Carbon dioxide and crop yields

One of the main causes for concern that the world may experience significant climate changes in the foreseeable future is the increasing carbon dioxide content of the atmosphere. The vast outpouring of carbon dioxide from fossil fuel combustion seems to be the main cause of the increase.

Probably also significant is the extensive clearing of forest, particularly rainforest, around the world; the trees give off the gas when they burn or decay, and so does soil organic material that decays when exposed by the clearing.

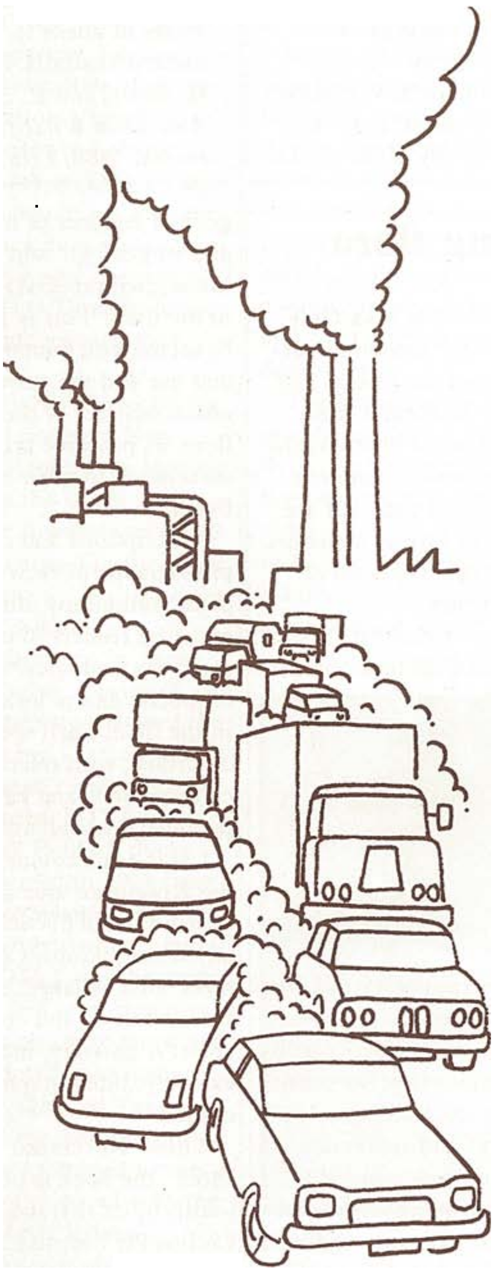
In terms of quantity, carbon dioxide is a very minor constituent of the atmosphere, accounting for only about 340 parts per million (p.p.m.) by volume. But it plays a large role in determining what types of climate different parts of the world experience, because of its effects on the global heat balance. Carbon dioxide traps heat near the ground — the well-known greenhouse effect.

Its concentration is rising by about 1·2 p.p.m. a year, and climatologists believe that a continuing increase must eventually affect weather patterns. What the effects will be, however, is highly uncertain.

One of the most widely quoted predictions is that a doubling of carbon dioxide concentration would raise temperatures at ground level by an average of 2–3°C. Larger rises would occur towards the North and South poles, and result in a big reduction in the areas covered by sea-ice.

This idea has recently been challenged in a paper published in *Nature* by two climatologists working in the United States, Dr Bhaskar Choudhury and Dr George Kukla. Their calculations suggest that the increased absorption of shortwave infrared radiation by higher concentrations of carbon dioxide in the atmosphere could result in increased polar snow and ice. This is because less of the radiation, which is important in heating the surface of snow and water, would reach ground level. The result would be intensified production of cold arctic air masses in winter, spring, and autumn.

Clearly, science cannot yet tell us what effects the additional carbon dioxide will have on the weather around the world. And how any changes in weather patterns will affect the ability of food-producing areas to meet the needs of the world's rapidly expanding population can only be guessed at.



Crop effects

Probably the only impact of the rising carbon dioxide concentration that can now be assessed with much confidence is the direct influence on crop yields. Atmospheric carbon dioxide provides the carbon needs of all vegetation, and higher concentrations can encourage faster growth. Experiments can be conducted to determine what effects any increase in concentration will have.

At the CSIRO Division of Plant Industry, Dr Roger Gifford recently studied wheat growth in an atmosphere enriched with carbon dioxide. Wheat was grown in two artificially illuminated growth cabinets in the Division's controlled-environment laboratory. In one cabinet, carbon dioxide was kept at a concentration 250 p.p.m. above the level in the air outside. Unenriched air was used in the other.

Dr Gifford tested the effects of the extra carbon dioxide on wheat exposed to four different watering regimes. The wettest corresponded to abundant rainfall and the driest to near-drought conditions that, in the field, would reduce grain yield to virtually nothing.

In all cases, the grain yield and the total crop weight at the end of the 99-day growing period were greater for the wheat exposed to the higher carbon dioxide level (see the graphs). Translated to a field situation, the results suggest that the present annual increase in atmospheric carbon dioxide concentration (1·2 p.p.m.) should give a grain yield increase in the range 5–13 kg per hectare.

In the field

Can the results be taken as an indication of the likely response of actual wheat crops? Although conditions in the growth cabinets were rather different from those encountered outside — for example, the temperature was kept at a constant 19°C and the wheat was exposed to a constant light level during 16-hour simulated days — Dr Gifford thinks they cannot be dismissed as irrelevant to what happens in the field.

This is because important aspects of wheat growth in the cabinets corresponded closely to measured field performance. For example, the efficiency of water use matched well, as did the effects of water availability on it. Other indicators that suggested good correspondence included the harvest index — the ratio between grain yield and the dry weight of whole shoots.

Dr Gifford drew on a detailed analysis — by two CSIRO scientists, Dr John Angus of the Division of Land Use Research and Dr Ross Cunningham of the Division of Mathematics and Statistics — of Australia's wheat yields between 1960–61 and 1975–76 to see whether any trend existed that could be related to increases in atmospheric carbon dioxide. It turned out that the trend was firmly downwards in some areas and upwards in others, while in some districts yields were virtually static. There was no clear national trend (see the graph).

He concludes that, as the rising carbon dioxide concentration seems to be increasing the yield potential of wheat crops, whatever factors have caused the fall in yield in some districts may be more severe than previously thought. By the same token, where the yield trend is upwards an important part of the cause may be atmospheric change rather than managerial or genetic factors.

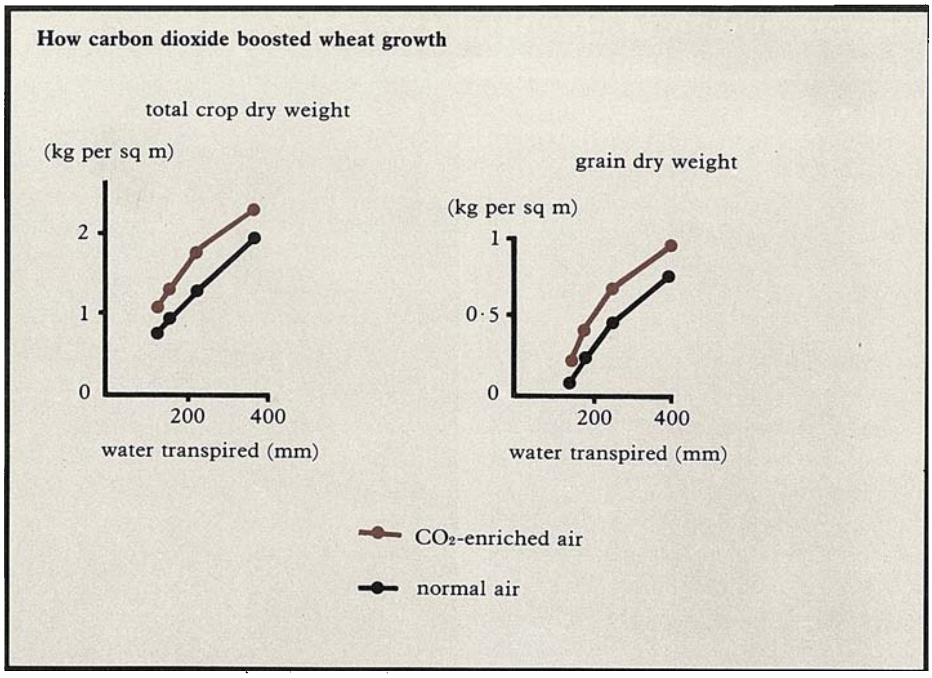
The global cycle

Dr Gifford's results lead him to believe that carbon uptake by plants, and hence their growth, may be more responsive to increasing carbon dioxide concentrations than is generally thought by scientists involved in modelling the global carbon cycle.

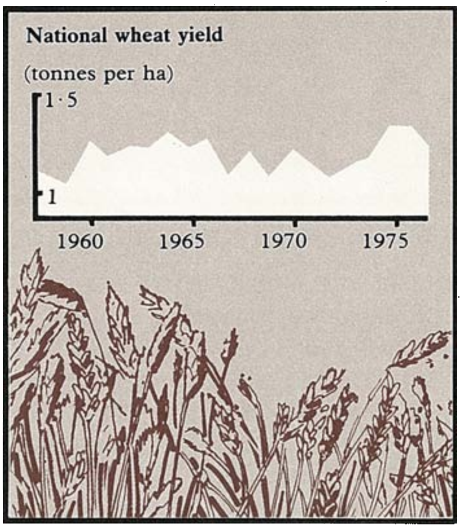
One of the questions these scientists are trying to answer is: where does all the carbon dioxide emitted by Man's activities go? The measured increase in concentration in the atmosphere accounts for less than half of it. A large amount is believed to dissolve in the oceans, but some remains unaccounted for.

These scientists accept that, as the atmospheric concentration increases, so does the rate of plant growth and hence the rate of carbon dioxide uptake. But this effect is taken to be small. In mathematical models of the global carbon cycle, increases in uptake of 0·4% or, more usually, less, have been assumed for a 1% rise in carbon dioxide concentration.

Dr Gifford's wheat experiments, by contrast, produced figures ranging from 0·5% to more than 0·8%. The highest figures were recorded for plants subjected to the greatest water stress. Reducing the amount of light to which the wheat was exposed also tended to boost the percentage increase in carbon dioxide uptake.



The graphs show how wheat performed under watering conditions ranging from the equivalents of near-drought to abundant rainfall. Weights were measured after 99 days' growth.



Yield figures show no trend that could be related to increasing atmospheric carbon dioxide.

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Much of the earth's vegetation exists in environments where a shortage of water or light limits growth. Dr Gifford suggests that it is reasonable to surmise that these restrictions tend to increase the response of most plants — not just wheat — to rising carbon dioxide concentrations.

He concludes that scientists estimating where carbon dioxide goes should probably assign a greater role than they have in the past to uptake by vegetation. But he doesn't think the uptake is big enough to account for all the carbon dioxide whose fate has not yet been traced.

Robert Lehane

More about the topic

Growth and yield of CO_2-enriched wheat under water-limited conditions. R. M. Gifford. *Australian Journal of Plant Physiology*, 1979, **6**, 367–78.

Carbon dioxide and plant growth under water and light stress: implications for balancing the global carbon budget. R. M. Gifford. *Search*, 1979, **10**, 316–8.

Impact of CO_2 on cooling of snow and water surfaces. B. Choudhury and G. Kukla. *Nature*, 1979, **280**, 668–71.

Vine response to carbon dioxide enrichment during heat therapy. P. E. Kriedemann, R. J. Sward, and W. J. S. Downton. *Australia Journal of Plant Physiology*, 1976, **3**, 605–18.

Boosting growth in greenhouses

Greenhouse farmers in some of the cooler parts of the Northern Hemisphere are already taking advantage of the ability of increased carbon dioxide levels to boost plant production. They have found that it is economically worth while for them to keep carbon dioxide in greenhouse atmospheres at about three times the level outside. The result is an increase in production of leafy vegetables of about 50% and a somewhat lesser increase for other crops such as tomatoes.

The enriched atmosphere has its largest effect in the early stages of growth. In laboratory studies at the CSIRO Division of Horticultural Research, Merbein, Vic., Dr Paul Kriedemann and Dr Jim Walcott found that enrichment to about 1000 p.p.m. carbon dioxide increased early growth in Chinese and European cabbages by a factor ranging from five to almost ten. A team at the Division of Irrigation Research led by Dr Kriedemann, now Chief of that Division, has begun a long-term project on the growth response of various vegetable crops to carbon dioxide enrichment under greenhouse conditions.

The obvious way to supply the carbon dioxide is by burning a fuel such as kerosene or liquefied petroleum gas; this is much cheaper than using carbon dioxide from a cylinder. However, the combustion system has to be carefully designed to limit the output of nitrogen oxides and unburnt hydrocarbons, as even small concentrations of these can damage plants.

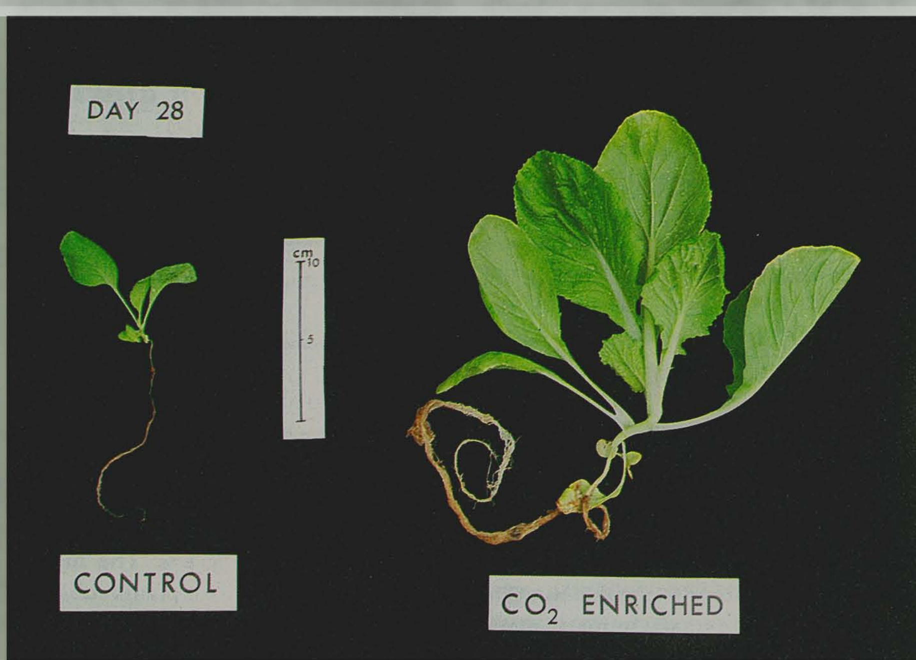
Another problem in warm parts of the world, like most of Australia, is that the burning process adds heat as well as carbon dioxide to the greenhouse atmosphere. This is fine in winter, but in summer can raise temperatures to levels that harm the crop.

Dr Kriedemann and his colleagues are examining methods of greenhouse design that may overcome this problem. One approach is to maintain a gentle vertical flow of carbon-dioxide-enriched air past the crop. The moving air would extract heat as the illuminated plants consumed carbon dioxide. The warm air stream, now depleted of carbon dioxide, would be vented through the top of the greenhouse.

In earlier experiments, they also found that air enriched with carbon dioxide helps plants survive the stresses imposed by high temperatures. Plant pathologists have found that they can eliminate some virus diseases of horticultural plants by propagating shoot tips from parent material grown for periods up to 6 months at constant temperatures of 37–40°C. The experiments were designed to test the effects of increased carbon dioxide concentrations under such conditions, which often result in the death of the plants being treated.

The team found that the growth of plants, especially their root systems, improved, and plant water use became more efficient. Starch accumulation in the foliage increased markedly, improving the prospects for establishing plants from cuttings.

Will a bigger wheat crop be one effect of rising carbon dioxide levels?



Chinese cabbages after 28 days' growth in ordinary air (left) and an atmosphere enriched to about 1000 p.p.m. carbon dioxide.