

FAQ QUESTION #3

How do I know if I need CO₂ control?

The CO₂ concentration inside your growth chamber or room can affect the growth rate of the majority of plant species. CO₂ concentrations lower than 375ppm can almost linearly reduce growth (Sage & Coleman 2001), whereas elevated CO₂ concentrations (700 to 900ppm) generally stimulate growth, but at a lower magnitude than low CO₂ growth reduction (Mortensen 1987, Poorter 1993). CO₂ growth effects are most pronounced and prevalent in plants that use C₃ photosynthesis, which include the majority of plant species. To fully realize the growth stimulus of elevated CO₂ pot size, nutrition, temperature, and light intensity (PPFD) must scale with the desired growth response (Cao et al 1994, Chagvardieff et al 1994, McConnaughay et al 1993). For pot size, CO₂ growth effects appear to be somewhat proportional to general pot size effects on growth, with greater absolute biomass gains at higher CO₂ concentrations in larger pots (Arp 1991, Kerstiens & Hawes 1994, Poorter et al 2012). Plants that use C₄ photosynthesis show a more variable growth response to CO₂ concentration, and in general show less growth effects across a wider range of CO₂ concentrations below and above current atmospheric (415ppm) compared to C₃ plants. Plants that use Crassulacean Acid Metabolism generally show CO₂ growth effects in between those of C₃ and C₄ plants (Poorter 1993). In the leaf and seed tissue of C₃ plants grown at elevated CO₂, protein and mineral nutrients are generally reduced, whereas in leaf tissue total non-structural carbohydrates and soluble phenolics increase, as well as one report of increased iron content in lettuce (*Lactuca sativa* L.)

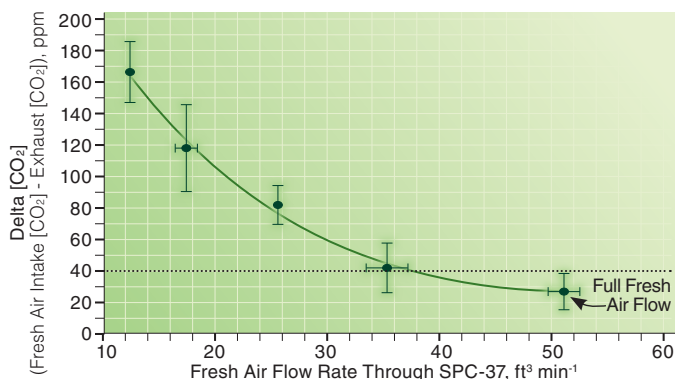
(Chagvardieff et al 1994, Myers et al 2014, Poorter et al 1997).

Plants photosynthesize and consume CO₂, drawing down the CO₂ concentration inside growth chambers and rooms. Fresh air replaces the CO₂ consumed through photosynthesis; more fresh airflow means less CO₂ drawdown. Conversely the more plant material inside a growth chamber or room, the greater the CO₂ drawdown. For most reach-in growth chambers at full fresh air flow, in most situations the CO₂ drawdown will be within 10% of the fresh air coming in (eg. if the fresh air coming in is 400ppm CO₂, the CO₂ concentration inside the growth chamber will be 360ppm or higher) (Friesen 2017, Peet & Krizek 1997, Figure 1). While reach-in chambers generally have sufficient fresh airflow per unit volume of growth space to mitigate substantial CO₂ drawdown, larger walk-in rooms may be more susceptible to larger CO₂ drawdowns if they are filled with large, actively-growing plants.

The other important variable that determines the CO₂ concentration your plants experience is the CO₂ concentration of the fresh air flowing into the growth chamber or room. Without CO₂ control, the CO₂ concentration of the fresh air flowing into a growth chamber will depend on a number of factors that are challenging to estimate. First, proximity of the growth chamber facility to large urban centers and industry will affect how close CO₂ concentrations are to current atmospheric. On average, ground level CO₂ concentrations were 25 to 95ppm higher than atmospheric CO₂ concentration over

FIGURE 1:

Drawdown of CO₂ concentration as a function of fresh air flow inside a BioChambers SPC-37 filled with well-watered and fertilized maize and soybean (mean ±SE). Leaf temperatures ranged from 25.5 – 26.5°C and photosynthetic photon flux densities (PPFD) averaged 430 μmol m⁻² s⁻¹ across the upper leaves. The leaf area index (leaf area/growth area, m² m⁻²) of all plants was 0.48. Flow rates were decreased by manually closing the fresh air intake valve from fully open (arrow). After each flow rate change, at least 45 minutes was given before measurements were recorded to allow for steady state conditions. Dotted line is the 10% recommended drawdown limit of Morse (1963) assuming the ambient CO₂ concentration entering the chamber is current atmospheric (~400ppm).



a 24 hour period across three locations on different continents (Ziska et al 2001). Next, the topography surrounding the facility can also affect the CO₂ concentration of the building's fresh air intake. For example, CO₂ concentrations can be further elevated when CO₂ is trapped within a natural or constructed valley and close to industry or urban centers (Bjorkegren et al 2015).

Building layout and volume, ventilation, and occupancy can all further affect the CO₂ concentration of the air flowing into your growth chamber. Smaller volume spaces, less ventilation, and more people (exhaling CO₂) increase the CO₂ concentration inside the facility, often increasing throughout the workday (Franco & Leccese 2020, Persily & de Jonge 2017). Even with a building ventilation rate acceptable for the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) indoor air quality standards and typical occupancy, indoor CO₂ concentration can often reach 1000ppm or more (Janssen 1989, Persily & de Jonge 2017). When CO₂ concentrations are continually measured inside buildings at a university campus, variability in CO₂ concentrations are due to overall occupancy and building volume per person (Franco & Leccese 2020). The more CO₂ enriched air from building occupants mixes into growth chamber spaces, the more the CO₂ concentration of the air entering growth chambers is elevated above outside concentrations. Generally, the closer growth chambers are to occupied spaces, the more CO₂ will diffuse and buildup in the air entering growth chambers. If growth chamber exhaust air re-enters the same space, the number of growth chambers and rooms filled with plants in the same space can also affect the CO₂ concentration of the air inside them. During the day, CO₂ drawdown can lower the CO₂ concentration inside other equipment if they all share the same intake and exhaust air.

During the night when most plants respire CO₂, the opposite effect can occur and CO₂ concentrations can build up.

Questions to ask yourself when deciding whether or not to include CO₂ control:

- Are the growth rates of my plants strongly affected by CO₂ concentration?
- What are my plant growth goals?
- Is a comparable growth rate to other studies important to my research?
- Are comparable leaf or seed tissue concentrations of protein, iron, zinc, non-structural carbohydrates, or soluble phenolics to other studies important to my research?
- Would it be cost effective to include additive CO₂ to stimulate plant growth for production purposes?
- Will I be completely filling a large growth room with plants in a generally unoccupied space, where a CO₂ drawdown below current atmospheric is possible?
- Will my growth chamber or room be installed in a space with CO₂ concentrations 500 to 1000ppm higher than the CO₂ concentration of the air outside the facility due to the exhalation (respiration) of people working inside the building?
- Will people be working inside a growth room for extended periods? If so, is a buildup of CO₂ concentration acceptable?

These are the questions to ask yourself when deciding whether to include CO₂ control in your new growth chamber or room. CO₂ control options include additive CO₂ to elevate CO₂ concentration above fresh air ambient and CO₂ removal (scrubbing) to achieve below fresh air ambient CO₂ concentrations. For a more detailed discussion of fresh air intake and CO₂ drawdown, please read: Are you filling your chambers to capacity? You may be starving your plants. (https://www.biochambers.com/pdfs/fresh_air.pdf)

References

- Arp WJ. 1991. Effects of source-sink relations on photosynthetic acclimation to elevated CO₂. *Plant, Cell & Environment*, **14**: 869-875.
- Bjorkegren AB, Grimmond CSB, Kotthaus S, Malamud BD. 2015. CO₂ emission estimation in the urban environment: Measurement of the CO₂ storage term. *Atmospheric Environment*, **122**: 775-790.
- Cao W, Tibbitts TW, Wheeler RM. 1994. Carbon dioxide interactions with irradiance and temperature in potatoes. *Advances in Space Research*, **14**: 243-250.
- Chagvardieff P, d'Alletto T, André M. 1994. Specific effects of irradiance and CO₂ concentration doublings on productivity and mineral content in lettuce. *Advances in Space Research*, **14**: 269-275.
- Franco A, Leccese F. 2020. Measurement of CO₂ concentration for occupancy estimation in educational buildings with energy efficiency purposes. *Journal of Building Engineering*, **32**: 101714 (1-9). <https://www.sciencedirect.com/science/article/abs/pii/S2352710219316912>
- Friesen P. 2017. Are you filling your chambers to capacity? You may be starving your plants. BioChambers Inc., 1-4. https://www.biochambers.com/pdfs/fresh_air.pdf
- Janssen J. 1989. Ventilation for acceptable indoor air quality. *ASHRAE Journal*, **31**: 40-42.
- Kerstiens G, Hawes CV. 1994. Response of growth and carbon allocation to elevated CO₂ in young cherry (*Prunus avium* L.) saplings in relation to root environment. *New Phytologist*, **128**: 607-614.
- McConnaughay KDM, Bertson GM, Bazzaz FA. 1993. Limitations to CO₂-induced growth enhancement in pot studies. *Oecologia*, **94**: 550-557.
- Morse RN. 1963. Phytotron design criteria – engineering considerations. In Proceedings of a Symposium on Engineering Aspects of Environment Control for Plant Growth, September 1 – 5, 1962, p. 20-61. CSIRO, Highett, Victoria, Australia.
- Mortensen LM. 1987. Review: CO₂ enrichment in greenhouses. Crop responses. *Scientia Horticulturae*, **33**: 1-25.
- Myers SS, Zanobetti A, Kloog I, Huybers P, Leakey ADB, et al. 2014. Increasing CO₂ threatens human nutrition. *Nature*, **510**: 139-142.
- Peet MM, Krizek DT. 1997. Carbon Dioxide. In: *Plant Growth Chamber Handbook*, eds. RW Langhans, TW Tibbitts, pp. 65-80: Iowa State University, NCR-101 Publication No. 340. <https://www.controlledenvironments.org/wp-content/uploads/sites/6/2017/06/Ch04.pdf>
- Persily A, de Jonge L. 2017. Carbon dioxide generation rates for building occupants. *Indoor Air*, **27**: 868-879.
- Poorter H. 1993. Interspecific variation in the growth response of plants to an elevated ambient CO₂ concentration. *Vegetatio*, **104**: 77-97.
- Poorter H, Bühler J, van Dusschoten D, Climent J, Postma JA. 2012. Pot size matters: a meta-analysis of the effects of rooting volume on plant growth. *Functional Plant Biology*, **39**: 839-850.
- Poorter H, Van Berkel Y, Baxter R, Den Hertog J, Dijkstra P, et al. 1997. The effect of elevated CO₂ on the chemical composition and construction costs of leaves of 27 C₃ species. *Plant, Cell & Environment*, **20**: 472-482.
- Sage RF, Coleman JR. 2001. Effects of low atmospheric CO₂ on plants: more than a thing of the past. *Trends in Plant Science*, **6**: 18-24.
- Ziska LH, Ghannoum O, Baker JT, Conroy J, Bunce JA, et al. 2001. A global perspective of ground level, 'ambient' carbon dioxide for assessing the response of plants to atmospheric CO₂. *Global Change Biology*, **7**: 789-796.

