CO_2 ENRICHMENT IN CHANGING TIMES

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Hot Lime Labs pilot system, producing CO_2 from waste wood

The greenhouse industry is facing mounting challenges in the energy space, with extreme increases in energy prices, increasing carbon emission costs and uncertainty about natural gas supply after 2022. With these uncertainties in mind, many growers are looking for alternative energy options.

One aspect to consider is carbon dioxide (CO_2) enrichment. CO_2 enrichment means injecting extra carbon dioxide gas into a greenhouse to boost the growth and production of crops. CO_2 is often produced by combustion of natural gas. In view of the energy woes, growers want to know what the true benefits are of CO_2, what quantities of CO_2 are required for certain conditions, if there are alternative CO_2 sources available and what CO_2 price is justifiable.

There are no simple answers. This article hopes to address some of these questions and provide an estimate of how much CO_2 your greenhouse operation may need.

Ambient CO_2 concentration

Carbon dioxide is a colourless gas and a natural component of air. Currently the average concentration of atmospheric CO_2 is approximately 415 parts per million (ppm), which equals 415 millilitres per m^3 of air or 0.0415%. The CO_2 concentration has risen by about a third since 1950 (315 ppm), which is regarded as one of the key factors behind global warming and climate change.

CO_2 from natural gas

Combustion of natural gas produces flue gases that are high in CO_2 and virtually free of impurities, providing the burner is working properly. However, it is far from ideal that CO_2 and heat are produced at the same time yet are required at different times. This problem can be partly resolved by using a heat buffer: gas is burned during the day for CO_2 and the heat that is produced at the same time is stored in the buffer and released the following night. Many large and medium greenhouse operations are on natural gas and use a large heat buffer. The very core of their greenhouse operation is in jeopardy if the gas price doubles and if gas is not available in the future.

A standard minimum supply rate is considered 50 kilograms per hectare, per hour (50 kg/ha/hour, which equals 5 g/m^2/hour). This requires the boiler to burn about 25m^3 of natural gas per hectare per hour or nearly 1 GigaJoule/hectare/hour (1 GJ/ha/h). Depending on the conditions, the chosen injection rate is often four to six times the standard amount – sometimes more.

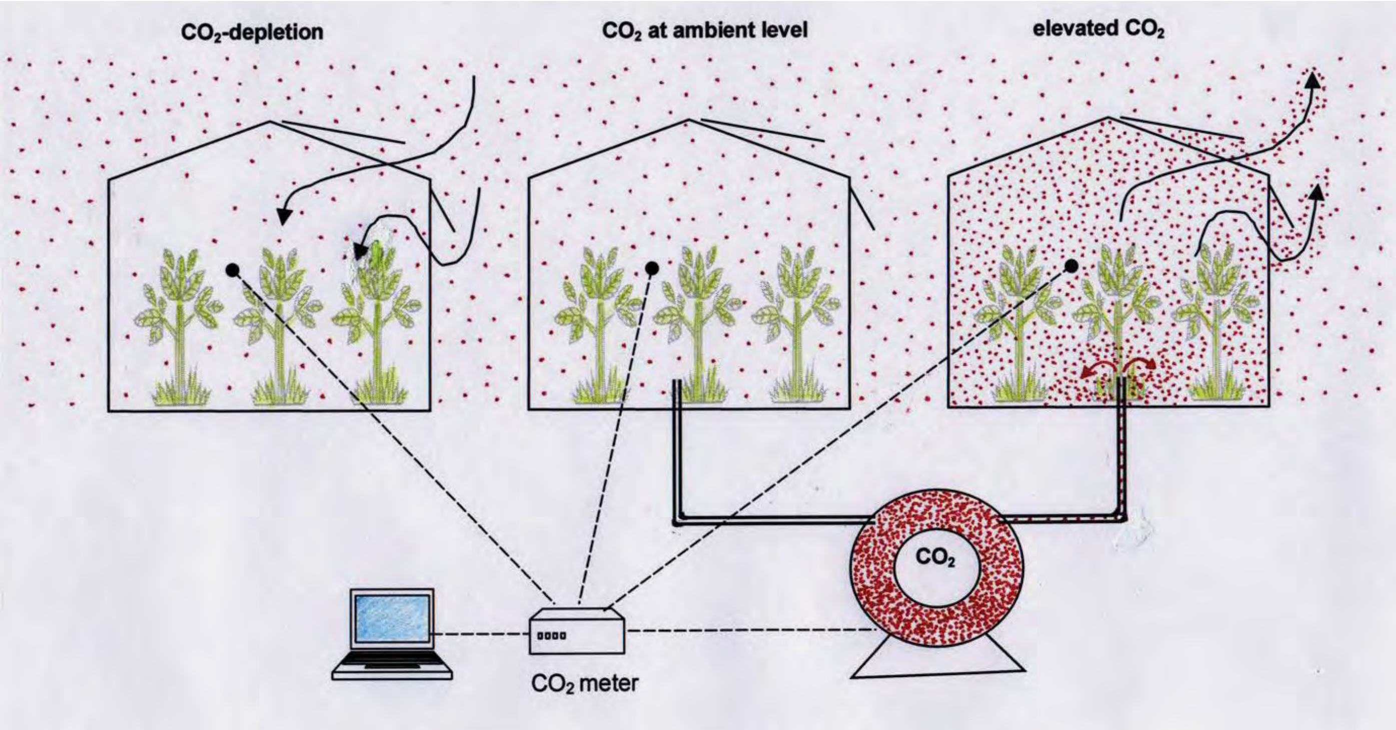

Figure 1: *Three situations:* ***Left:*** *CO_2 depletion (CO_2 below ambient level) – CO_2 uptake very low, but no CO_2 loss.* ***Centre:*** *CO_2 inside the same as outside – low to moderate CO_2 uptake, also no CO_2 loss by ventilation* ***Right:*** *CO_2 enrichment to elevate the CO_2 level – very high CO_2 uptake, but also CO_2 lost by ventilation*

This requires that the burner is fully adjustable and controlled, so that it burns the amount of gas needed for CO_2 or heating or both.

Alternative fuels for CO_2

Alternative sources of CO_2 have been sought for decades, as many growers (e.g. on the South Island) had no access to natural gas. To date, no alternative that fits the quality and affordability requirements for CO_2 enrichment has been identified. There are other fuels that are suitable for CO_2 enrichment though, including propane, butane, premium kerosene (paraffin), low-sulphur oil and LPG. These fuels are rarely used in large-scale greenhouse operations, for different technical or practical reasons. Of course, all fuels will be subject to increasing carbon emission costs, so they offer no respite.

Coal, wood products and heavy oil, when burned, do not produce suitable CO_2. Their flue gases contain dangerous compounds that cause severe damage to plants (and possibly harm humans too). Wood-based fuels also have the disadvantage of an inconsistent composition, making it difficult to maintain the right fuel-to-air ratio.

Hot Lime Labs system

A promising development is underway whereby waste wood biomass (wood and crop) is burnt in a low oxygen environment in a gasifier to produce clean CO_2-rich gas. Patented limestone pellets temporarily fix the CO_2 within a Hot Lime reactor and can be released on demand into a greenhouse.

New Zealand company, Hot Lime Labs, has developed and tested their system successfully at pilot scale and are now building the first commercial unit.

Pure/liquid CO_2

Overseas, exhaust gas from heavy industries is a core source of CO_2. By undergoing an expensive purification process, it is transformed into nearly 100% pure CO_2. It can then be pumped via a network of pipes or delivered by a road truck. The CO_2 must be of horticultural quality, which differs from medical or food grade CO_2. In New Zealand, pure or liquid CO_2 from industrial sources is available, but it is generally too expensive for most greenhouse cultivations.

CO_2-uptake / photosynthesis

Plants exposed to (sun)light absorb CO_2, transforming it into sugars and ultimately, into new plant tissue. This process is called photosynthesis, or CO_2 assimilation. For every kilogram of CO_2 fixated by a plant, approximately 10 kilograms of new plant material is produced. In mature tomato plants, for example, 80% of this (i.e. 8 kg) ends up in fruit and the remaining 20% make up the leaves, stems and roots. Note that this is the percentage of CO_2 absorbed, not the percentage of CO_2 that is injected into the greenhouse. Photosynthesis requires light, therefore CO_2 enrichment at night is pointless unless lighting is being used. In darkness, plants respire (burn sugars) and emit CO_2, causing the CO_2 concentration to rise above ambient levels overnight – especially if the vents are closed.

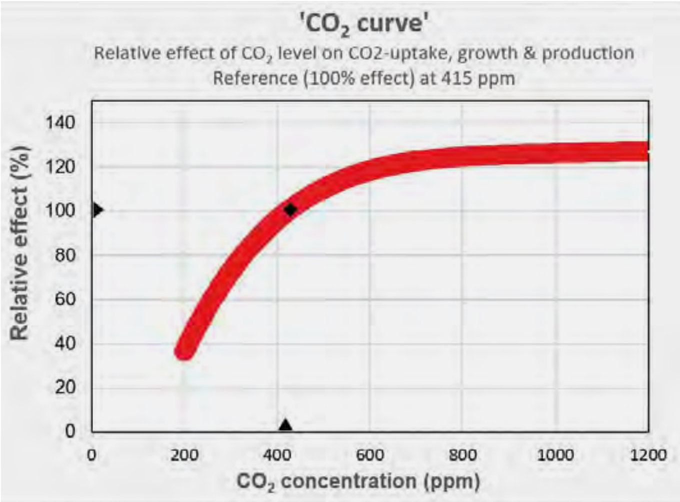

Figure 2: *The CO_2 curve shows the relative photosynthesis and crop production (in %) at various levels of CO_2 (in ppm). The wide band accounts for the variation in response for various crops and various conditions*

CO_2 depletion

During cold winter days with no ventilation, there is little fresh air coming in. When sunny, CO_2 is consumed and not replenished by inflow of fresh air. This can lead to a drop in CO_2 concentration, even below the outside concentration. This is called CO_2 depletion (Figure 1).

Low CO_2 levels hamper the plant's uptake of the gas. If CO_2 is injected during CO_2 depletion, the level will rise and so too will the CO_2 uptake. As long as the CO_2 level inside the greenhouse is lower or equal to the outside CO_2 level, there is no CO_2 loss. Therefore, all CO_2 injected ends up being absorbed by the plants (100% uptake).

The 'CO_2 curve'

CO_2 enrichment stimulates plant growth, resulting in bigger leaves, branches, flowers, fruit and also higher yield. Figure 2 depicts the relative production versus the CO_2 concentration – known as the 'CO_2 curve'. The CO_2 curve has a wide band, because it is based on many experiments with a range of crops. For instance, at 900 pm some crops gave a 20% increase in production, while others gave a 30% increase – hence the wide band.

At a very low CO_2 level (e.g. 200 ppm), photosynthesis and plant growth are nearly zero. Lifting the CO_2 concentration from 200 to 300 ppm gives an enormous boost to the photosynthesis and growth. A further lift from 300 to 400 ppm provides another large jump in photosynthesis. Every further increment in CO_2 concentration increases the photosynthesis further, but not as much. The effect CO_2 has on photosynthesis gradually lessens at higher CO_2 levels. By 1000 ppm, the effect of adding CO_2 gradually plateaus, and beyond about 1,100 ppm, there is almost no benefit to the plant in adding more CO_2.

CO_2 concentration →	200 ppm	350 ppm	415 ppm	500 ppm	900 ppm
without ventilation:					
CO_2 uptake by plants (g/m²/h)	0 - 3	2 - 5	2.5 - 5.5	3 - 6	4 - 8
CO_2 loss by leak (g/m²/h)	0*	0*	0*	2 - 3	3 - 5
CO_2 supply rate (g/m²/h	0 - 3	2 - 5	2.5 – 5.5	5 - 9	7 - 13
With little venting:					
CO_2 uptake by plants (g/m²/h)	0 - 3	2 - 5	2.5 - 5.5	3 - 6	4 - 8
CO_2 loss by little venting (g/m²/h)	0*	0*	0*	10 - 20+	15 – 50+
CO_2 supply rate (g/m²/h)	0 - 3	2 - 5	2.5 – 5.5	13 - 26+	19 – 58+
With ample venting:					
CO_2 uptake by plants (g/m²/h)	0 - 3	2 - 5	2.5 - 5.5	3 - 6	4 - 8
CO_2 loss ample venting (g/m²/h)	0*	0*	0*	25+	50+
CO_2 supply rate (g/m²/h)	0 - 3	2 - 5	2.5 - 5.5	28 - 31+	54 - 58+

Table 1: Ballpark estimates for CO_2 uptake, CO_2 loss and CO_2 supply at various CO_2 lev, either with closed vents, or with a little or ample ventilation. For comparison: 1 gram/m²/hour equals 10 kg/hectare/hour. This is roughly 0.5 m³ of natural gas per hectare per hour or nearly 0.5 GigaJoule/hectare/hour (0.5 GJ/ha/h)

Photosynthesis or production

The CO_2 curve is similar for photosynthesis and production. Photosynthesis responds immediately to elevated CO_2, but the production takes a lot longer to show. In tomatoes, the yield is the result of photosynthesis over many weeks while the fruit grow. If CO_2 enrichment is only applied at specific times, e.g., only early in the morning, or for certain weeks of the month, then the effect on production is proportionally smaller than what the CO_2 curve anticipates.

Optimum CO_2 level

Lifting the CO_2 concentration comes with some risk, such as accumulation of noxious gases that can be present in small amounts in the flue gases from burning natural gas. There is also the effect that high CO_2 slightly closes the stomata (pores in the leaves). Further, there are costs associated with high CO_2 concentrations. Therefore, it is not recommended to raise the CO_2 concentration unnecessarily high.

A level as high as 1000 ppm is only useful in good conditions – healthy producing plants, good light, low ventilation rate, cheap CO_2 and favourable produce prices. In less favourable conditions, such as poor light or expensive CO_2, the target level should be modest – 600 or 500 ppm.

This would reap easy benefits, while keeping costs down. Oversupplying CO_2 can be prevented by using the computer settings well. For instance, let the target level automatically decline with wider vent opening. Or fix the CO_2injection rate at say, 60 kg/ha/hour permanently. Or limit the CO_2 injection rate at 25 kg/ha/hour when vent opening is at 25% or more. In these latter examples, the CO_2 concentration is not set, but will depend on the conditions.

CO_2 enrichment in figures

When CO_2 enrichment is reviewed, greenhouse operators want to know how much CO_2 is needed in various seasons. This depends on so many factors, but we give some indications in the table. The CO_2 demand equals the CO_2 uptake by the plants, plus the amount of CO_2 lost by venting. The latter (CO_2 loss) depends on the ventilation rate and can be multiple times more than the CO_2 uptake. On an annual basis, the amount of CO_2 injected varies greatly. An absolute minimum would be 3 kg/m²/year (mostly restricted to winter), while a fairly ample supply will easily use 25 kg/m²/year or much more. For comparison: CO_2 enrichment of 1 g/m²/hour equals 10 kg/ha/hour. This is roughly 0.5 m³ of natural gas per hectare per hour, or nearly 0.5 GigaJoule/hectare/hour (0.5 GJ/ha/h).