
BioChambers
PROVIDING GROWTH TO RESEARCH.
Are you filling your chambers to capacity?
You may be starving your plants.
By Patrick Friesen, PhD

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You may be starving your plants.
Why it matters to consider fresh air flow.

Maintaining CO_2 concentrations in the plant canopy can be critical for normal growth and development. Plants photosynthesize and consume CO_2 during growth. In contained environments such as plant growth chambers, the consumed CO_2 must be replenished in order to prevent appreciable drops in CO_2 concentrations. Appreciable drops in CO_2 concentrations can lead to reductions in biomass, delay or prevent flowering, and alter gene expression. Introducing ambient air into plant growth chambers is one method to replenish the CO_2.

How do plant area and fresh air flow rates affect CO_2 concentrations?

The more plant area inside a growth chamber, the greater the depletion of CO_2 (Fig. 1). The rate of CO_2 depletion is related to the total net CO_2 assimilation rate (rate of photosynthesis) of the entire plant area. With well-watered plants, light intensity, temperature, and the CO_2 concentration inside the chamber itself primarily affect the rate of CO_2 assimilation[1].

If growth chambers are filled to capacity, the fresh air flow rates through the chambers have a considerable effect on the CO2 concentrations inside. With their standard fresh air flow rates, CO_2 concentrations dropped to 280ppm inside both a reach-in chamber filled with field mustard (*Brassica rapa*)[2] and a walk-in growth room filled with poplar trees (*Populus* sp.)[3]. In chambers built before 1984, fresh air flow rates are generally even less and can result in CO_2 concentrations of 150ppm and 50ppm inside a chamber filled with cotton (*Gossypium* sp.) and maize (*Zea mays*) respectively[3-5]. Increased fresh air flow rates increase the CO_2 concentration around plants by replacing the CO_2 consumed during photosynthesis at a greater rate (Fig. 2).

A BioChambers short plant chamber (model SPC-37) filled with young maize and soybean plants provides a fresh air flow rate that exceeds 50 ft^3 min^{-1}, mitigating CO_2 depletion to less than 40ppm (Fig. 3). Assuming an ambient CO_2 concentration close to atmospheric (~400ppm), the 51 ft^3 min^{-1} fresh air flow rate of the SPC-37 is within this 10% CO_2 drawdown, the most stringent recommendation of Morse (1963)[6] in the **Plant Growth Chamber Handbook**[7].

In addition, we estimate net CO_2 assimilation rates per unit growth area for plants that use C_3 and C_4 photosynthesis at various growth temperatures using leaf level gas exchange data and comparable whole chamber experiments for a tall plant chamber (model TPC-19). These estimates were used to calculate the required fresh air flow rates to achieve a 10% CO_2 drawdown and are based on an assumed leaf area index (leaf area/growth area, m^2 m^{-2}) of 1.5 for tall plants (Table 1). Theoretical estimates for the SPC-37 using this same approach are ±1.3 ft^3 min^{-1} of actual measurements from the experiment with maize and soybean.

How do low CO_2 concentrations and inadequate fresh air intake affect plant growth and development?

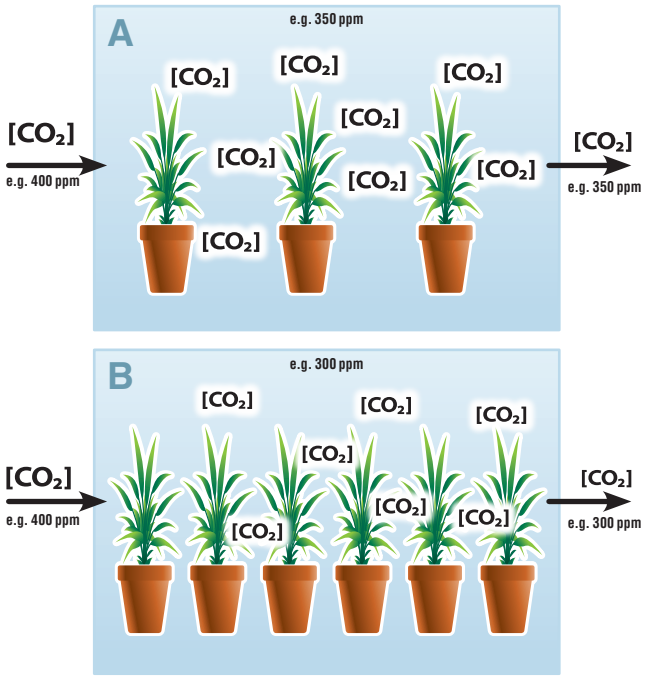
When CO_2 concentrations inside growth chambers drop below ambient (~400ppm), growth and development for plants that use C_3 photosynthesis are reduced and impaired (eg. wheat, soybean, rice)[16-26]. The majority of plant species use the C_3 photosynthetic pathway, where at low CO_2 concentrations, CO_2 itself becomes the primary limitation on carbon gain. Ribulose-1-5 carboxylase/oxygenase (Rubisco) is the photosynthetic enzyme that fixes CO_2 into sugars for growth and development. When CO_2 concentrations are low, Rubisco and carbon gain are limited by CO_2[27, 1]. Rubisco also reacts with O_2 in the energetically wasteful process of photorespiration[28]. Here O_2 competes with and inhibits CO_2 binding, exacerbating the CO2 limitation on carbon gain as CO_2 concentrations decline, especially at warm temperatures[29-32]. Across a number of plants that use C_3 photosynthesis, reductions in biomass are roughly proportional to reductions in CO_2 concentrations below current atmospheric levels (~400ppm). Here, a 50% reduction in CO_2 concentration results in a 50% reduction in biomass (see ref. 24, Fig. 3). Other effects of low CO_2 concentrations on C_3 plants include increased water use, a reduction in the ratio of root:shoot biomass, and delayed or failure to flower (reviewed in ref. 19). The stress of low CO_2 concentration affects gene expression and quantitative traits, potentially confounding the expression profiles from treatment factor(s) of interest[2]. Plants that can concentrate CO_2 around Rubisco experience reduced effects of low CO_2 concentrations on growth and development, such as plants that use C_4 photosynthesis (eg. maize, sugarcane)[18,23].

In addition, gases emitted by plants such as isoprene and ethylene can potentially build up and have feedback effects if fresh air flow is inadequate. These feedbacks could have undesirable effects and further confound experiments. Increased isoprene exposure can hasten the onset of flowering and may artificially increase tolerance of high temperatures[33-35]. Low CO_2 environments can increase isoprene emissions, further compounding the problem of inadequate fresh air supply[36]. Superambient ethylene exposure accelerates fruit ripening and can slow or accelerate plant growth depending on the species[37,38].

Photosynthetic Type	Leaf Temp (°C)	Required Fresh Air Flow Rate ($ft^3\ min^{-1}$)
C_3 (eg. wheat)	21	31
C_3 (eg. wheat)	30	33
C_3 (eg. wheat)	35	29
C_4 (eg. maize)	21	28
C_4 (eg. maize)	30	44
C_4 (eg. maize)	35	46

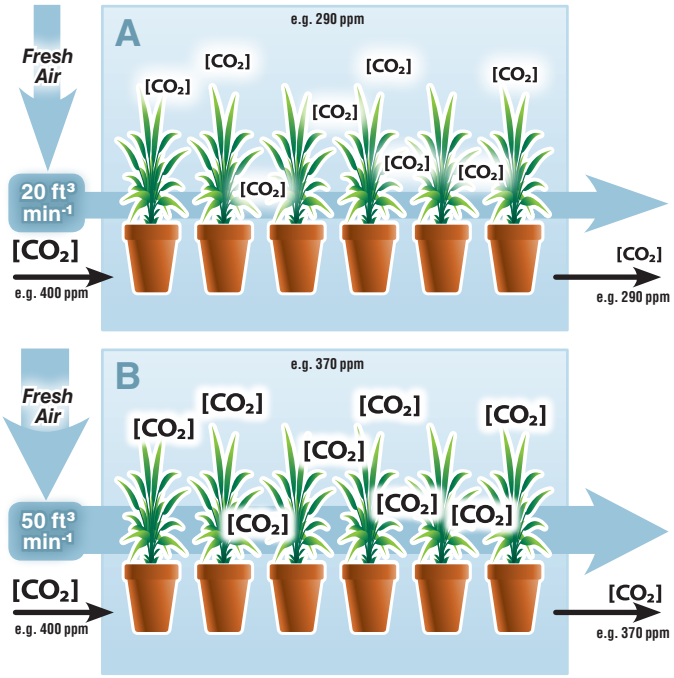
Table 1:
Calculated fresh air flow rates ($ft^3\ min^{-1}$) required to maintain a 10% reduction in ambient CO_2 concentration inside a tall plant chamber (model TPC-19) filled to capacity for plants that use C_3 or C_4 photosynthesis at different growth temperatures. Calculations assume a 400ppm CO_2 concentration entering the chamber and a leaf area index (leaf area/growth area, $m^2\ m^{-2}$) of 1.5. Estimates are based on published leaf level net CO_2 assimilation rates and comparable whole chamber CO_2 assimilation studies[8-15]. These estimates incorporate the maximum photosynthetic photon flux density and growth area of the TPC-19 which are 1500 µmol $m^{-2}\ s^{-1}$ and $1.87 m^2$ respectively. The TPC-19 has a fresh air flow rate of 60 $ft^3\ min^{-1}$, exceeding these requirements under the given assumptions.

Figure 1



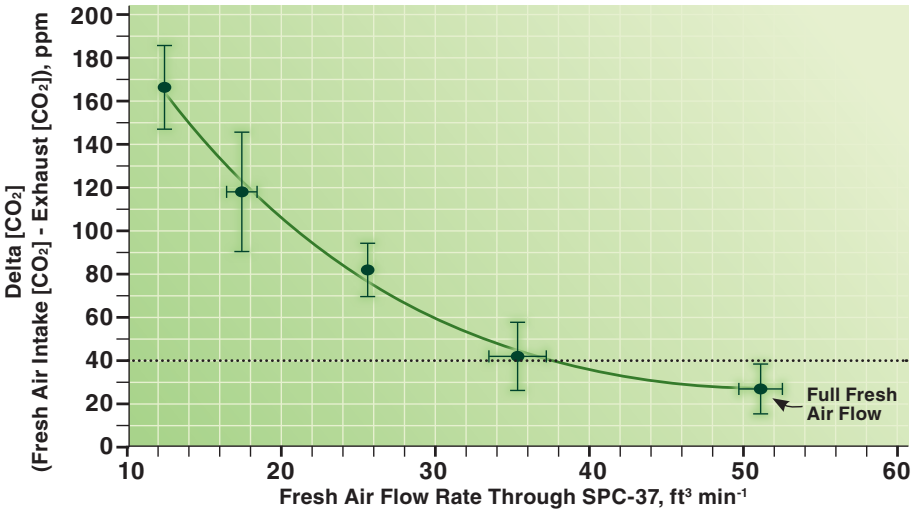
The effect of greater plant mass/area on CO_2 concentration inside a growth chamber. During photosynthesis plants consume CO_2 from the surrounding air. The greater the leaf area inside a growth chamber, the greater the rate of CO_2 drawdown from photosynthesis. Six plants (B) will lower the CO_2 concentration more than only three plants (A) of equivalent size and development.

Figure 2



The effect of greater fresh air flow on the CO_2 concentration inside a growth chamber. Greater fresh air flow replaces the CO_2 consumed during photosynthesis at a faster rate, increasing the CO_2 concentration or mitigating the drawdown from photosynthesis. With an equivalent number of plants of the same size and development, increasing the fresh air flow from 20 $ft^3\ min^{-1}$ (A), to 50 $ft^3\ min^{-1}$ (B), can prevent a nearly four-fold internal drawdown of CO_2 concentrations (see Figure 3).

Figure 3



Drawdown of CO_2 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 averaged 430 µmol $m^{-2}\ s^{-1}$ across the upper leaves. The leaf area index (leaf area/growth area, $m^2\ m^{-2}$) 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)[6] assuming the ambient CO_2 concentration entering the chamber is current atmospheric (~400ppm).

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