TO OPERATE AS A PC2 (PLANTHOUSE) FACILITY FOR WORK WITH TRANSGENIC PLANTS.

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The Canberra Phytotron was commissioned in 1962 and was Australia's first major controlled environment facility. A range of differing controlled environments are provided: these include 15 glasshouses, 50 reach-in artificially lit growth cabinets, 25 naturally lit photoperiod cabinets and 5 walk-in growth rooms.

Originally designed to cater for experimentation in the disciplines of plant physiology, agronomy and biochemistry, the recent advances in plant molecular biology and the development of genetically modified plants have significantly impacted upon the demands and operation of the Phytotron. Today over 80% of all plants grown within the facility are genetically modified.

To accommodate these changes in scientific direction, the Phytotron has recently undergone a $A1.5 million upgrade, and now provides a modern environment that is better suited for experimentation with transgenic plants.

Many of the changes have been necessary to ensure that the Phytotron is fully compliant with the regulations set down by the Australian Office of the Gene Technology Regulator. To facilitate work with transgenic materials, other enhancements have included the provision of tissue culture manipulation facilities, clean laboratories and transgenic waste handling areas.

A COMPREHENSIVE FORMAT FOR SPECIFYING AND REPORTING CONTROLLED ENVIRONMENT REGIMES

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A flexible format for specifying controlled environment regimes is presented, which allows definition of a wide variety of standard and complex regime types. The format is time-series based and arranged in a database table style to assist management of the regime variables. Regime definition fields in the table include: i) regime name, ii) regime step, iii) step start delay, iv) step target level, v) number of step cycles, vi) cycle period, vii) ramp function to achieve target level, and vii) ramp duration. The table also includes information required for statistically-based reporting of regime conditions. These fields are: i) sampling interval, ii) record duration, and iii) expected precision (as the standard error of the record mean).

The format is designed to allow:

- Explicit definition of constant and cyclic regimes
- Definition of regimes as continuous (e.g. $T = f(t)$) and piecewise functions (e.g. simulation of meteorological data)
- Ramps of differing types (e.g. step, linear, sinusoidal, exponential decay)
- Level definition in terms of other parameters (e.g. $T = f$ (VPD)
- Specification of level with required precision and measurement regime
- Consistent and coherent specification and performance reporting
- Storage and retrieval with standard relational database applications
- Automated computer processing for process operation and subsequent analysis

NESTING MULTIPLE CONTROLLED ENVIRONMENTS FOR INDEPENDENT MANIPULATION OF SHOOT AND ROOT TEMPERATURES

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In nature, the roots and shoots of many crops are frequently exposed to greatly differing temperatures. We combined three environmental control systems to allow independent manipulation of shoot and root temperature for seedlings. Two growth chambers (Conviron PGW36, Winnipeg) were used to house apparatus within which the shoots and roots of juvenile maize were subjected to different temperatures. The maize plants were grown from seed in acrylic cuvettes, with a thin soil layer, which provided a means for researchers to quantitatively and non-destructively monitor root growth. The cuvettes were waterproofed and placed in covered water baths held at constant temperatures of 10, 15 and 20 °C. Above the baths, shoots were surrounded by acrylic boxes, within which the shoot temperatures were independently controlled. The chambers were maintained at a constant temperature and a data logger (Campbell Scientific, Logan) was used to individually control the cooling and heating of the water baths and acrylic boxes.

THE GEORGIA ENVIROTRON: MULTI-DISCIPLINARY STUDIES OF PLANT STRESSES USING CONTROLLED ENVIRONMENT CHAMBERS

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The Georgia Envirotron is a multi-disciplinary research facility located at the Griffin campus of the University of Georgia, and is available to both on and off campus researchers as well as to visiting scientists. The facility comprises multiple controlled environment areas, allowing researchers to study plant/environment interactions under a variety of controlled conditions and at different scales. Nine walk-in growth chambers (Conviron CG-72 and PGW 36, Winnipeg) provide researchers with opportunities to study the effects of light, temperature and CO_2 on both plants and plant pests and diseases. Treatments with enhanced levels of ozone will be available in the near future.

In addition three moveable sunlit chambers are available for field research. The chambers were developed by the University of Georgia, with temperature, humidity, and CO_2 control comparable to that obtained in the walk-in chambers. Each chamber covers 4 m^2 of ground and may be placed directly over an existing plant canopy. The facility also includes eight greenhouses with temperature control and supplementary lighting, and four reach-in chambers with sub-zero temperature capability

PLANTS IN SPACE - TRANSITION FROM SPACE SHUTTLE TO SPACE STATION AND BEYOND

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The International Space Station (ISS) promises longer research times suitable for long-term plant research beyond the 16 days available to date on the US Space Shuttle. However, during the station buildup, and due to the reduced crew of only 3 astronauts, research capabilities will be initially severely limited due to the lack of available crew time. Mass, power and volume constraints on the transfer from and to the Space Station, as well as the lack of adequate sample storage capabilities, such as freezers, further limit the research capabilities during the next few years. Research has to rely on automated systems for plant germination, plant growth, and sample preservation on orbit. Freezer capabilities and transport of frozen material back to Earth for post-flight analysis will not be available for several years.

Several plant research capabilities are available for spaceflight, with only a few capable of supporting long-term growth aboard the Space Station: the AstroCulture™, the Plant Generic Bioprocessing Apparatus (PGBA), and the Plant Growth Facility (PGF), all flown, the Biomass Production System (BPS, built, not flown), the Commercial Plant Biotechnology Facility (CPBF) and the Plant Research Unit (PRU), both under development.

Plant research topics for spaceflight have recently seen a shift from ‘Advanced Life Support’ concepts (plants for food, water and atmosphere recycling) to genetic research topics using gene chip array analysis not yet available several years ago. Only few, if any, of the spaceflight chambers are actually prepared to support such research easily and in an efficient manner for early Space Station research. While ‘Advanced Life Support’ (ALS) or ‘Controlled Ecological Life Support Systems’ (CELSS) have seen a reduction in funding, some research and support continues in food augmentation projects such as a ‘Salad Machine’, or small plant growth facilities in inflatable, and potentially low pressure / transparent structures for Space Station and even for planetary surfaces such as Mars.

Many technological questions remain difficult to answer, and have resulted in focused research projects, such as water / nutrient supply and distribution in porous media under microgravity conditions, moisture sensing, optimal light sources with minimal power requirements and heat generation and proper spectral quality. The small size of the spaceflight chambers often results in large gradients of environmental variables such as light and atmosphere composition. Temperature and humidity control are often compromised by the limited amount of power.