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1992 SCIENTIFIC MEETING

"CO_2 ENRICHMENT FOR CLIMATE CHANGE RESEARCH"

Volume 3

Contents

L.D. Incoll (editor)

CONTROLLED ENVIRONMENT USERS GROUP

1992 SCIENTIFIC MEETING

CO_2 ENRICHMENT FOR CLIMATE CHANGE RESEARCH

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

SUMMARIES OF PAPERS

D.W. Hand (Horticulture Research International, Littlehampton, West Sussex, BN17 6LP)

Measurement and control of CO_2 in greenhouses and daylit cabinets

During the past 25 years the protected crops industries have greatly benefited from the use of supplementary CO_2 as an aerial fertilizer. The technique of enriching greenhouse atmospheres with CO_2 is now firmly established as a means of improving the output, quality and value of vegetables, cut flowers and ornamental plants. So far as CO_2 sources are concerned, the trend in recent years has been towards the use of pure CO_2 gas (199 ha) and natural gas (131 ha). LPG propane (58 ha) and low sulphur kerosene (305 ha) are favoured by many growers with small areas of heated greenhouses (less than 4,000 m) because the CO_2 is produced fairly cheaply and the heat of combustion can provide a significant proportion of the daytime heat requirement in winter. All sources of CO_2 have advantages and disadvantages, though cost and convenience are probably paramount with growers.

CO_2 enrichment in protected cropping

Commercially, CO_2 supplements are used during winter and early spring to raise the greenhouse CO_2 from ambient (normally about 350 vpm) to 1,000 vpm. This threefold level of CO_2 enrichment boosts crop yields by 20-40%, depending on environmental conditions and the purity of added CO_2. For example, the technique increases both the number and size of fruits on individual trusses of an early tomato crop and gives up to a 40% increase in overall value at the end of the growing season. Other crops which respond beneficially to CO_2 include cucumbers (more fruit and earlier cropping), sweet peppers (earlier cropping with increases in number and size of fruit), chrysanthemums (thicker and longer stems with bigger blooms of better form and colour) and roses (more marketable blooms and fewer blind shoots).

Threefold CO_2 enrichment is uneconomic during late spring and summer because ventilation is needed increasingly for greenhouse cooling. However, some enrichment is beneficial because even with ventilators open the rate of fresh air exchange is often insufficient to prevent crops depleting the atmosphere of CO_2 and the concentration falls below ambient. Enriching a greenhouse atmosphere with CO_2 to avoid depletion in summer can increase the yield and value of long-season cucumber and tomato crops by 5-15% depending on conditions.

Measurement and control of CO_2

Control of the greenhouse CO_2 concentration is needed (i) to maximize photosynthesis, growth and yield, (ii) to ensure that CO_2 supplements are used cost-efficiently, and (iii) to minimize damage to crops from gaseous air pollutants when hydrocarbon fuels are burnt directly in the greenhouse atmosphere for CO_2 enrichment. It is axiomatic that the precision of control can be no better than the accuracy of the measurement of the greenhouse CO_2 concentration. Infra-red gas analysis is the preferred option for measuring the greenhouse CO_2 concentration. Despite the high capital cost (from £1,000 to £4,000, depending on model) the method is attractive because it offers a continuous, highly discriminating and non-destructive measurement which is free of hysteresis. Other advantages of infra-red gas analysis are high sensitivity, linearity, rapidity and reproducibility of response, plus excellent stability in both the short- and the long-term.

Guidelines for Using CO_2, Analyzers

Successful CO_2 monitoring requires that errors of sampling, analysis and calibration are kept to a minimum. Attention to detail is vital. For sampling, this necessitates using nylon tubing for air sample lines, preventing condensation in air sample lines, using hermetically sealed pumps for forwarding the air sample to the analyzer, blowing rather than sucking the airstream through the analyzer, and testing regularly for air leaks in the pipework. Infra-red gas analyzers will give high performance by shielding the analyzer from direct sunlight, avoiding mechanical disturbance of the analyzer, diminishing analyzer response to water vapour, using microporous dust filters, allowing time to achieve equilibrium when switching from one airstream to another, stabilizing temperature and pressure of the airstream, sampling and calibrating at identical temperature and pressures, and maintaining a constant CO_2 level inside the analyzer housing.

Guidelines for calibration include checking the zero of the analyzer with nitrogen or CO_2-free air, spanning the measurement range with test mixtures, establishing the overall calibration and re-calibrating the analyzer regularly (weekly).

CO_2 control in daylit cabinets

Ten separate and identical daylit, controlled-environment cabinets are being used at HRI-Littlehampton in a series of experiments to quantify the long-term effects of elevated CO_2 and temperature on the yield responses of a range of temperate vegetable crops (representative of the main commodities and contrasting in terms of their adaptation to climate). The use of these daylit cabinets allows the crops to be grown in natural light, common atmospheric humidities and non-limiting supplies of water and mineral nutrients. CO_2 concentration is controlled +30 vpm at levels above ambient. Overall mean daytime concentrations achieved inside the daylit cabinets for three controlled levels of CO_2 enrichment (viz. 500, 650 and 800 vpm) imposed during late summer were 501, 650 and 808 vpm.

Measuring canopy photosynthesis

A method has been developed at HRI-Littlehampton for measuring the rates of net photosynthesis of mature, row crop canopies of cucumber and other protected crops over periods of 10 minutes in a single-span glasshouse (c. 9 m x 18 m in area). Photosynthetic rate is measured as the amount of CO_2 injected into the greenhouse atmosphere to maintain a CO_2 concentration equal to that in the air outside the greenhouse. Controlling the greenhouse

CO_2 concentration at the same level as ambient (normally about 350 vpm) ensures that, whatever the ventilation rate, there can be no **net** exchange of CO_2 through the ventilators and glass overlaps. The input of CO_2 is, therefore, equal to that being assimilated by the crop during photosynthesis. Corrections are made for any gains or losses of CO_2 in the greenhouse atmosphere between the beginning and end of each measurement period. Also, allowance is made for the CO_2 released from the root-zone environment by microbial activity.

Accuracy of control of the CO_2 concentration in the greenhouse atmosphere is kept within + 10 vpm of the normal ambient level. The amounts of pure CO_2 injected through a high-input solenoid valve (when necessary) and a low-input solenoid valve are metered by linear mass flowmeters and recorded by digital integrators. Readings are logged at 10-minute intervals and synchronized with measurements of the light flux density above the crop canopy. Release of CO_2 into the greenhouse atmosphere is accomplished through a network of perforated pipes at ground level and positioned along the midlines of the crop rows.

Conclusions

There is a wealth of experience in the glasshouse industry concerning the technique of CO_2 enrichment. Daylit, controlled-environment cabinets and glasshouses may be of use in future studies of the impacts and adaptations of crops to climate change. It is, however, necessary to make accurate and reliable measurements of the CO_2 concentrations before attempting to obtain precision of control

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R. Baxter & C.R. Rafarel (Institute of Terrestrial Ecology, Bangor). **Exposure facilities for climate change research - CO_2 and temperature control**

(1) Outdoor open-top exposure chambers

Open-top chambers have been constructed and are operating at ITE Bangor. Their design criteria demanded that they be cheap and relatively easy to construct, using any modestly well equipped workshop facilities; that they be portable in the field, and that they should give adequate carbon dioxide control at the level of the plant canopy. Full details of the design, construction and operating parameters of the chambers are given in Ashenden, Baxter and Rafarel (1992). The chambers are 1.3 m in diameter and 1 m tall. They have been designed to be placed over low growing grass and/or herbaceous vegetation.

To date, control of the atmospheric CO_2 concentration (± 6% of the desired target concentration of 680 $\mu l\ l^{-1}$) has been achieved in both chambers with a lid attached and in chambers with the lid modified to provide a frustrum. This has been achieved simply by using mass flow controllers to bleed a steady stream of CO_2 into the inlet ducting. An adequate maintenance of concentration can be achieved except when the chambers experience strong gusting wind when manual changes of CO_2 injection rate are necessary. A computer control system to maintain CO_2 concentration is planned in the near future.

The perennial problem of unwanted temperature rises within outdoor chamber systems and their control is currently under investigation at ITE Bangor. A large capacity refrigeration and air conditioning unit will be used to cool air when necessary prior to injection into the chamber.

(2) Controlled Environment Cabinets

The Bangor group have six Sanyo Gallenkamp controlled environment cabinets with high light facilities. These are currently being equipped with CO_2 monitoring and control equipment (PP Systems Ltd) for use at elevated CO_2 atmospheres.

(3) Solardome Facility

A major new development at ITE Bangor has been the transfer of the Solardome Climate Change Research facility, from the National Power Research Laboratories at Leatherhead, to a site on the Bangor University Farm, Aber, Gwynedd. This Solardome system was previously used for studying the effects of acidic gaseous pollutants on plants before being modified for climate change research, just prior to the closure of the Leatherhead Laboratories.

The system consists of eight 4.4 m diameter Solardomes laid out in an East-West line. The domes are glazed with Sanalux glass to give extended light transmission into the UV region.

The experimental treatments are arranged to give a factorial design with two levels of CO_2 (ambient and ambient plus 340 $\mu l\ l^{-1}$), two levels of temperature (ambient and ambient plus 3.0°C) and two replicates for each CO_2 x temperature combination.

Fresh air is passed through each dome at 3.7 volume changes a minute by a fan and ducting system. A variable speed fan draws air through a particulate filter and over either an electrical heater or a heat exchanger, depending on the temperature required. For elevated CO_2 domes, CO_2 from a bulk liquid CO_2 supply with vaporiser is then injected into the airstream. The air is then ducted underground to emerge vertically from a 60 cm diameter opening just above ground level in the centre of the dome. The air is then deflected downwards and across the plants by a deflector suspended over the opening to finally exit the dome through 14 perimeter vents.

Temperature control, for domes to be maintained at ambient temperature, is achieved by cancelling any solar heat gain and fan heating effects by passing the air through a cooled heat exchanger. The temperature of domes at 3.0°C above ambient is maintained by "topping up" the heat inputs to the system with electrical heating. An unusual feature of the system is the computer algorithm which uses solar radiation to predict and control the dome temperatures.

Air, from inside each dome together with two ambient sampling points, is drawn back through PTFE tubing to the control building by a Gas Handling Unit. Gas analysers monitor CO_2, H_2O, NO, NO_2, SO_2, and O_3 levels in each dome, sequentially, with a 3-minute dwell time and data is recorded on chart with hourly means being logged via a Macsym 350 computer. Temperature, relative humidity, and solar radiation are read every 3 minutes both inside the domes and outside, for the ambient conditions, and hourly means are logged together with duct air flow measurements.

Reference;

L.D. Incoll (editor)

Ashenden, T.W., Baxter, R. and Rafarel, C.R. (1992) . An inexpensive system for exposing plants in the field to elevated concentrations of CO_2. Plant, Cell and Environment, 15, 3 65-372.

A.R. McLeod (Institute of Terrestrial Ecology, Monks Wood) **Problems of controlling gases in the open air**

A number of methods have been developed to release and control gases in the open air in order to overcome spatial and temporal changes in gas concentration and achieve a realistic experimental exposure. Systems were initially developed for use with gaseous pollutants and have only recently been used with carbon dioxide. One can recognise 2 types of system: (1) air exclusion systems which displace the air mass surrounding plants and (2) plume systems which introduce discrete plumes of gas that are mixed and diluted by the surrounding air.

Air exclusion systems generally have large bore perforated ducts and are used between rows of plants. They have been used to protect plants against ambient pollutants and for fumigation with added gases. Hole number and size have been varied to generate concentration gradients along the rows and computer feedback control has been applied to try to maintain exposure concentrations.

Plume systems have developed from single points of gas release to designs with grids of perforated vertical and horizontal pipes within, above and surrounding the vegetation. The object of the gas source patterns in later designs was to minimise the spatial variation in concentration across the experimental area. Early experiments used constant rates of gas release but more recent systems have employed sophisticated algorithms in computers to operate a feedback control of gas release rate against both measured concentration and changes in wind velocity. Careful attention to system design has greatly improved the spatial and temporal distribution of gas concentration so that realistic exposures can now be achieved.

Open air systems offer several advantages over other field techniques. They avoid: (1) significant decrease in solar radiation and alteration of the diffuse/direct beam ratio by the walls and structure; (2) altered coupling of the canopy and bulk atmosphere through unnatural patterns of air flow, turbulence, temperature; (3) altered soil water patterns caused by diversion of natural rainfall by chamber walls and frustrums; and (4) impedance of propagule, pest and grazer movement by the walls. Their large size also makes them suitable for a large number of investigations on a wide range of ecosystem components.

However, open-air systems also have potential drawbacks: (1) Humidity within open-air plots is influenced by the transpiration of the surrounding vegetation which, in CO_2 studies, is at ambient concentration, and this transpiration may be higher than for vegetation at elevated CO_2; (2) Open-air plots may be foci for attacks by herbivorous insects and pests; and (3) Open-air exposure systems require a larger capital outlay, have higher running costs and manpower maintenance costs on a per installation basis.

It is important to decide whether the new biological insights provided by open-air experiments can justify the expenditure; whether the control of concentration in time and space is realistic and whether the system is reliable. Biological knowledge from studies with pollutant gases has revealed the importance of the technique but also its limitations. Open-air exposure of plants to gases is an important research tool which together with a range of other methods of gaseous exposure can greatly extend our understanding of plant and ecosystem functions.

J. Townend (Lancaster University) **Attempting to simulate natural rooting environments in controlled atmosphere chambers**

The majority of studies of the effects of elevated CO_2 on plants are presently carried out in controlled atmosphere chambers. A great deal of attention has therefore been paid to the development of systems capable of producing a wide variety of atmospheric conditions within such chambers. For the purposes of environmental research, however, it is necessary to consider not only the above ground conditions experienced by plants but also the conditions experienced below ground by the unseen parts of a plant - the roots.

A number of studies have involved planting directly into the ground under the chambers, but this is not possible on all sites for a variety of reasons (egs. high water table, unsuitable soil type for the species under study, difficulties of controlling water inputs for drought studies, or chambers situated within a building). A traditional solution to this problem has been to place the plants in plant pots within the chambers, however, it seems likely that such plants will experience rooting conditions far removed from those in the ecosystems we wish to represent.

Experiments at Lancaster are taking place in Solardomes (hemispherical daylit chambers approx 4 m diameter). Within these, Sitka spruce seedlings are being grown in large wooden boxes (1 m x 1 m x 0.5 m), lined with polythene and filled with peat. It is possible therefore to make simple comparisons between a relatively large volume of soil such as this, and the conditions occurring in plant pots placed in the same chambers.

Temperature was the first factor to be considered. On a warm day in August, the maximum and minimum air temperatures recorded were 26°C and 12°C respectively, the corresponding temperatures 10 cm below the surface in the large boxes were 17°C and 15°C, whilst temperatures at greater depths were even more stable. This can be compared with the maximum and minimum temperatures in a 15 cm pot (2 litres) which were 22°C and 14°C respectively.

The second factor considered was the availability of water in the soil, which can be monitored with soil moisture tensiometers. These revealed that in the large boxes the soil water potential at 15 cm depth remained at around -5 kPa in the well watered treatments, whilst a water potential of approx -40 kPa had been reached 120 days after watering had stopped in the droughted treatment (near the bottom of the boxes, but still within the rooting zone, no water potentials lower than -20 kPa have been recorded). By comparison, a seedling grown in a 15 cm pot, which started the year the same size as the plants grown in the boxes, was able to induce a soil water potential of -70 kPa in 7 days. Such a rapidly occurring drought represents a very different situation from that occurring in the large boxes since the plants would have no time to modify their root architecture by shedding roots growing in the driest parts of the soil and producing more roots lower in the profile, as might occur in a natural situation.

The final factor considered in this work was the interaction between decreasing water supply and increasing concentrations of nutrients in the soil water, because of reduced leaching. It is unclear to what extent this occurs in natural rooting systems but there was shown to be a very significant effect in the boxes used in this study. Though scientists may choose to ignore this kind of complexity, the plants, undoubtedly, will not.

In summary, we can say with some certainty that there are major differences between the rooting conditions experienced by many of the plants used in environmental research and the conditions experienced in the ecosystems to which we wish to apply our results. So what is the importance of these differences? It is difficult to know, but efforts should be made to either avoid them or quantify their effects. If the results of this kind of work are to be taken seriously by the policy makers, planners and the wider public, it is essential that these questions are not merely left unanswered.

C. Barton & **H. Lee** (Institute of Ecology and Resource Management, Edinburgh University).

Comparative studies on elevated CO_2 using open top chambers, tree chambers and branch bags

This project is funded by the C.E.C. to study the effects of elevated CO_2 on European forests. Trees are slow growing and have different morphology and physiology at different developmental stages therefore, it is important to perform long term experiments on both juvenile and mature tissue. To this end a variety of exposure facilities, including a range of open top chambers and branch bags are being used. The aim is to maintain the CO_2 concentration of elevated chambers 350 vpm above that of ambient chambers while keeping other environmental variables as close to those outside the chambers as possible.

The Institute of Terrestrial Ecology at Bush has 10 open top chambers (OTCs) devoted to elevated CO_2 research. Space in these chambers is being used to grow Sitka spruce, birch and beech trees. The birch and beech were grown from seed under elevated CO_2 while the spruce was moved into the chambers as 1+1 and are now 5 years old. All of the plants in the chambers are in pots and are watered by drip irrigation. A fan constantly blows air through the chamber and CO_2 is added to the air stream in the elevated CO_2 chambers. A problem with OTCs is incursions of air, when wind enters the chamber and flushes it out making it difficult to maintain the desired CO_2 regime. To reduce incursions a frustum and shelf are incorporated into the chambers. Air temperature in the chambers in 1-2°C above ambient on sunny days.

An advantage of growing plants in pots is that they can be taken into the lab to measure gas exchange under controlled conditions. Disadvantages with pots are extreme temperature fluctuations to roots and the possibility of root being constricted and altering plant growth. Furthermore, a strong correlation between pot size and the plant response to elevated CO_2 has been shown (Arp 1990).

Ideally, to assess the effects of elevated CO_2 on mature trees the whole tree should be fumigated. However, this would be prohibitively expensive and a compromise is to fumigate branches. We are using branch bags on 17-year-old Sitka spruce trees. Each bag is a cylinder 2.5 m long and 0.5 m diameter, consisting of a wire frame covered with a polyethylene sleeve. There is a zip sewn into the sleeve to permit access to the branch. The bags are fixed to the trunk at one end and flexibly mounted to scaffolding at the other, this permits the tree to move freely in the wind. A fan blows air through the bag (3 air changes per minute) which is open at the trunk. CO_2 is metered into the airstream by precision needle valves and concentrations in the bags are monitored using a PC-controlled system (common to all the exposure systems at Edinburgh). Air is continuously drawn through sample lines from each chamber and a three-way solenoid valve in each sample line diverts air from a selected chamber to the infra-red gas analyzer. The reading is stored to disk and the next chamber selected. The system can also be used in feedback mode to drive mass-flow controllers rather than needle valves to regulate the addition of CO_2 to each chamber. This is useful when incursions or variable fan speeds mean that a fixed injection rate of CO_2 cannot be used. The branch bags have been in place for 1.5 years so far and will be retained for at least two more years.

The birch grown from seed in the ITE OTCs became too big to remain in the OTCs and in order to assess the long term effects of elevated CO_2 on them they have been planted in the ground inside tree chambers. These chambers are of a cheap construction using a frame of 6 hoops of polythene water pipe 1 m in diameter spaced out at 60 cm intervals on six 6 mm stainless steel rods 3 m long. This frame is covered with a polythene tube open to the sky. Each chamber has a large and a small fan to supply air. The large fan is used during the day when a high volume air flow is needed to keep temperatures near ambient and the small fan used at night maintains some air movement through the chamber but reduces the CO_2 and electricity consumption.

For short term experiments on potted plants eight mini-OTCs (1.5 m tall by 1 m dia) in a glasshouse are used. Due to their siting inside a glasshouse they are not prone to incursions and thus have stable CO_2 concentrations. They are currently being used to look at the effects of elevated CO_2 and water stress on five species of *Eucalyptus.*

Next year we will be using the Forestry Commission's extended OTCs at Glendevon. These are similar to those at ITE but have been extended in height to 3.5 m to allow taller trees to be grown. The five-year old spruce trees from the ITE OTCs will be planted in the ground and allowed to grow for a further 2 years.

Reference

Arp, W.J. (1991) Effects of source-sink relations on photosynthetic acclimation to elevated CO_2. Plant, Cell and Environment, 14, 869-874.

L D Incoll
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