Factsheet **29/05**

Cucumber

PC 159

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Getting the best out of CO_2 enrichment for cucumbers

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This factsheet provides information on CO_2 toxicity of cucumbers and guidelines for growers on how to optimise CO_2 enrichment without running the risk of crop damage.

Introduction

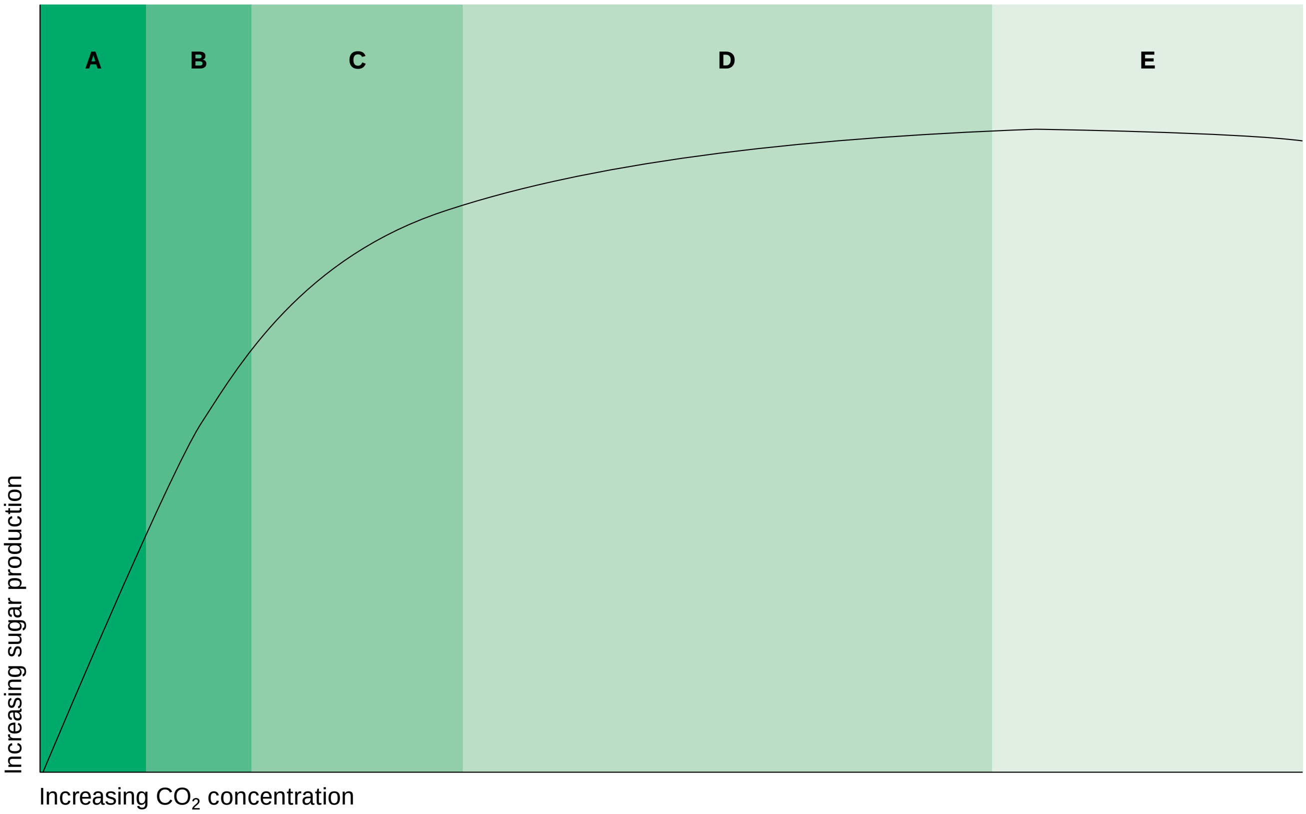
It is well established that CO_2 enrichment improves the productivity of many crop plants through increases in plant growth and yield. As a result CO_2 enrichment is now commonplace in commercial glasshouse crop production. Increasingly however, many cucumber growers have reported the development of phytotoxic plant symptoms, mainly leaf bleaching, at high concentrations of CO_2. HDC project PC 159 identified the underlying basis of this leaf bleaching which has led to these guidelines being developed.

Biology behind CO_2 enrichment

The processes involved in CO_2 assimilation by plants are complex. Plants give out (respire) CO_2 all the time just like we do as a natural process of living – hence the increase in CO_2 levels in glasshouses at night. During daylight, however, they also take in CO_2 and convert it into organic molecules such as sugars. This process, known as photosynthesis, increases with increasing light, temperature and available CO_2 and is represented by the so-called carbon dioxide (CO_2) curve (Graph 1). This curve shows that the production of sugars and starches (and hence plant growth and fruit yield) increases with increasing levels of CO_2, until a point is reached where production slows down (where the slope changes to horizontal). Beyond this point, increasing levels of CO_2 actually reduce sugar and starch production and correspondingly plant yield (when the curve starts to move back to the origin). In practice this means that as the CO_2 level is increased, the growth of the crop will respond at differing rates according to the position on the curve.

1 CO_2 damage of cucumber plants

Graph 1 The carbon dioxide curve



A	**area of most rapid increase in growth (best economic return on CO_2 used)**
B	**slight reduction in the rate of increase in growth (but still worth enriching)**
C	**rapid reduction in the rate of increase in growth (only worth enriching if source of CO_2 is very cheap)**
D	**virtually no increase in growth for any increase in CO_2 (not worth enriching whatever the cost of CO_2)**
E	**actual decline in growth from extra CO_2 (toxic effects starting to be seen)**

Note: Because the levels at which the line curves depends on light levels and temperature as well as CO_2 no units are given

Economic importance of the CO_2 curve

If you think of the CO_2 curve as your chance to improve the production of your crop then in the section marked 'A' it is easy and relatively cheap to get an increase in production from increased levels of CO_2.

In the section marked 'B' that increase in production becomes more expensive, but it is still worthwhile if the heat produced with the CO_2 can be used.

From the section marked 'C' onwards the use of CO_2 is no longer worthwhile, and will actually begin to reduce production by damaging the crop.

Putting actual CO_2 levels onto these areas of the curve can only be a guide because light levels and temperature also affect the curve – for instance the poorer light at the start and end of the day reduce the rate of photosynthesis and this reduces the levels at which the curve changes.

However, if you aim for CO_2 levels of 500–600 ppm at the start and end of the day and work up to 800–1000 ppm during the brightest period in the middle of the day you should get the best return from your CO_2 enrichment.

Higher levels of CO_2 risk phytotoxicity, particularly in the poor light levels at the start of the year and when the crop is under fixed thermal screens. Damage caused by high levels of CO_2 may not be seen for many days after it occurs; keep levels below 1000 ppm at all times but below 800 ppm in poor light levels at the start of the year particularly when fixed screens are used.

What are the symptoms of CO_2 toxicity damage?

The main symptom of CO_2 toxicity in cucumber crops is inter-veinal leaf bleaching, which is first seen around the edge of leaves (Figure 2). Continued exposure to high CO_2 levels can then result in bleaching of the whole leaf area, which reduces the overall efficiency of photosynthesis. It is important to note that these effects of high CO_2 are not seen within the leaf tissue for a considerable period after the damage occurs. This is often up to 10–12 days after the high CO_2 level has occurred, but can be up to 30–35 days when a prolonged period of low light levels are followed by brighter weather.

Other morphological changes to cucumber plants grown at high levels of CO_2 include: a reduction in stomatal density and therefore the ability of the plant to take up CO_2; and a reduction in evaporation, which can cause leaf temperature to increase. Increasing leaf temperature can damage the leaf tissue and accelerate the breakdown of the green pigment chlorophyll, which is manifested as further leaf bleaching (Figure 3).

2 **Initial leaf bleaching occurs around the edge of the leaf (left) and damage is more evident where the leaf has been exposed to more sunlight (right)**

3 **Considerable damage caused to the upper leaves following high levels of CO_2 exposure under a fixed screen. Damage was not seen for some time after the problem (caused by inaccurate analysis). But note new growth produced at normal CO_2 levels is unaffected**

What are the causes of leaf damage?

The visual symptoms of CO_2 toxicity in cucumber plants occur in the leaves and result from a combination of high atmospheric CO_2 concentrations (eg above 1000 ppm) and high light intensities (eg 500–850 W/m²). This damage was originally thought to be due to a build up of starch in the leaf tissue, but appears to be because of a super-abundance of intermediate components in the process of photosynthesis. This effectively allows electrons to build up in the chloroplasts and these have an oxidising effect on the tissue – probably producing the bleached appearance of the older leaves. Both high levels of CO_2 and high light levels are needed to cause the damage!

Leaf age is also an important factor in the amount of damage seen in the crop. In the experiments carried out in HDC project PC 159 younger leaves showed little or no signs of reduction in rates of photosynthesis compared to older leaves. Experiments at 2000 ppm CO_2 on high wire crops with a leaf age of 20–25 days did not produce the damage seen on cordon crops at the same CO_2 concentration, which had a leaf age of 10–15 weeks (Figure 4). The decline of older leaves seems to be complex and is not just a factor of leaf age.

4 The upper leaf damage to a cordon crop grown at CO_2 levels of up to 2000 ppm. The high wire crop in the background was grown at the same level but has no signs of foliage damage

When is CO_2 damage likely to occur?

Damage is most likely to occur during the establishment phase of a winter planted crop. Light levels are low and these are usually reduced further by the use of thermal screens for energy saving. This combination of short days and low light levels produces a very weak leaf structure that is easily damaged by elevated CO_2 levels. This damage may not be seen for many days after the problem occurred because of the need for higher light levels to bleach the leaf tissue.

Glasshouses will also be sealed at this time to reduce energy losses so high levels of CO_2 (above 800 ppm) can easily occur. These high levels of CO_2 can persist for long periods as plant uptake is low due to the low light levels and ventilation is minimal. This can be particularly damaging to young plants.

How can CO_2 toxicity damage be avoided?

By maintaining a specified set point that will not damage the plant – this is usually around 600 ppm in the low light levels of February to March and 800 to 1000 ppm during spring and summer. It is important to ensure that the set point is not exceeded by proper calibration and maintenance of the detection and dosing equipment.

Maintaining desired levels of CO_2

The set points you enter into the environmental control computer should be aimed to deliver enough CO_2 to provide the increase in growth you require, without allowing the actual levels to climb to toxic levels. The graph in Figure 5 (taken from the HDC experiment on 52 week production using lighting) shows a stable level across the day. This graph was produced on a dull day when light levels were stable and low – and more importantly when ventilation levels were low. The day starts at 650 ppm – during the period when the lights are on and rises to 800 ppm when natural light levels increase.

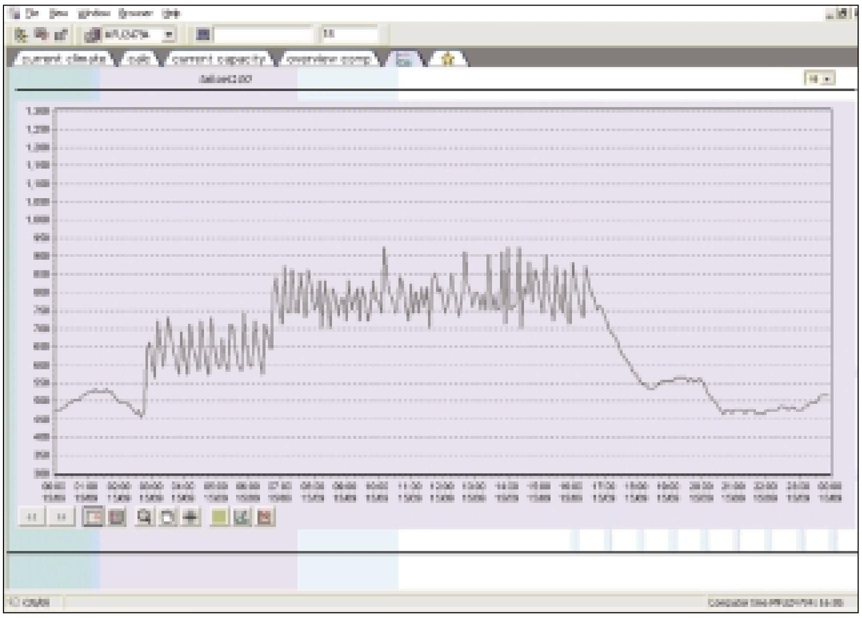
In comparison, Figure 6 shows the same environmental control settings and the actual achieved levels on a bright day – when ventilation levels were higher and it was more difficult to achieve the set points.

It is important to ensure your set points do not aim to give levels above 1000 ppm. It is also vital to ensure the delivery system does not overshoot especially during the early morning period and in the early stages of the crop under thermal screens when foliage is more susceptible to damage.

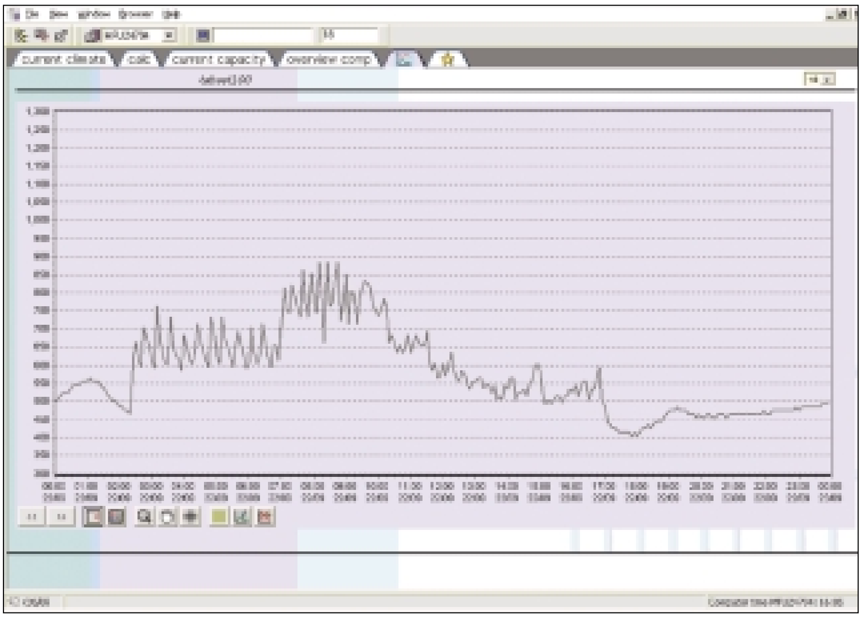
It is also important to bear in mind the effects of ventilation on your ability to enrich with CO_2. Restricting the amount of ventilation – especially wind side ventilation – gives a higher and more stable CO_2 level, but it may give reduced humidity deficits (increased RH) that may have undesirable effects on disease levels. You need to balance all the requirements of the plant and try to achieve the high levels of CO_2 you desire for increased crop production without increasing the risk of disease from reduced ventilation and without increasing the risk of crop damage from high levels of CO_2.

Shading

Whilst leaf bleaching can be avoided (even at high CO_2 concentrations) by shading the plants (<75%) during the brightest periods in the glasshouse, it can also reduce the production of starch and sugars and associated crop yield. Where screens are available they should be used at light levels above 650 W/m^2 – this will also reduce general stress on the crop and can be particularly useful on high wire crops.



5 Actual graph from STC readout showing stable levels over the 24 hour period – with CO_2 enrichment from 2.45 am, increasing at 6.45 am when natural light levels increase (sunrise), then falling away at 6.30 pm – one hour before the lights are switched off. Note the increase over night from 11.00 pm to 1.30 am – when plant respiration is adding to the CO_2 levels in the glasshouse



6 Actual graph from STC with the same settings as Figure 5 but on a bright day showing fairly stable CO_2 levels up to the point where increasing ventilation makes it difficult to achieve the set point

Strategy for avoiding CO_2 toxicity

Glasshouse management

Prior to the start of the growing season:

1.Check all analyser equipment for accuracy:

- check for correct readings – calibrate equipment against standard gases – especially at the start of the season when damage is more likely to occur
- check for leaks in sample tubes – or better still replace them regularly
- check for blockages in sample tubes – tubes easily collapse over heating pipes or fill with water where they move from warm to cold conditions (outside)
- check for leaks on valves in multiplexors etc – cracked pipes or loose valve seats can produce inaccurate readings

2. Consider using an analyser in each block being sampled:

- this reduces the problems with multiplexor system leaks
- it eliminates any delay in sample time with multiplexor systems which can produce overdosing of CO_2 levels
- Remember, you still need to check the individual analysers!

3. If you do not use single analysers in each block – pump every sample line so that a fresh sample is available at the analyser for each cycle and use short cycle times to reduce errors.

On large systems where there are a number of glasshouse blocks being sampled the time delay in getting around the blocks can produce considerable over-dosing. For instance if it takes 2 minutes to check each block and there are 6 blocks on a system the full cycle time is 6 x 2 minutes = 12 minutes – this is the time between each check and the levels can easily overshoot in that period and may cause damage. Try to keep cycle time delays as short as possible, but remember that the analyser needs about 45 – 60 seconds on each sample to register any change in levels so don't set cycle times too short!

Early stages of crop development

Start CO_2 enrichment early in the life of the crop. This is most important on summer crops where establishment is rapid and CO_2 usage can be high. The CO_2 supply from flue gas also supplies moisture that helps reduce the humidity deficit and therefore reduces establishment pressure on the crop.

- Do not set CO_2 levels above 600 ppm in the early stages of the crop – especially if fixed thermal screens are used.
- Make sure you do not exceed this 600 ppm set point by balancing CO_2 production from boilers or engines with demand from the crop.
- Set a low CO_2 alarm level during this period – say 900 ppm – this will then allow you to vent off any high levels and may avoid leaf damage and crop losses.

Established crop

Once the crop is established and the fixed thermal screens are removed or moveable screens are off during the day you can move to a more normal regime.

- Increase set points to 700 – 900 ppm. **Do not exceed 1000 ppm** there is no production advantage and it can still damage the foliage.
- Check analysers regularly – under dosing does not damage the plant but it does not increase production either. Some growers have second 'check systems' in all blocks to give a constant check on levels.

Day to day maintenance

To maintain the set level of CO_2 across the day it is important to balance the input with the removal of CO_2 to the plant or to outside the glasshouse by ventilation.

- Start at sunrise with a level of 600 ppm
- Increase this level as the light levels increase and plant activity and uptake increase eg increase from 600 to 600 + 300 ppm with the extra 300 ppm being controlled by increasing light levels from 150 – 400 W/m².
- To prevent high levels occurring at the start of the day it is worthwhile starting at a level of 600 ppm and adding to the level 2 to 3 hours after sunrise to (say) 600 + 100 ppm and then only adding 200 ppm for increasing light levels.
- Reduce the level at the end of the day back down to 600 ppm and then switch off at 30 – 60 minutes before sunset to prevent high levels occurring overnight.

This should give you a steady increase in demand as the light levels increase across the day, with supply matching that demand. Then as the light levels reduce the set point and the actual levels will decline. This avoids any peaks in measured levels that produce the problems involved in CO_2 enrichment.

Costs

Remember the cost, NO CO_2 is free.

- CO_2 coming in from outside the glasshouse can only get in if you open the ventilators – this exchanges the 'free' CO_2 for heat.
- Burning gas for CO_2 has cost – even if you are using heat dumps to conserve energy. The installation and maintenance of the heat dump system has costs.
- The only time you can justify burning gas for CO_2 without considering the cost is during the first part of the CO_2 curve – and that demand is supplied when you are heating the block.
- It is no longer economic to burn gas just for CO_2 production.
- Running levels above 1000 ppm CO_2 will only increase your CO_2 use and it will have little effect on production and may actually reduce it. Also the costs involved

in maintaining these levels during any period of ventilation make the whole exercise uneconomic.

- It is important to remember, however, that you need to maintain the set level and this is where the production gains can be found. Your CO_2 system should be large enough to maintain the set point, but sensitive enough to maintain it without going too high above or too low below that set point.

Acknowledgements

Figure 4 courtesy of Dr A Lee (formally Stockbridge House – now Substratus).

Additional information:

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