Edited by Joe J. Hanan

Bulletin 434
August, 1986

Published by the Colorado Greenhouse Growers' Assoc.,
Inc. in cooperation with Colorado State University

research bulletin

THE PROMISE OF ENRICHMENT

The Grower (British), IDH(3):31-37, July 18, 1985

David Hand of the *GCRI* reviews the technique of CO_2 enrichment in late spring and summer

Carbon dioxide is a key factor for photosynthesis. This is the basic process whereby green plants use absorbed light energy to convert CO_2, water, and mineral nutrients into organic compounds needed for growth and development.

For crops supplied with adequate water and mineral nutrients it is important to recognise that an environmental limitation to yield is imposed through the restriction of photosynthesis by light and CO_2. In Britain the threefold decline in incident light between the autumn equinox and the winter solstice is especially restrictive for the production of high-value salad crops.

The crucial role of light in determining crop performance is generally acknowledged and, during winter, efforts are made to maximise the light transmission in glasshouses. Nevertheless, light remains a limiting factor and enrichment of the glasshouse atmosphere with CO_2 is invaluable for improving crop productivity.

Commercially, CO_2 supplements are used during the winter and early spring to raise the CO_2 concentration inside a glasshouse from the normal ambient level (340vpm) to 1,000vpm. Practising a threefold level of CO_2 enrichment inside a glasshouse counteracts the adverse biochemical effects of atmospheric oxygen on photosynthesis. During the wintertime enrichment can boost photosynthesis by up to 50% and, depending on the environmental conditions and the purity of CO_2, can result in growers obtaining increases of 20 to 40% in crop yield.

CO_2 depletion

From late spring onwards it becomes increasingly necessary to ventilate glasshouses during the daytime, to limit the rise in air temperature from solar heat gain. Threefold CO_2 enrichment is impractical in these circumstances because the CO_2 assimilated by the crop is small in comparison with that lost to the outside air through ventilation.

This low CO_2 utilisation efficiency (the net CO_2 uptake by the crop expressed as a percentage of the CO_2 added to the atmosphere) makes it impossible to recoup the recurrent costs of using CO_2 supplements in these conditions, despite the very beneficial physiological response of crops to elevated CO_2 concentrations. However in the absence of CO_2 enrichment the rates of air exchange are often insufficient to prevent crops from depleting the atmosphere of CO_2 and the concentration falls below 340vpm.

At the GCRI Gerry Slack and Malcolm Hannah have found that a CO_2 depletion of 5 to 10% is fairly typical for a fully-ventilated cucumber or tomato house on a warm sunny day in June (**Fig. 1**). The situation is very much worse on cold bright days in late spring when relatively little ventilation is practised. In these conditions the amount of fresh air entering the house by natural leakage is too small to prevent depletion.

For an unventilated single-span cucumber house at the Institute the mean daytime CO_2 concentration can be as low as 260vpm (an average CO_2 depletion of 24%) with long periods in the middle of the day at 160vpm or less (a CO_2 depletion of 53% or more). The CO_2 concentration can be expected to be even lower in large multi-span blocks or Venlo-type houses with comparatively less natural air exchange taking place. Indeed, in near airtight glasshouses it is possible in bright light conditions for the CO_2 concentration to fall to a level at which both photosynthesis and growth virtually cease (usually between 50 and 100vpm CO_2 depending on irradiance and temperature).

In this respect, efforts to conserve heat by restricting the air exchange of glasshouses (by lap-sealing of glass sheets, lining of gable ends and sides with film- or bubble-plastic, and cladding structures with large plastic sheets) can be counterproductive. Problems of CO_2 depletion have also been accentuated by changes like the use of artificial growing media (peat bags, rockwool or nutrient film) instead of soils rich in organic matter.

Depletion of CO_2 in the glasshouse atmosphere is obviously undesirable because it depresses photosynthesis, slows growth, and reduces yield. For example, the net photosynthetic rate of a fully-expanded tomato leaf at a growing temperature of 20C will decline by about 9% in bright light and by about 6% in dull light for a 10% fall in CO_2 concentration below the normal ambient level of 340vpm (**Fig. 2**).

Work at the GCRI by Gerry Slack *(Grower,* January 10, 1985) and at Stockbridge House EHS by Dan Drakes

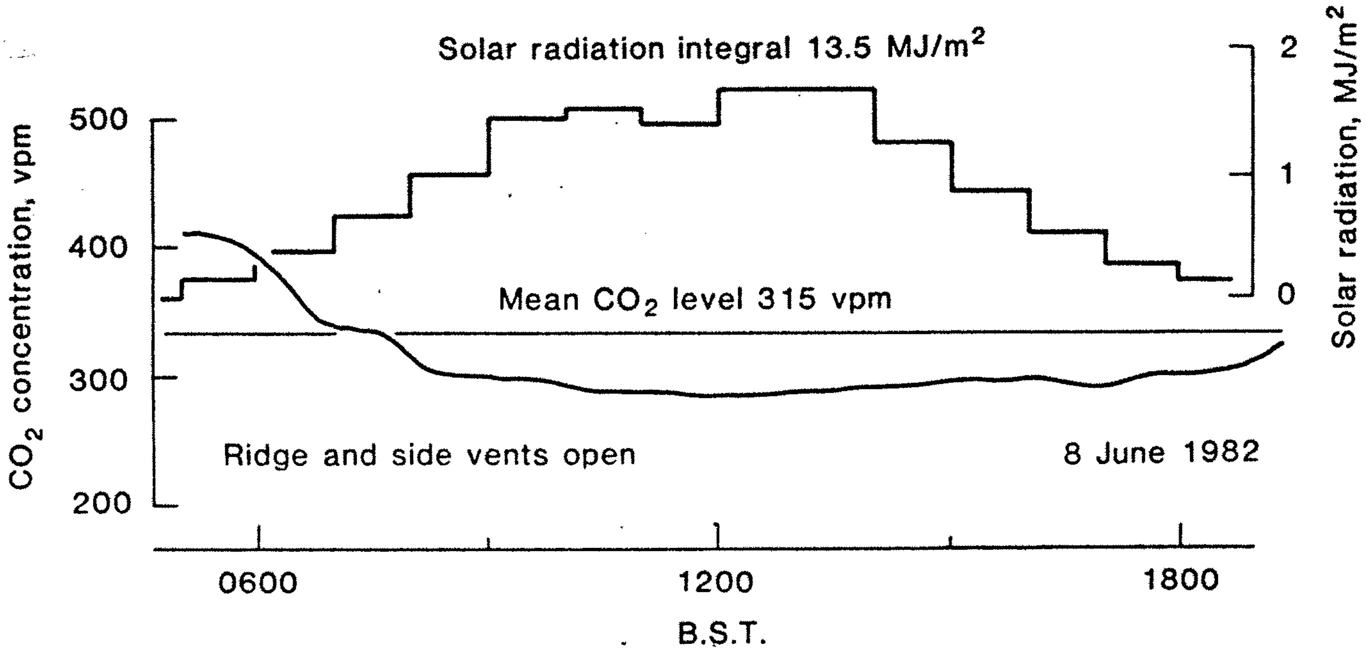

Figure 1. CO$_2$ depletion measured in a ventilated cucumber house at GCRI.

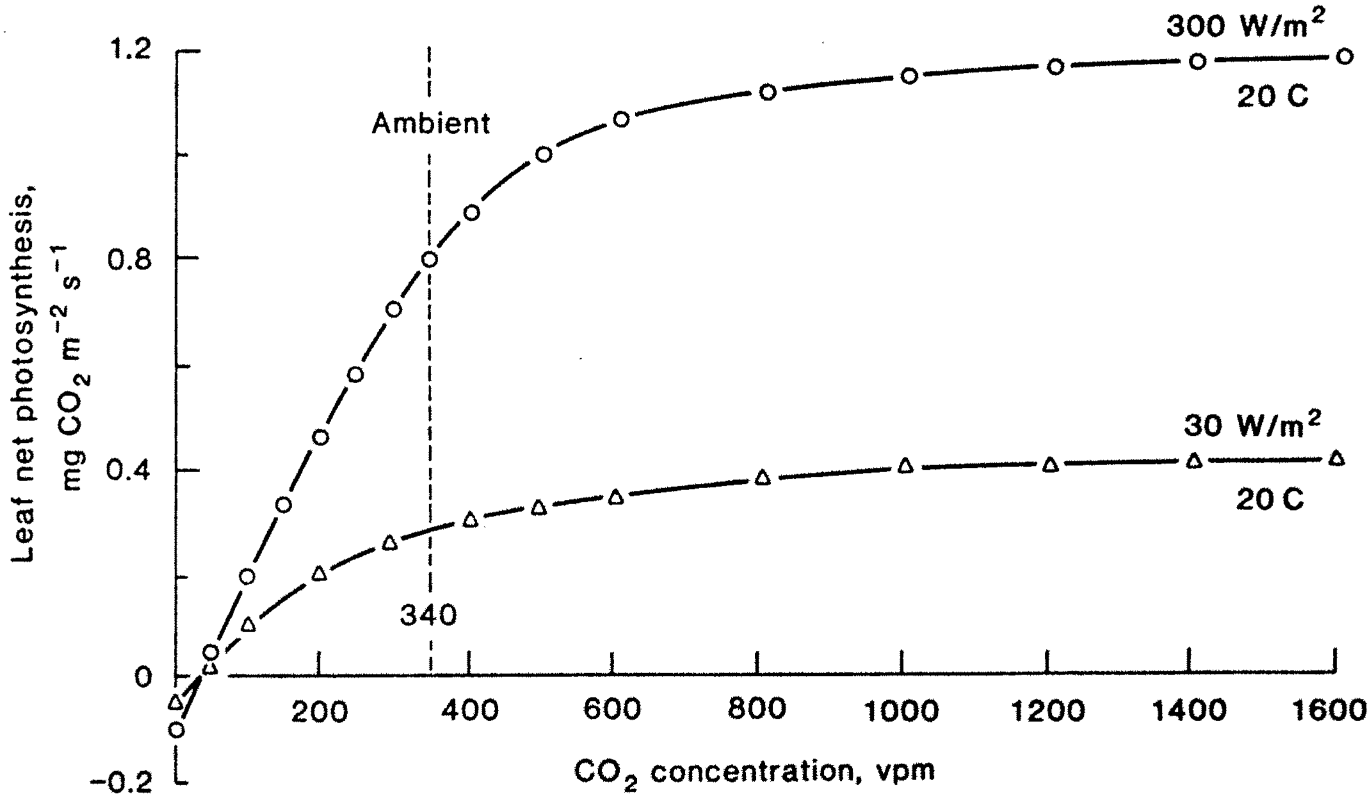

Figure 2. Measured net photosynthesis/CO$_2$ response curves for an attached tomato leaf.

(*Grower*, April 25, 1985) have established the merits of using CO$_2$ supplements during the summer for long-season cucumber and tomato crops. Depending on the extent to which depletion occurs the yield and value of these crops can be increased by about 5 to 10%.

Indeed, the technique has proved so financially attractive in the UK that the area of glasshouses equipped for summer CO$_2$ enrichment has expanded to 100ha in just two growing seasons. It is estimated that the area will increase by a further 25% in 1985.

Growers in Humberside are now fairly confident that with the help of summer CO$_2$ it will be possible to achieve yields of 35kg and 50kg per sq metre for long-season tomato and cucumber crops respectively. On the South Coast the target of 40kg per sq metre (160 tons per acre) for the early-heated tomato crop is now within the reach of the most efficient producers.

The annual increases in crop yield directly attributable to summer CO_2 enrichment are currently worth between \$1.4 million and \$3.5 million. After deducting recurrent CO_2 costs of about \$0.3 million, the benefit to the British protected crops industry is \$1.1 million to \$3.2 million.

Partial CO_2 enrichment of a glasshouse atmosphere to avoid depletion is a highly efficient way of using CO_2 supplements. When the CO_2 concentration of the atmosphere inside a glasshouse is maintained at the same level as ambient there can be no net exchange of CO_2 with the outside air through leakage or ventilation.

For practical purposes, the amount of CO_2 required to prevent a glasshouse from being depleted of CO_2 equals that being assimilated by the crop during photosynthesis. By metering the input of CO_2 into the glasshouse atmosphere it is possible to measure crop photosynthesis.

At the GCRI a null balance method has been used to measure the canopy net photosynthesis of a stand of tomato plants growing in a near-airtight daylit cabinet at a constant atmospheric CO_2 concentration. **Figure 3** shows the measured net photosynthesis/light response curve for the crop, grown at 20C.

At the maximum irradiance experienced under glass at the summer solstice the measured rate of crop photosynthesis for the tomato is equivalent to 40kg CO_2/hectare/hour (36lb CO_2/acre/hour).

This represents the maximum hourly rate of CO_2 supplementation likely to be required to avoid depletion and contrasts with a daily requirement in mid-summer of about 300kg/hectare (272lb CO_2/acre) for a tomato crop.

This latter figure was obtained at the NIAE in the 1950s when Len Morris and his colleagues first examined the subject of glasshouse ventilation and maintenance of an adequate supply of CO_2 to crops. Indeed, it was estimated that CO_2 depletion in glasshouses could be kept to an acceptable level by providing for an hourly ventilation rate of up to 24 cubic metres of fresh air per square metre of ground area.

Crucial to the success of practising summer CO_2 enrichment is the ability to measure and control the CO_2 concentration inside the glasshouse both reliably and accurately. This is easier said than done and, in practice, there is an urgent need to improve the performance of many of the CO_2 controllers currently in use. The object should be to keep the atmospheric CO_2 concentration to within ± 20vpm of the ambient.

It is axiomatic that the precision of control can be no better than the accuracy of the measurements. Growers who practise summer CO_2 enrichment should therefore ensure that their CO_2 monitoring instruments are checked regularly at least twice a week.

Infra-red absorption, conductimetric and diffusion types of CO_2 analyser can be calibrated by using a series of test mixtures of CO_2 in nitrogen or CO_2-free air. Standard gas mixtures can be obtained in either aerosol cans marketed by some of the companies selling CO_2 analysers or in cylinders from firms supplying ancillary equipment for gas analysis. Ideally, there should be five points on the calibration (zero and four points spaced at equal intervals over the range 100 to 400vpm CO_2) and each should be determined within 5% so that the overall calibration is known to an accuracy of about 2%.

Regrettably, many nurseries are not yet equipped for automatic control of glasshouse CO_2. Those growers who want to practise the technique of summer CO_2 enrichment will therefore have to add CO_2 to the house atmosphere at a constant rate.

The problem is deciding how much to apply. There is no single answer because crop photosynthesis is a light-dependent process. The requirement for supplementary CO_2 will thus vary considerably both from day to day and from hour to hour with changing light levels.

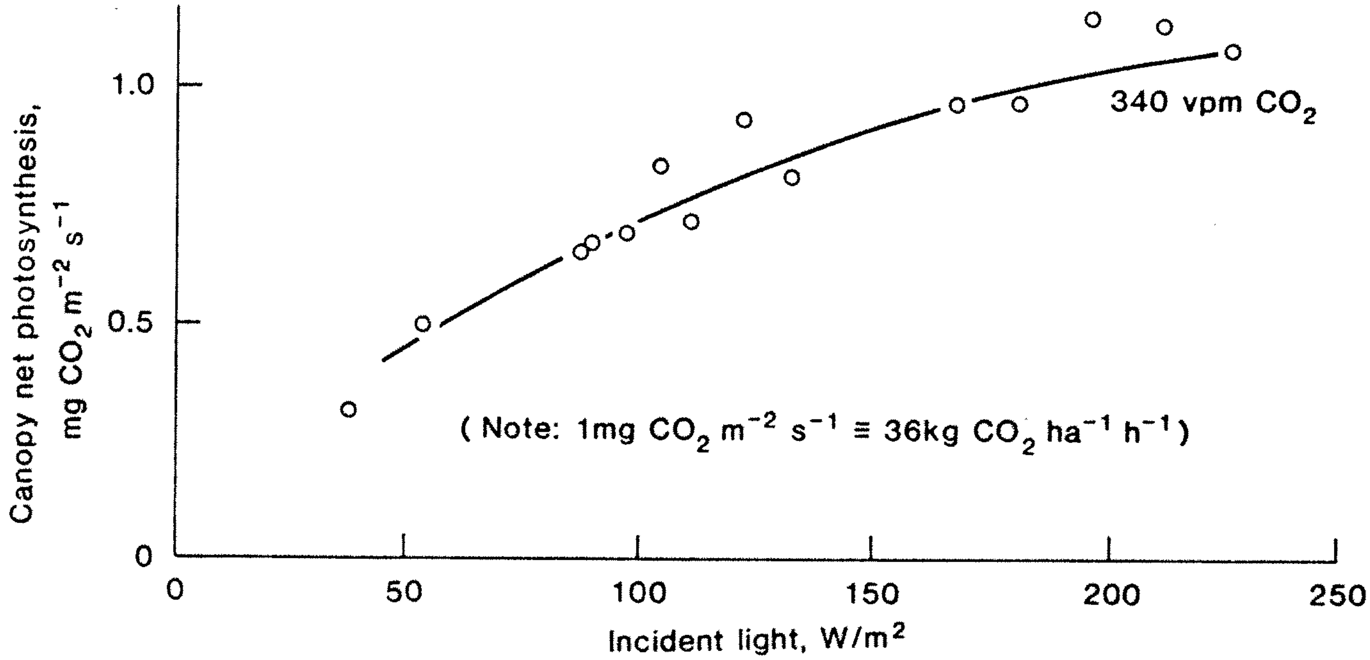

Figure 3. Measured net photosynthesis/light response curve for a stand of tomato plants in a near-airtight cabinet at a normal CO_2 concentration.

Experience at the GCRI suggests that an hourly supplementation rate of between 20 and 40kg CO_2/hectare (18 to 36lb CO_2/acre) will normally suffice. In practice this should prevent CO_2 depletion, provide beneficial above-ambient CO_2 enrichment for some of the daytime, and prove cost-effective in most situations. To summarise, preventing CO_2 depletion in the late spring and summer and increase the yield and value of long-season cucumber and tomato crops by about 5 to 10%, depending on conditions.

In Britain, summer CO_2 enrichment has proved very cost-effective and the technique is being practised throughout the country with increasing enthusiasm. It is particularly attractive to those growers equipped with bulk storage facilities for liquid CO_2 because no heat is released inside the glasshouse during enrichment. In this respect British growers have a technical advantage over their Dutch counterparts who have to use flue-gases from central gas-fired boilers as the main source of CO_2.

Work at the GCRI has shown that further gains in productivity can be achieved by enriching with CO_2 to maintain levels above ambient, though more research is needed to establish the optimum level of summer CO_2 enrichment for maximum profitability. Also, computer-assisted control systems that can provide modulation of CO_2, temperature and humidity in relation to weather offer new opportunities for optimising the glasshouse environment.

Acknowledgements: The author is indebted to Dr. L.J. Ludwig for providing the data in Fig. 2 and Dr. W.M. Dullforce (Editor, Scientific Horticulture) for granting permission to reproduce the material in Fig. 2.

FORT COLLINS GREENHOUSE CLIMATOLOGICAL SUMMARY FOR FOUR WEEKS, BEGINNING JUNE 1, 1986 (See Bulletin 426 for details.)

	Week beginning							
	June 1		**June 8**		**June 15**		**June 22**	
	Day	Night	Day	Night	Day	Night	Day	Night
Average outside temperature (°F)	70	60	68	56	78	64	77	64
Maximum outside temperature (°F)	90	76	87	70	94	81	96	76
Minimum outside temperature (°F)	56	—	50	40	58	49	57	52
Degree-days of heating	0	18	0	32	0	4	0	4
Average hours in the period	13	11	13	11	13	10	14	10
Accumulated total solar radiation (MJ/sq.m.)	146	1	139	1	145	1	156	1
Average relative humidity (%)	55	75	52	79	34	56	41	60
Maximum relative humidity (%)	100	100	87	96	69	90	81	90
Minimum relative humidity (%)	13	—	18	56	10	19	13	22
Average absolute vapor pressure (mb)	14	13	12	12	11	11	13	12
Average wind speed (mph)	2	2	4	1	2	1	2	1
Maximum wind speed (mph)	23	16	27	6	22	23	22	25
Average CO_2 concentration (Pascal)	18	—	18	—	18	—	17	—
Maximum CO_2 concentration (Pascal)	23	—	26	—	24	—	26	—
Accumulated gas consumption (cu.ft./sq.ft.)	1	1	3	4	1	2	1	1

cga

Dick Kingman, Executive Vice President
2785 N. Speer Blvd., Suite 230
Denver, Colorado 80211
Bulletin 434

Direct inquiries to:
Office of the Editor
Horticulture Department
Colorado State University
Fort Collins, Colorado 80523