Energy and CO_2 enrichment

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CO2 enrichment has become common practice for many growers. Some use bulk CO2 (carbon dioxide) from bottles or a tank, but most of the larger operations use CO2 from natural gas combustion. A heat storage tank can be employed to enable CO2 enrichment when no heat is required. Then a considerable amount of energy is used over the summer. This article aims to give some ball-park figures on CO2 enrichment. A later article will give some further information about energy consumption for CO2 and heat storage.

CO2 and the environment

CO2, or carbon dioxide, is a gas that naturally occurs in air. We know it as the gas in fizzy drinks. The CO2 concentration in fresh air is around 0.035 %, or 350 millilitre per m^3 air, or 350 ppm (parts per million). CO2 arises from decomposition of organic material and a major part comes from burning fossil fuel. The CO2 content in the earth's atmosphere is rising rapidly due to human activity. The unnaturally high CO2 level presumably contributes to global warming and climate change.

CO2 enrichment in greenhouses means increasing the CO2 level. Plants absorb CO2 and keep it out of the atmosphere, but that is only for as long as the plant material exists. CO2 enrichment causes CO2 to flow out of the greenhouse into the atmosphere. The best action towards reducing CO2 emission is reducing the energy use, which in summer is largely for CO2 enrichment.

Photosynthesis (CO2-uptake)

Plants absorb CO2 and transform that into sugars and then into new plant tissue. Every gram of CO2 fixated by the plant yields around 10 grams of new plant material. This so-called photosynthesis (or CO2-assimilation) requires good light and suitable growing conditions. Plants consume more CO2 at more light and also at a higher CO2 level. The very reason of CO2 enrichment is that elevated CO2 levels boost the CO2 uptake. The increase can be up to 40%, as is shown by the CO2 curve (Figure 1). The effect of CO2 enrichment on the yield is proportional to the amount and the time of CO2 enrichment. If CO2 is given only during the early morning hours, e.g. 3 hours out of 12 hours, then the yield increases proportionally less than 40%, e.g. 10%. In fact it will be less than 10%, because the lightest hours of the day count more.

This article aims to provide some generic figures about CO2. The CO2 uptake depends on the crop, the leaf area and on the conditions. It is expressed in gram CO2 gas per m^2 ground area per hour ($g/m^2/h$). The CO2 uptake varies from 0 during very poor conditions to about 5 $g/m^2/h$ under excellent light conditions, and up to 7 $g/m^2/h$ under excellent light conditions combined with high CO2 levels. At night no CO2 is taken up; in contrast, the plants produce CO2 due to respiration. Hence the CO2 level in a closed greenhouse naturally increases overnight to above-ambient levels.

CO2 depletion

The CO2 level can drop to below the ambient level. This is known as CO2 depletion (Figure 2, left). It happens when it is bright but cold, with vents closed, and no CO2 supply. The plants absorb CO2 due to good light. The inflow of fresh air is not enough to replenish the CO2. If the CO2 level remains low, the plants can’t absorb it easy enough, and the photosynthesis declines. This reduces the growth and production. For instance at a CO2 level of 150 ppm, photosynthesis (and hence growth) is reduced to half the growth at 350 ppm. Below 150 ppm the photosynthesis comes to a standstill. Depletion only happens at daytime, when there is light for photosynthesis. The first purpose of CO2 enrichment is to avoid depletion.

Effect of ventilation

Ventilation has a strong influence on the CO2 level. We distinguish three situations. The first is CO2 depletion: the CO2 level is below ambient. Any leakage or ventilation will bring CO2 into the greenhouse (Figure 2, left). Ample ventilation can prevent CO2 depletion.
The second situation is with elevated CO2 levels due to CO2 enrichment (Figure 2, right). The CO2 gas will rapidly be lost during venting, depending on the vent opening, the wind speed and the CO2 level.
The third situation is in between the other two: when the CO2 level in the greenhouse is equal to the level outside (around 350 ppm, Figure 2, middle). The influx of fresh air plus the CO2 supply exactly compensates the CO2 absorption by the plants. In this situation no CO2 is lost.

CO2 demand

The CO2 demand equals the CO2 absorption by the plants plus the CO2 lost by leak or ventilation. Table 1 shows the CO2 demand for various CO2 levels (rough estimates only!). At 200 ppm (CO2 depletion) thee is no CO2 enrichment (0 g/m^2/h), otherwise there was no depletion. In this case there is no CO2 loss by venting. In contrast, there is CO2 coming in, which is immediately absorbed by the plants.
At ambient CO2 level (350 ppm) the photosynthesis is 2-5 g/m^2/h, depending on the light conditions. There is no CO2 loss by leak or ventilation (because inside and outside the level is the same). The total CO2 demand is thus 2 - 5 g/m^2/h.
At CO2 levels of 500 or 900 ppm, the photosynthesis and the loss by leakage increase. In case the vents are a tiny bit opened, the loss by ventilation increases considerably, and the CO2 supply rate has to increase accordingly. Obviously, loss by venting will be very much more when the vents are opened wider, and at higher wind speeds.

Recommendations

Traditionally, the dosing rate was around 5 g/m^2/h. The strategy was to aim for a CO2 level of two to three-fold the ambient level, i.e. around 700-1000 ppm when the vents are closed. During ventilation, the target level was set lower (e.g. 400 ppm). Alternatively, the target level remained the same, but the achieved CO2 level was lower due to limited CO2 supply. The table shows that a CO2 supply rate of 5 g/m^2/h is sufficient if there is only leakage (no venting). But it is not sufficient if the photosynthesis is very high (high light and high CO2).
Nowadays a dosing rate of 5 g/m^2/h is considered low. Growers who generate CO2 from natural gas and use heat storage can achieve CO2 supply rates of for instance 20 g CO_2/m^2/hour. This dosing rate exceeds the photosynthesis, and will result in an elevated CO_2 concentration even during venting.
However, the costs should be considered. The benefits of CO2 enrichment should outweigh the costs. The benefits depend on the yield increase due to CO2, as well as on the price of the produce. Excessive enrichment is sometimes wasting money, while moderate CO2 enrichment is often feasible.
CO2 enrichment should not go beyond 1000 ppm, as it is not beneficial for the plants and unnecessarily expensive. Plants that are sensitive to physiological damage (young plants, stressed plants, sensitive species) should not be exposed to more than 700 ppm CO2. Too high CO2 levels cause partial closing of the pores in the leaves, which is not good for plants under stress. Also, at higher CO2 concentration, there is higher risk of accumulation of noxious gases that can be present in the CO2 gas. Obviously CO2 enrichment at night is not useful at all, because there is no photosynthesis at night.

***Table 1**: approximated amounts of CO2 needed (in gram/m[2]/hour) to maintain CO2 level, either with no ventilation (only leakage) or with very little ventilation.*

CO_2 level:	**200 ppm**		**350 ppm**		**500 ppm**		**900 ppm**	
light level:	low	high	low	high	low	high	low	high
photosynthesis	1	1	2	3-5	3	4-5	3	5-7
loss by leak (no venting)	~ *	~ *	0	0	1-2	1-2	2-3	2-3
loss by very little venting	~ *	~ *	0	0	3-4	3-4	12	12
CO2 supply rate if there is no venting	0*	0*	2	3-5	4-5	5-7	5-6	7-10
CO2 supply rate with very little venting	0	0	2	3-5	6-7	7-9	15	17-19

** CO2 depletion (CO2 level below ambient) occurs when there is no CO2 supply. In fact a bit of CO2 comes from outside into the greenhouse, and this is immediately absorbed by the plants.*

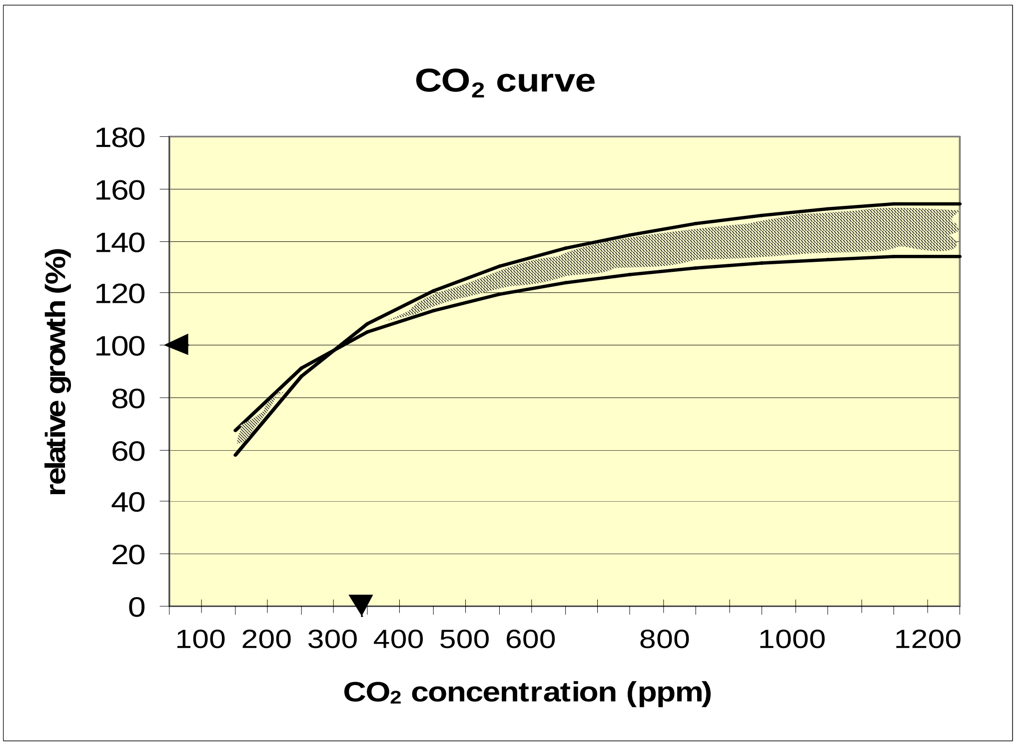

***Figure 1**. CO_2-curve. Crop production (in %) at various levels of CO_2 (in ppm). The production at ca. 350 ppm is taken as the standard production level (100%). The wide band accounts for the variation between crops and conditions. The graph is based on data from sixty experiments done at various places with many different greenhouse crops. (Source: Nederhoff, 1994)*

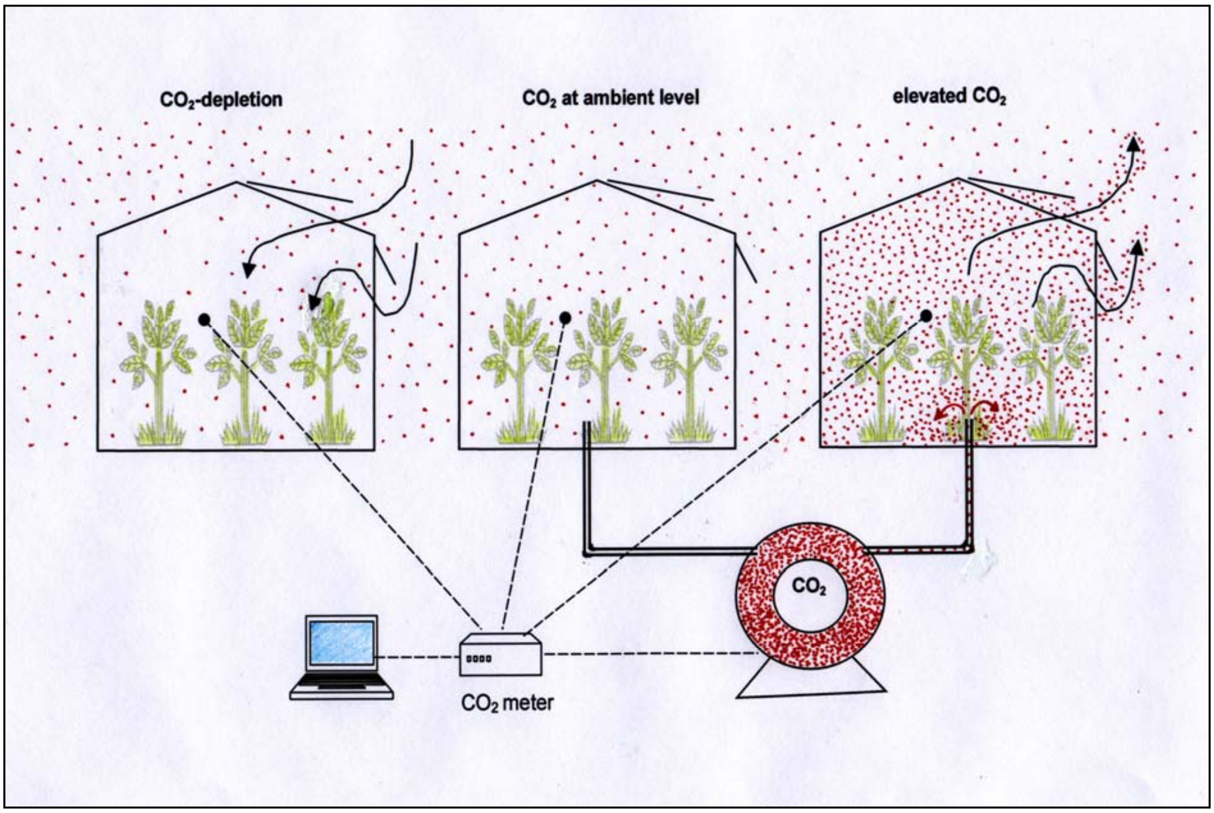

Figure 2. *Three situations of CO_2 levels in the greenhouse.*