Can we use Elevated Carbon Dioxide to Increase Productivity in the Orchid Industry?

J. W. H. Yong¹, E. Y. C. Lim¹ and C. S. Hew²

ABSTRACT

In the last eleven years, it had been proven scientifically that CO₂ enrichment could speed up the growth rates of both thin-leaved (C₃) and thick-leaved (CAM) orchids in tissue culture and later, in their vegetative stages leading to flowering. There were also some indications that flowers harvested from plants grown in CO₂-enriched environment have a longer vase-life. However, more work is needed here to confirm this assertion. It is recommended that both hobbyists and commercial growers evaluate this technique in shortening the growing time taken between a young plantlet and an adult plant. The potential wide-spread implementation of CO₂ enrichment techniques within the orchid industry to boost productivity is dependent on growers’ scientific awareness and the financial cost associated with the technology.

INTRODUCTION

Atmospheric carbon dioxide (CO₂) is rising at an unprecedented rate and the upward trend is mostly linked to anthropogenic emissions. This has promoted considerable interest in the potential impacts of elevated CO₂ on natural ecosystems and agricultural systems.

In a nutshell, CO₂ plays a pivotal role in the life of this planet for two reasons:

• CO₂ is a “gaseous nutrient” for photosynthetic (“green”) organisms - most importantly our forests, crops and marine algae.

• CO₂ is an important “greenhouse” gas, absorbing infrared radiation from the earth. It thus plays a central role in influencing global temperatures and climatic patterns.

CO₂ is essential to photosynthesis, the process by which plants use sunlight to produce carbohydrates - the material of which their roots and body consist. Increasing CO₂ level reduces the time needed by plants to mature. Scientists and some enlightened growers have long realized that CO₂ enhances plant growth, which is why they pump CO₂ into greenhouses, especially in the temperate regions.

Most applied research on horticultural plants have dealt with the effects of environmental conditions on plant growth. Factors such as water, light, temperature and nutrients are more easily controlled to achieve optimum growth. With improvements in technology, it is also now possible to control and accurately measure CO₂ concentrations in greenhouses.

CO₂ contributes to plant growth as part of the miracle of nature known as photosynthesis. CO₂ enters the plant through microscopic pores that are mainly located on the underside of the leaf. This enables plants...
to combine CO₂ and water, with the aid of light energy, to form sugar at the chloroplasts. Some of these sugars are converted into complex compounds that increase plant matter for continued growth to final maturity. However, when the supply of CO₂ is cut off, or reduced, the complex plant cell structure cannot utilize the sun’s energy fully, and growth and development is curtailed.

Although CO₂ is one of three main components that combine to generate the products necessary for plant growth, the amount of CO₂ in the air is only 0.037% (about 370 parts per million, ppm). This compares to 78% nitrogen, 21% oxygen and 0.97% trace gases in normal air. Numerous gas measurements have proven that during the day, CO₂ concentrations inside greenhouses, containing “normal” (C3) plants is invariably much lower than in the air outside (“a CO₂ drawdown phenomenon”). This same phenomenon has also been shown to occur in controlled environment gardens.

**Current Elevated CO₂ Practices for other Horticultural and Agricultural Plants**

Research has shown that in most cases, the rate of plant growth under otherwise identical and favourable growing conditions, is directly related to CO₂ concentration (till about 1000-1500 ppm).

The amount of CO₂ a plant requires to grow may vary from plant to plant, but tests show that most plants will stop growing when the CO₂ level decreases below 150 ppm. Even at 220 ppm, a slow-down in plant growth is significantly noticeable.

The normal CO₂ levels found outside averages around 370 ppm. In an enclosed environment similar to a greenhouse, these levels can quickly be depleted, creating an environment that decreases growth due to CO₂ depreciation (i.e. CO₂ drawdown). Increasing CO₂ levels around the plants, using pure CO₂, to levels between 600 and 1400 ppm can dramatically increase photosynthetic rates and hence growth. The ideal level for most crops ranges between 1000 to 1400 ppm. It is noteworthy that nutrients and water uptake may also change (usually an increase) when CO₂ enrichment is used (Fig. 1).

![Figure 1. Growth enhancement of Spathoglottis plicata plantlets under elevated CO₂ conditions after 2 months.](image)

Note: All plantlets were grown in half-strength MS media without sucrose. There were four plantlets per GA7 container. Light (Photosynthetic Active Radiation) within the GA7 was between 100 and 150 µmol m⁻² s⁻¹.

Our own positive experience (70% increase in dry matter) in growing cotton plants under elevated CO₂ had been encouraging (Yong et al., 2000). Based on nearly 800 scientific observations around the world, a doubling of CO₂ concentrations from present levels (ca. 370 ppm) would improve plant productivity on an average of 32 percent across species (e.g. Kimball, 1983; Poorter, 1993). Controlled experiments have shown that under elevated CO₂ conditions:

- Tomatoes, cucumbers and lettuce average between 20 and 50 percent higher yields.
• Cereal grains, including rice, wheat, barley, oats and rye, average between 25 and 64 percent higher yields.
• Food crops, such as corn, sorghum, millet and sugar cane, average yield increases from 10 to 55 percent.
• Root crops, including potatoes, yams and cassava, show average yield increases of 18 to 75 percent.
• Legumes, including peas, beans and soybeans, post increased yields of between 28 and 46 percent.

CO₂ enrichment generally causes plants to develop more extensive root systems with two important consequences. Larger root systems allow plants to exploit additional pockets of water and nutrients. This means that plants have to spend less metabolic energy to capture vital nutrients. Additionally, more extensive, active roots stimulate and enhance the activity of bacteria and other organisms that break nutrients out of the soil, which the plants can then exploit.

Scientific Basis to Explain the Positive Effects of Elevated CO₂ on Orchid Growth

It is generally accepted that orchids have either C3 or Crassulacean Acid Metabolism (CAM) mode of photosynthesis, and these are usually associated with thin or thick leaves (see Arditti, 1992; Hew and Yong, 1997). In C3 photosynthesis, the carboxylating enzyme Rubisco has a relatively low affinity for CO₂ molecule and therefore an increase in CO₂ concentration will increase the rate of CO₂ fixation. An increase in CO₂ concentration will also inhibit the rate of photorespiration. The net effect of these two events is an increase in net photosynthesis (Drake et al., 1997; Hew and Yong, 1997).

The explanation for CAM plants is even more complex (see Drennan and Nobel, 2000). In these plants, the carboxylating enzyme for dark fixation is phosphoenolpyruvate carboxylase (PEPCase). PEPCase has a high affinity for the CO₂ molecule. This, together with the inactivity of ribulose bisphosphate oxygenase at night means that increasing CO₂ concentration will have little effect on the rate of dark CO₂ fixation in CAM. Since Rubisco is responsible for late afternoon CO₂ fixation (phase 4) in CAM plants, the degree of enhancement due to increasing CO₂ concentration will depend on the proportion of C3 photosynthesis (phase 4) inherent in the CAM plant.

In this article, we will use the C3 or thin-leaved orchid as an example because the gas-exchange patterns of such orchids are simpler to understand (Fig. 2).

Thus, after studying Fig. 2 closely, one can see that an orchid leaf will have greater rates
of photosynthesis at higher levels of atmospheric CO₂ concentration. This in turn will generate more carbohydrate available for growth and development. Is CO₂ enrichment a viable option to speed up orchid growth rate and potentially increase flower production? The answer is “yes”, if we provide the right conditions (Fig. 3, Fig. 4; see also Tanaka, 1991). Table 1 examines some of the research work carried out by colleagues overseas and in Singapore. In summary, the use of elevated CO₂ in orchid cultivation can be divided into two approaches (in vitro conditions and normal cultivation). For in-vitro cultures, the scientific data indicated that there must be sufficient light (at least around 80-100 µmol m⁻² s⁻¹) to generate the positive effects on growth in elevated CO₂ (Fig. 1.). The current practice of using fluorescent tubes as light sources for in-vitro orchid cultures in some laboratories and commercial farms may not be suitable for elevated CO₂ treatments.

Practical Aspects of CO₂ Enrichment

Carbon dioxide is generally introduced by one of three ways:
1. Burning a hydrocarbon such as propane or kerosene.
2. Placing containers of dry ice in the greenhouse or growth cabinet/room.
3. Using pure carbon dioxide from a pressurized container (Fig. 3, Fig. 4).

The third option is the preferred one because pure CO₂ contains fewer growth limiting pollutants. The cost factor will ultimately dictate the purity level of bottled CO₂ used in any commercial orchid farm. In Singapore, it is our hope that in the near future, piped CO₂ to boost orchid and other valuable crops growth (i.e. significantly shorten production time) will be provided by the re-capture of exhaust CO₂ generated during the production of electricity by power generating companies. Thus, growing orchids under elevated CO₂ is one possible avenue for Singapore to do
its small part in carbon sequestration to minimize global greenhouse gas emissions. For C3 orchids (thin-leaved orchids like *Oncidium* Goldiana, *Spathoglottis plicata*), CO₂ enrichment should commence at sunrise or when photoperiod begins and refrain during darkness hours. The average CO₂ level that is recommended is 700 to 1500 ppm. For CAM orchids (thick-leaved orchids, like *Dendrobium* and *Phalaenopsis*), CO₂ enrichment should commence at three to four hours before sunset, continue through darkness hours and stop when photoperiod begins. For example, a custom-built system (Fig. 3 and Fig. 4) can be installed with the relevant CO₂ sensors and injectors to achieve the desired CO₂ level. One such local company that delivers such a service is Telasia Symtomic Pte. Ltd. (email: telasia@pacific.net.sg; http://pachome1.pacific.net.sg/~rcduffer/).

### Table 1: Summary of selected experimental orchid papers involving the use of elevated CO₂

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Species/hybrids</th>
<th>Positive outcome in CO₂ enriched conditions</th>
<th>Photosynthetic pathways</th>
<th>Remarks</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-vitro culture</td>
<td>Cymbidium sp.</td>
<td>Yes</td>
<td>C₃</td>
<td></td>
<td>Kozai et al. (1995)</td>
</tr>
<tr>
<td></td>
<td>Mokara White</td>
<td>Yes</td>
<td>CAM</td>
<td></td>
<td>Hew et al. (1995)</td>
</tr>
<tr>
<td></td>
<td>Mokara Yellow</td>
<td>Yes</td>
<td>CAM</td>
<td></td>
<td>Guo et al. (1997)</td>
</tr>
<tr>
<td></td>
<td>Mokara Yellow</td>
<td>Yes</td>
<td>CAM</td>
<td></td>
<td>Guo et al. (1999)</td>
</tr>
<tr>
<td></td>
<td>Dendrobium sp.</td>
<td>No significant effect on rooting</td>
<td>CAM</td>
<td>PAR was limiting (42 μmol m⁻² s⁻¹)</td>
<td>Mitra et al. (1998)</td>
</tr>
<tr>
<td></td>
<td>Cymbidium Flower</td>
<td>No</td>
<td>C₃</td>
<td>PAR was limiting (40 μmol m⁻² s⁻¹)</td>
<td>Tanaka et al. (1999)</td>
</tr>
<tr>
<td></td>
<td>Phalaenopsis Happy Valentine</td>
<td>Yes</td>
<td>CAM</td>
<td></td>
<td>Hahn &amp; Park (2001)</td>
</tr>
<tr>
<td></td>
<td>Neofinetia falcata</td>
<td>Yes</td>
<td>not known</td>
<td></td>
<td>Hahn &amp; Park (2004)</td>
</tr>
<tr>
<td></td>
<td>Cymbidium kanran</td>
<td>Yes</td>
<td>C₃</td>
<td>Very slow growing species. 40 days treatment may not sufficient.</td>
<td>Hahn &amp; Park (2004)</td>
</tr>
<tr>
<td></td>
<td>Cymbidium goeringi</td>
<td>No</td>
<td>C₃</td>
<td></td>
<td>Hahn &amp; Park (2001)</td>
</tr>
<tr>
<td>Vegetative growth of potted plants</td>
<td>Oncidium Goldiana</td>
<td>Yes</td>
<td>C₃</td>
<td></td>
<td>Yong (1995)</td>
</tr>
<tr>
<td></td>
<td>Oncidium Goldiana</td>
<td>Yes</td>
<td>C₃</td>
<td></td>
<td>Li et al. (2001)</td>
</tr>
<tr>
<td></td>
<td>Mokara Yellow</td>
<td>Yes</td>
<td>CAM</td>
<td></td>
<td>Li et al. (2002)</td>
</tr>
<tr>
<td></td>
<td>Phalaenopsis hybrids</td>
<td>Yes, increased daily leaf CO₂ uptake by 82%</td>
<td>CAM</td>
<td></td>
<td>Looeters &amp; Heusel (1998)</td>
</tr>
<tr>
<td>Flowering quality/yield</td>
<td>Phalaenopsis hybrids</td>
<td>Very life of cut flowers always improved under higher CO₂ levels</td>
<td>CAM</td>
<td></td>
<td>Endo &amp; Ikushima (1997)</td>
</tr>
<tr>
<td></td>
<td>Oncidium Goldiana</td>
<td>Yes, increase in dry mass of inflorescence and number of florets. But vase-life was not investigated</td>
<td>C₃</td>
<td></td>
<td>Yong (1995)</td>
</tr>
</tbody>
</table>

Keys to Table 1:
C3: Thin-leaved orchids are C3 plants. These plants use Rubisco (a bifunctional enzyme that can fix carbon dioxide or molecular oxygen, which leads to photosynthesis or photorespiration, respectively. Rubisco is the most abundant enzyme on earth) to make a three-carbon compound as the first stable product of carbon fixation. These plants may lose up to 50% of their recently-fixed carbon through photorespiration. More than 95% of earth’s plant species can be characterized as C3 plants.

CAM (Crassulacean Acid Metabolism): Thick-leaved orchids are CAM plants. These plants close their stomata during the day to reduce water loss and open them at night for carbon uptake. PEP carboxylase nocturnally fixes carbon into a four-carbon compound that is accumulated within vacuoles. During the day, this compound internally releases carbon dioxide, which is then refixed using Rubisco.

PAR: Photosynthetic active radiation

Why Do Some Plants Stop Responding

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To CO₂ Enrichment? Do Orchids Behave Similarly?

It has been well documented by scientists investigating climate change that plants adapt to CO₂ enriched environments. This adaptation has been termed ‘down-regulation’. A down-regulated plant still appears green and healthy to the human eye but reduces the amount of photosynthetic apparatus it has, namely by producing less of the enzyme Rubisco. The plant responds in this way because it does not have to work as hard to capture the CO₂ it requires for growth.

At present, we are not entirely sure whether orchids acclimatize to CO₂ enriched environments. This is quite unlikely if we provide sufficient nutrients and water to the orchids during the CO₂ enrichment treatment. Nonetheless, to avoid this potential problem of enriched CO₂ habituation (while scientists are busy at work to understand the mechanism), one may enrich the orchids with elevated CO₂ for two days and utilize normal ambient CO₂ on the third day. Research is now being carried out in our NUS and NTU laboratories to identify whether such an acclimatization phenomenon occurs in orchids, and to find sensible solutions (e.g. various combinations of high and normal CO₂ days) for the hobbyists and commercial growers.

Future Outlook/Recommendations

There are several things to do/consider:

• Is the financial investment put into CO₂ technology worth the time saved in shortening the growth cycle?
• Dips in flowering production (e.g. Aranda Christine 130) and bud drop have been reported, and perhaps we can overcome this problem with elevated CO₂ treatment at a certain point along the growth cycle. This approach is likely to work because orchids are known to be source limited (i.e. limited by “food” provided by the leaves, see Hew and Yong 1997).
• The time is right to conduct trials involving field CO₂ enrichment of several rows of orchids in selected farms.

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REFERENCES


