Proceedings of the UK Controlled Environment Users' Group

1996 SCIENTIFIC MEETING

"CONTROLLED ENVIRONMENTS FOR CLIMATE CHANGE RESEARCH"

Volume 7

Contents

1. Research beyond means - climate variability and plant growth. **J.R. Porter** 2 – 4

2. Possible impacts of increased UV-B - can you extrapolate between controlled environments and the field? **N. Paul** 4 - 6

3. Using the Ecotron to study global warming: Can model communities tell us anything? **T.M. Bezemer** 6 - 10

4. Controlled environment facilities at Newcastle. **C.J. Murgatroyd** 10 - 12

5. Climate change experiments at UCPE from laboratory to remote locations in the field. **J.P Grime** 12 - 13

L.D. Incoll (editor)

UK CONTROLLED ENVIRONMENT USERS' GROUP 1996

SCIENTIFIC MEETING

Controlled Environments for Climate Change Research

The scientific part of the annual meeting consisted of five invited contributions. Summaries of these, supplied by the speakers, follow.

SUMMARIES OF PAPERS

J.R. Porter (Department of Agricultural Sciences, The Royal Veterinary and Agricultural University, Agrovej 10, 2630 Tåstrup, Denmark) **Research beyond means - climate variability and plant growth.**

Introduction

How changes in the variability of growing conditions and the frequency of extreme events affect plant and animals has attracted increasing attention following attempts to assess the effects of climate change on crops and natural ecosystems. This is a different question from that normally posed in agro-meteorology where attempts are made to calculate the contribution that different environmental factors have on crop yield variability (e.g. Monteith, 1981; Grashoff et al., 1995).

The frequency of a meteorologically extreme event, such as temperature, can occur via either a change in the mean of a normal frequency distribution or, more obviously, via a broadening of the distribution but without a change in the mean level (Houghton *et al,* 1990) leading to a 'two-tailed' increase in extremes values. Clearly, extreme event frequency is more positively correlated with changes in the variability, as opposed to the mean values, of climatic variables (Katz et al., 1992).

The issue of the extent of changes in environmental variability is important because plant growth and development are connected to the environment via a combination of linear and non-linear responses. An important consequence of plants having some non-linear responses is that an estimate of the rate of a process depends on the spread within the environmental factor. When the rate of a process has a linear response to, say, temperature then the rate's numerical value does not depend on the width of the difference between a maximum and minimum temperature; all differences give the same mean value of the rate. In contrast, for a non-linear response, the estimate of the rate process differs depending on variation in the independent variable. Thus, using monthly average or daily input data for crop models gives different simulation results (Nonhebel, 1993). It is for this reason that variability has to be included as a separate factor in studies of plant and crop responses to climate.

Methods

A simulation analysis was made to compare the relative effects of a change in mean temperature and/or its variance on crop growth and development. There was (i) an increase in daily average temperature of 2 C and 4 C but without change in its variance and (ii) a halving or a doubling of the daily variance of temperature without change in mean value and (iii) a combined scenario with an increase in mean temperature of 4°C and a doubling of temperature variance.

Experimentally this hypothesis was tested by growing wheat with either a daily mean temperature elevation of 3°C per day or with no change in the mean but an increase in the daily amplitude of temperature (Moot *et al.*, 1996). A re-analysed experiment with grass (Robson, 1973) examined the effect of reducing the diurnal temperature cycle on various growth parameters.

At the community level, resistance to the initial damage of an extreme event like late frost was studied by exposing five herbaceous plant communities to simulated frost and measuring species' recovery rates.

Results

The simulated effects of such temperature changes were examined for grain yield. An increase in average temperature had the effect of reducing grain yield but with little change in its coefficient of variation (CV); CV was, in fact, predicted to drop with increased average daily temperature. Increasing the variability of temperature had a similar effect in decreasing mean grain yield (by 7%) as did an increase in the mean value of 2°C. For the combined scenario, the predicted decrease in yield was 19%, which is larger than the sum of the decreases for the constituent individual scenarios.

Changes in the variance of temperature affected the CV of yield more than did changes in mean values. The increase in the CV of grain yield for the (2 x s.d.) scenario was 90%, a value much higher than for any scenario with a simple change in mean temperature. The immediate experimental effects were a reduction in grain yield of 13%, a value in line with model predictions, and in maximum leaf area but with no effect on the rate of ontogenic development.

The effect of reducing the diurnal cycle of temperature on growth in grasses was dependent on whether the day or night time temperature was altered; day temperatures had a larger influence on growth parameters (Robson, 1973).

This effect extends also to insects, such as the fruit fly *(Dracus tryoni),* where the time taken for egg maturation was lower when a constant day temperature of 20°C was alternated with night temperatures which increased from 8°C to 20°C (Meats *et al.*, 1976). At the community level, the subsequent recovery of plants from a frost event, however, was negatively correlated with the ability to withstand poor nutrient conditions. A clear positive relationship was found between the frost resistance of the above-ground biomass and the genome size of the plants. This was postulated to occur because of the positive relationships between genome size and cell division rates, on the one hand, and cell division rate and earliness of growth, on the other (Macgillivray *et al.*, 1995).

Conclusions

Important questions for the future, and particularly in the context of climate change studies, are: what is the relationship between the degree and scale of environmental variability and consequential plant-to-plant variability? Secondly, much physiological experimentation is geared to elucidating how differences in growing conditions lead to differences in plant growth. However, what mechanisms he behind the relatively conservative responses of plants to wide fluctuations in their growing conditions?. A third question is how do we approach this topic experimentally? Finally, how and to what extent do the considerations highlighted above apply to animals and micro-organisms?

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N. Paul (Biology Division, IEBS, University of Lancaster, Lancaster LA1 4YQ)

Possible impacts of increased UV-B - can you extrapolate between controlled environments and the field?

Ultraviolet-B radiation (UVB) radiation is arbitrarily defined as that part of the electromagnetic spectrum between 280 and 315 nm. In fact definitions vary somewhat, and UVB is best considered simply as representing the shortest wavelengths of sunlight to penetrate through the atmosphere to the ground. Shorter wavelength UVC radiation (200-280 nm) is highly energetic, and causes severe damage to many biological systems, but is completely absorbed by oxygen and ozone in the atmosphere. Thus damage caused by artificial UVC sources, such as widely used "germicidal" lamps, is of little relevance to studies of environmental ultraviolet. UVB is also absorbed in the atmosphere, especially by ozone, but absorption is not complete. Variations in ozone, whether natural or resulting from man's activities such as the release of CFCs, therefore influence the penetration to the ground of UVB, especially shorter wavelengths within this waveband. By contrast longer wavelength UV-A (315-400 nm) is virtually unaffected by ozone depletion. Increasing concern over man-made depletion of stratospheric ozone, evident in the widespread media coverage of the "ozone-hole", has focused attention on the biological consequences of increasing UVB. Research arising from concern over ozone depletion has shown that many organisms can respond to UVB wavelengths, and stimulated interest in the effects of variation in "ambient" UVB, which changes substantially with time of day, season, latitude, cloud cover and tropospheric pollution, as well as stratospheric ozone.

Attempts to extrapolate the UVB responses of plants in controlled environments (CE) to the field must depend on careful consideration of experimental conditions. While many aspects are common to all CE studies, some issues are of particular importance for UVB research. A key issue with investigations of UVB responses is the provision of relatively "high light" conditions. "Low light" in terms of photosynthetically active radiation (PAR: 400-700 nm), and perhaps UVA, predisposes plants to the damaging effects of UVB. For example, field studies show small reductions in the growth and yield of pea under elevated UVB but no effects on gas exchanges or chlorophyll fluorescence[1]. Similar UVB responses are observed in our CE research at Lancaster in which peas are grown at PAR irradiance around 900-1000 µmol m^{-2} s^{-1} (from a combination of 400 W metal halide and 1000 W high pressure sodium lamps providing approx. 40 mol d^{-1} PAR)[2]. By contrast, CE studies of pea under low light (< 300 µmol m^{-2} s^{-1} PAR) have found that UVB caused visible damage to leaves and grossly reduced CO2 fixation and chlorophyll fluorescence.

In our CE studies we provided UVB from specialised fluorescent tubes. Such lamps, supplied by a number of manufacturers, are the most common method of manipulating UVB. However, a major issue in interpreting experiments using artificial lamps is the spectral composition of the light they emit. In sunlight irradiance increases exponentially with increasing wavelength in the range 290 to 340 nm. Typical artificial UVB sources have a peak around 310-315 nm and are far richer than sunlight in shorter UVB wavelengths. Spectral differences are of major concern since many biological processes are very dependent on wavelength. The relationship between wavelength and a specific response, formally defined by an action spectrum, differs between responses. Action spectra remain poorly defined in many cases and at least three contrasting spectra might be chosen for whole plant responses to UVB. The most widely used is the generalised plant action spectrum (PAS) obtained by M.M. Caldwell some 25 years ago[3]. This spectrum indicates that plant responses decrease exponentially with increasing wavelength within the UVB, and that UVA has no effect. More recent plant action spectra suggest that responses are less wavelength-dependent, with marked responses to UVA, in some cases even to the longer UVA wavelengths[4,5]. For any action spectrum the output of a given light source can be expressed as "biologically effective" radiation: the product of the action spectrum and the spectral distribution of the radiation. Artificial lamps, rich in short wavelength UVB, are more effective in producing biologically effective radiation weighted according to action spectra dominated by responses to shorter wavelengths (like PAS), than alternatives with greater UVA responses. Thus, providing 100% of summer maximum PAS would provide only 10-30% of summer radiation weighted using alternative plant action spectra. This greatly influences the interpretation of CE data. Interpretation of plant responses to experimental doses which cover the range of PAS under ambient conditions and varying degrees of ozone would be very different if an alternative action spectrum was adopted since even the highest dose would be less that the current ambient maximum. Clearly, in the latter case, the data would be hard to relate to the possible consequences of ozone depletion[6].

Given the limits on artificial UV sources and the uncertainty over the appropriate action spectra (indeed perhaps no single action spectrum is "most appropriate" considering the diversity of potential plant responses) interpretation of CE studies must take account of the alternative action spectra. Nonetheless, given this cautious interpretation, CE studies conducted under adequate PAR remain valuable in determining the mechanisms of UVB responses which provides an essential complement to field investigations.

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T.M. Bezemer (Imperial College at Silwood Park, Brockhurst Road, Ascot SL5 7PY) **Using the Ecotron to study global warming: Can model communities tell us anything?**

Introduction

The Ecotron, housed in the NERC Centre for Population Biology at Silwood Park, Ascot, Berkshire, is a controlled-environment facility, suitable to study the effects of climate change on ecosystems. This paper briefly describes the Ecotron and shows its importance for climate change research.

The Ecotron

The Ecotron consists of 16 integrated environmental chambers, separated in two banks (Figure 1), in which miniature model terrestrial ecosystems are constructed. These ecosystems can be run for many months under controlled environmental conditions. Although artificial, these communities mimic what is found in the field.

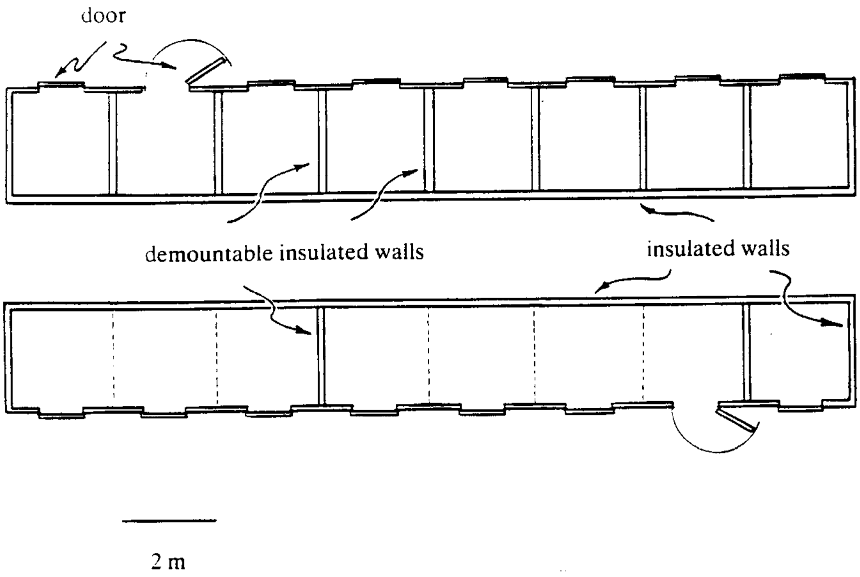

Figure 1. Ecotron plan view illustrating the overall construction of units in two banks of eight chambers each. The internal walls of each bank are demountable thereby allowing variation in unit chamber dimensions.

In the current Climate Change Experiment, the ecosystems consist of soil fauna, bacteria and fungi, different plant species, snails and different insect herbivores and parasitoids. In separate experimental runs, the effects of elevated CO_2 (ambient + 200 µmol mol^{-1}), elevated temperature (ambient + 2°C), and a combination of both elevated temperature and CO_2 on these ecosystems are investigated. Every run lasts 9 months; in this period 3 full generations of plants are completed. Every run consists of one control bank and one "elevated" bank.

The Chamber

Figure 2 shows an overview of an Ecotron chamber. Each chamber has a floor that averages 2 m x 2 m and is 2 m high from floor to the ceiling, which is formed by the airtight, UV-transmitting, Perspex window of the lamp housing. The materials used to build the chambers are all phytotoxin-free.

Air enters the chamber from beneath the floor, is mixed in the chamber by 2 air circulation fans and removed through the chamber air outlet. Before air enters the chamber it is filtered and conditioned. On every cycle 27% of air is exchanged with filtered outside air.

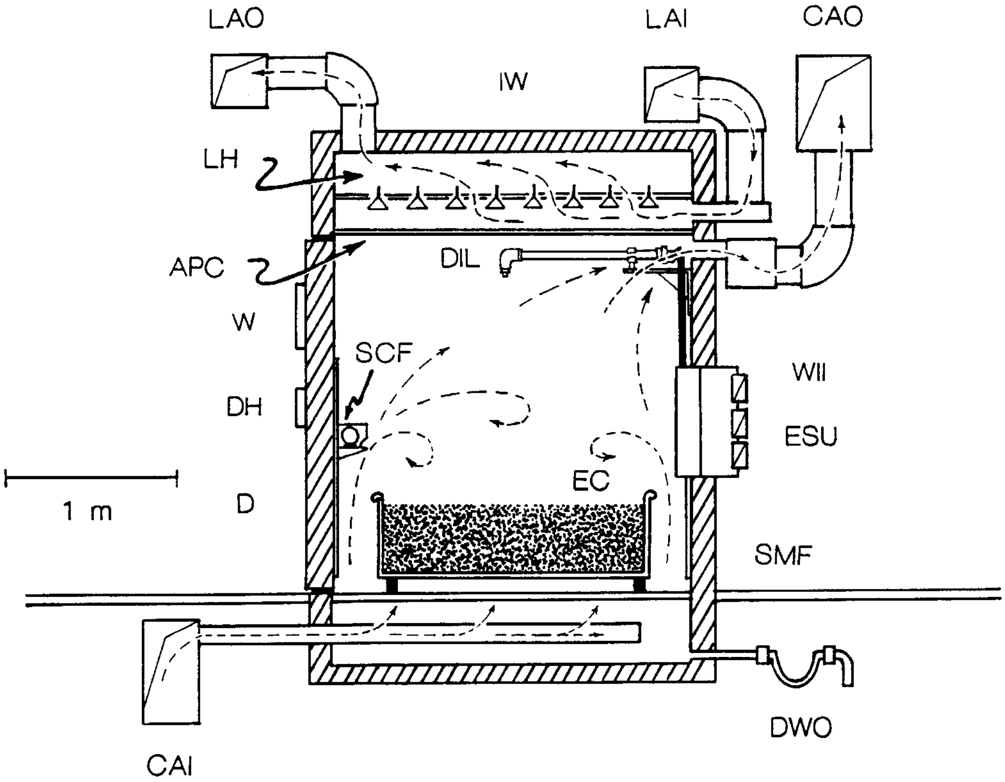

Figure 2. Side elevation of a single chamber. APC, airtight Perspex ceiling, CAI, chamber air inlet; CAO, chamber air outlet; D, door, insulated and with airtight seals; DIL, demountable irrigation lance; DH door handle; DWO, drainage water outlet; EC, ecosystem container; ESU electronic sensors unit; IW, insulated walls; LAI, lamp house air inlet; LAO, lamp house air outlet; LH, lamp house with separate air flow for cooling; SCF, secondary circulation fan; SMF, stainless-steel mesh floor; W, window, shuttered and insulated, WII, water irrigation unit.

Lighting

Every Ecotron chamber is provided with 60 quartz halogen and 18 fluorescent lamps. The lamp house is separated from the chamber by UV-transmitting Perspex. The complete light system provides a spectral output which closely simulates daylight on an overcast day (Figure 3). Every chamber has a separate air handling unit to remove the air produced by the lights to keep the climate in the chambers unaffected.

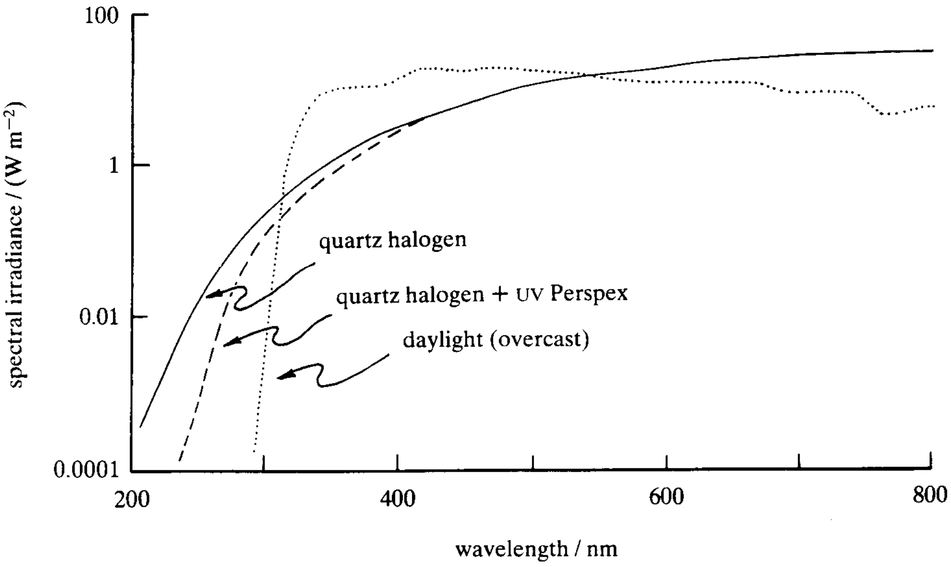

Figure 3. Spectral properties of Ecotron lighting. (Fluorescent lamps are not included in this graph but they improve the fit towards overcast daylight).

Climatic control

To simulate "normal" outside conditions, temperature and humidity in the chamber fluctuate over a 24-hour cycle (Figure 4). During daytime, temperature increases and humidity decreases and this is reversed at night time.

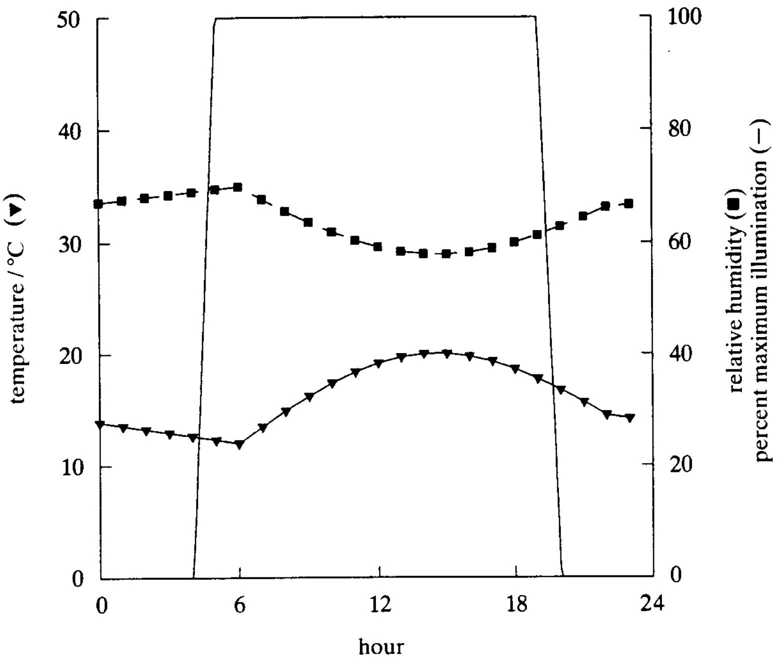

Figure 4. Diurnal pattern of temperature, humidity and light-intensity in the Ecotron.

Light intensity is gradually decreased or increased to provide a dusk and dawn period, respectively. Humidity and temperature control takes place in the central air-handling units (Figure 5) and are smoothly varied.

The climate is regulated by computer control. Climatic measurements are taken before air enters the chamber and when removed from the chamber. In this way, changes in climatic conditions caused by the ecosystem (e.g. temperature fluctuations, carbon dioxide fluxes) can be determined within the chamber. Individual chambers have sensors that provide experimental information on humidity and temperature for information only.

When studying the effects of elevated CO_2, exactly 200 µmol mol^{-1} is added to the ambient air CO_2 level. Thus fluctuations of the actual concentration of CO_2 are equal in both treatments.

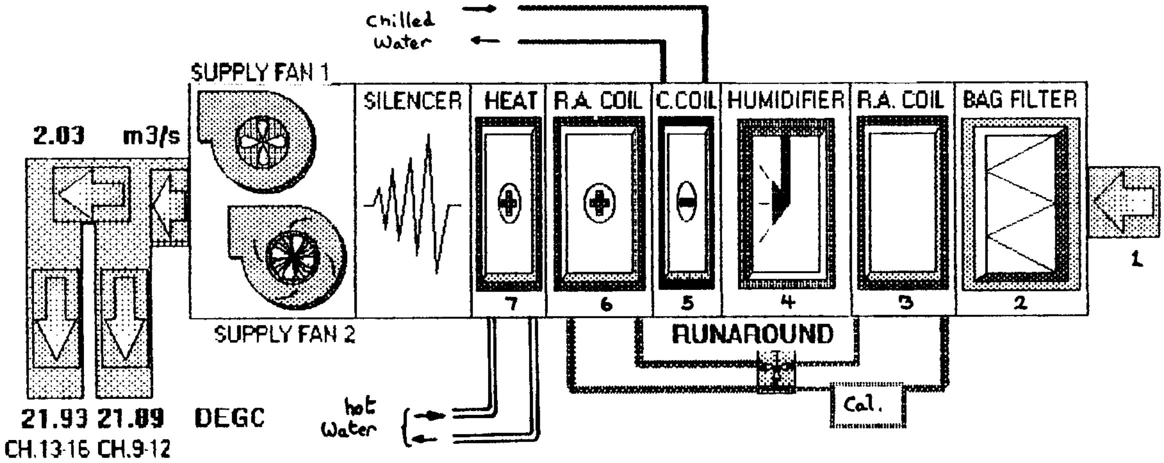

Figure 5. Incoming air (1) is filtered (2) and passes through a runaround coil (3) into the humidifier (4) where the RH is increased to almost 100%. The airstream is immediately cooled to achieve the wet bulb temperature. The second runaround coil (6) and the reheat coil (7) warm the air to its correct dry bulb temperature. The interconnected runaround coils (3) and allow more economical running.

Climate Change Experiment

Although the current climate change experiment has not yet finished, results already show that elevated CO_2 and temperature might have severe impacts on ecosystems. The importance of the Ecotron in gaining insight on how climate change might affect ecosystems can be illustrated with two examples of data from the elevated CO_2 experimental run.

Soil processes: The composition of different species of soil fauna changed significantly in elevated CO_2. Through their role in decomposition and nutrient supply, soil fauna are important ecosystem links. Changing the community structure of these animals may therefore have severe consequences for whole ecosystems. The results highlight the importance of including soil processes in climate change studies.

Plant biomass: In the Ecotron ecosystems, plant responses to elevated CO_2 did not only differ per species, as is already known from the literature, but also differed per plant generation. This aspect illustrates and underlines the fact that the impact of elevated CO_2 on plants cannot be predicted from results obtained from one generation only

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Acknowledgements
The Ecotron is maintained by a team of dedicated engineers. In particular, for the current experiment, Clive Jerram, Phil Small, Dennis Wildman & Richard Woodfin deserve special mention.

C.J. Murgatroyd (Air Pollution Laboratory, Department of Agricultural and Environmental Science, University of Newcastle, Newcastle upon Tyne NE1 7RU) **Controlled environment facilities at Newcastle.**

The greatest constraint on the progress of air pollution and climate change research is the technical difficulty of fumigating plants under conditions that are reproducible and environmentally realistic. The effects of air pollution on plants have been investigated in Newcastle since the early 1970s. Various approaches and techniques have been adopted as new technologies have become available and shortfalls of existing systems have become apparent.

At Newcastle, two major types of pollutant exposure facility have been developed. The first is a system to control air quality in the field and the second is to use controlled environment chambers in the laboratory. Both approaches have their advantages, the field system causes minimal alteration to the plant's environment but work tends to be seasonal. In the laboratory the environment is much more tightly controlled and reproducible but less environmentally realistic.

Field System

The present setup has been developed following tests conducted on an Open Release System (Wilbourn *et al.* 1995) where generated air was released above grass/clover plots in the field. Although it provided valuable data, several restrictions were evident with this system:

- labour intensive.
- ozone could only be applied at concentrations above ambient and there was no control over ambient ozone.
- wind speed was a major constraint on the level of control achieved.

A Field Air Exclusion System (FAES) is presently in use at the same site using some of the original equipment. Ambient air passes through a particulate and charcoal filter down a delivery plenum and is blown over plots partly excluding ambient air. Ozone can thus be added and applied to the plants under near ambient conditions. The initial FAES was based on a design used by Olsyzk *et al.* (1986). The technique employed was effective in excluding about 60% ambient ozone but resulted in both longitudinal and horizontal gradients in ozone concentrations over treated plots. Consequently we have developed a new delivery system using computerised modelling, where plants are grown inside two perforated rings, one supported above the other. Performance tests on this new configuration are currently underway in the field. The eventual aim is to achieve field exclusion and controlled ozone generation through computerised feedback control. Using Delta-T and Squirrel data loggers, ozone concentrations, light levels, air temperature, soil temperature, wind speed, wind direction and relative humidity are continually monitored at positions within and outside the controlled environment.

The current FAES has a number of important features:

- minimal alteration to the ambient environment.
- charcoal-filtered air is supplied to the plots. Therefore, the base level of ozone is controlled.
- reduced interference from wind due to the pattern of air flow over the plots.
- automation has reduced the amount of labour required.
- the size and number of plots and exposure to different pollutants can be altered with minimal cost.

Controlled Environment Chambers

The three most important factors contributing to the design of the current controlled environment chambers at Newcastle are:

1. Ashenden and Mansfield in the 1970's demonstrated that high flow rates and turbulence were necessary to reduce loss/deposition of pollutants and to produce low leaf boundary layer resistance.
2. Laboratory air used in early fumigation chamber work at Newcastle was found to be contaminated with gases such as NOx, ethylene and CO_2 which could interact with the pollutants under study. A flow-through system was required where external air with ambient CO_2 content is filtered by purifil and charcoal to remove pollutants.
3. The requirement for sufficient chamber replication.

Chambers for the study of ozone and elevated carbon dioxide

There are 24 chambers (0.6 m x 0.9 m x 1.3 m in dimension) constructed within an angle-iron framework with melamine board side panels and Teflon or UV-transmitting plastic forming the roof. External ambient ah is drawn through particulate, Purifil and finally activated charcoal filters and passes into a plenum for delivery into the top of the chambers at a rate sufficient to provide 2 ah changes per minute. Ozone is generated from clean compressed ah by a Wallace and Tiernan laboratory ozonator and carbon dioxide is provided directly from cylinders with permanganate filters to remove ethylene. O_3 and CO_2 are controlled by computerised feedback using mass-flow controllers with software developed in conjunction with Paul Jarvis and Craig Barton at the University of Edinburgh. The elevated CO_2 can be set at a fixed target concentration or can be maintained at a set level above ambient and O_3 is controlled to give a realistic profile of O_3 concentration throughout the day.

Lighting is supplied by 2 Siemens Harrier floodlamp fittings with Wotan HQITS 400 W metal-halide lamps positioned above each chamber. These provide a quantum flux at average plant height of 350 μmol m^{-2} s^{-1}. The system is capable of controlling the temperature between 16-24°C throughout the year with independent day/night temperature control (Barnes *et al.* 1995).

Chambers for the study of low-temperature/pollutant interaction

A second system consisting of 12 chambers is being used to study low-temperature/pollutant interactions. The air supply system is identical to that mentioned above but is capable of achieving three different temperature treatments. O_3 and CO_2 are provided as in the previous system. Each chamber is 50 cm and lined with polystyrene for insulation, with triple glazed roof panels which are covered with a solar reflecting coat to minimise radiant heating. Lighting is provided by Connect MS03 floodlamps (fitted with 250 W HQITS metal-halide lamps) which provide a quantum flux of 300 µmol m^{-2} s^{-1} at plant height. The temperature range is approximately 8-18 C although there is some seasonal variation.

Flexibility: the main cost involved in each of the systems is the air supply unit. The number of chambers, type of pollutant etc. can be altered for a minimal cost.
Low Cost: the setup cost for the 24 chamber system was £40 000. Annual maintenance costs are approximately £1000 exclusive of power supply! The FAES cost around £25 000, and annual running costs are minimal.
Reliability: Over the last four years the chambers have been out of service for no longer than half a day.

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J.P Grime (NERC Unit of Comparative Plant Ecology, University of Sheffield, Sheffield S10 2TN) **Climate change experiments at UCPE from laboratory to remote locations in the field.**

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