Lights, CO_2, GROW!

Learn how supplemental carbon dioxide (CO_2) changes affect the growth rate and health of basil, cilantro, mint, parsley and sage.

By Jennifer Boldt, Forrest Brown and Roberto Lopez

Lights, camera, action!

That's an iconic phrase we associate with movies and filmmaking. What might be the cues we can use to "set the stage" for a productive day of growing plants in the greenhouse? How about "lights, CO_2, grow!"?

Plants need light and carbon dioxide (CO_2) for photosynthesis. This is a process in which plants use these inputs to create sugars that can be used for growth and development. When plants do not have enough light or CO_2, they will grow more slowly. For edible crops like fresh-cut culinary herbs that are sold by fresh weight, quickly producing a lot of harvestable biomass is important.

The rate of photosynthesis is capped by whichever resource happens to be most limiting at the time. We often think of providing more light to boost photosynthesis. Many growers, especially in northern states, provide supplemental lighting between late fall and early spring to augment low amounts of ambient sunlight.

However, the CO_2 level in a greenhouse is also an important consideration. Unlike light that we can "see" and temperature that we can "feel," we might not think about CO_2 because it is a colorless, odorless gas that we cannot sense. But CO_2 is very important to plants.

> **This is the fifth article of a six-part series** on the environmental and cultural management of culinary herbs for controlled environments. Visit **greenhousemag.com/magazine** and navigate to the February, March, June and August issues.

Why might CO_2 be limiting in the greenhouse?

Ambient CO_2 levels outdoors are currently about 425

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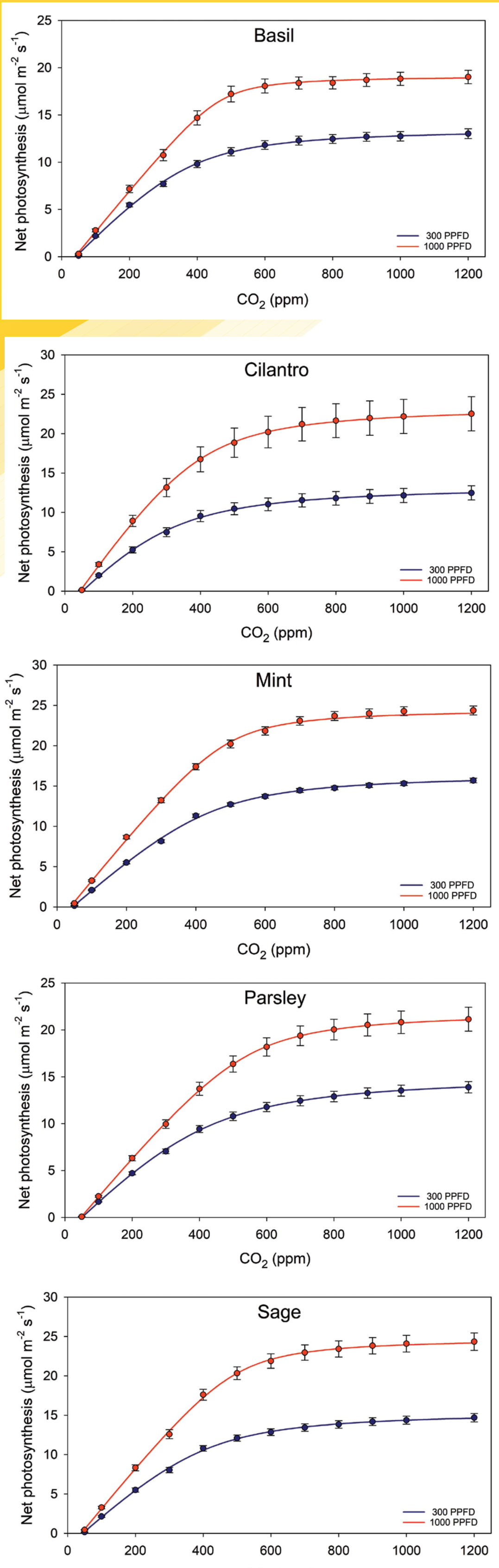

Figure 1. Photosynthesis curves in response to CO_2 for basil, cilantro, mint, parsley and sage. The curves were developed at a "moderate" (300 µmol·m^{-2}·s^{-1} photosynthetic photon flux density (PPFD); blue line) and a "high" (1000 µmol·m^{-2}·s^{-1} PPFD; orange line) light intensity.

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parts per million (ppm). During the day, the CO_2 concentration inside a greenhouse will fall below the CO_2 concentration outside as plants take up and use the CO_2 to photosynthesize. Greenhouse CO_2 concentrations can frequently fall below 300 ppm, especially on sunny winter days, when the greenhouse is tightly sealed to maintain temperature.

When the CO_2 concentration falls below ambient, photosynthesis will slow down, even if supplemental lights are turned on. Conversely, when additional CO_2 is provided, plants can utilize the extra CO_2 up to a point to boost photosynthesis.

One of our goals for this culinary herb project is to optimize the growing conditions for production. In this article, we will discuss how much CO_2 different culinary herbs need to sustain high rates of photosynthesis. We will also explore how adding CO_2 and light together can boost photosynthesis.

How do we measure plant response to CO_2?

We have an instrument that allows us to measure photosynthesis in real time. Keeping the leaf attached to the plant, we gently place the leaf in the measuring chamber. Inside this measuring chamber, we can monitor and adjust the light intensity, CO_2 concentration, temperature and relative humidity. It's like a miniature growth chamber.

We can set the measuring chamber to match the conditions that the plant is currently growing in and measure its photosynthetic rate. Or, we can change one or more conditions and see by how much the photosynthetic rate changes.

For this culinary herb study, we grew basil, cilantro, mint, parsley and sage in 4.5-inch pots for three to four weeks before we started collecting measurements. Then, one plant at a time, we measured the photosynthetic rate over a range of CO_2 concentrations, from very low to very high. We did this at a "moderate" light intensity (300 µmol·m^{-2}·s^{-1} photosynthetic photon flux density) and again at a "high" light intensity (1000 µmol·m^{-2}·s^{-1} PPFD). Finally, we used the data and fit models of photosynthetic rate for each herb at the two light intensities (**Figure 1**).

What did we find?

In general, photosynthetic CO_2 response curves have a similar shape. Photosynthesis will initially increase in a straight line (linearly) as the CO_2 concentration increases. However, as more and more CO_2 is provided, plants will eventually no longer be able to use the CO_2 as efficiently.

This is because something else will have become the limiting factor, such as the amount of an input (like light) or the amount of cellular machinery (like proteins) dedicated to photosynthesis. At this point, the shape of the response will begin to curve and then flatten into an almost horizontal line.

Each herb has its own unique response curve. Specifically, the slope of the linear portion of the response, how much of a bend in the curve there is and when CO_2 saturation occurs will differ with crop and growing conditions.

How limiting is low CO_2 to photosynthesis?

As we mentioned earlier, greenhouses can have low CO_2 concentrations, especially around

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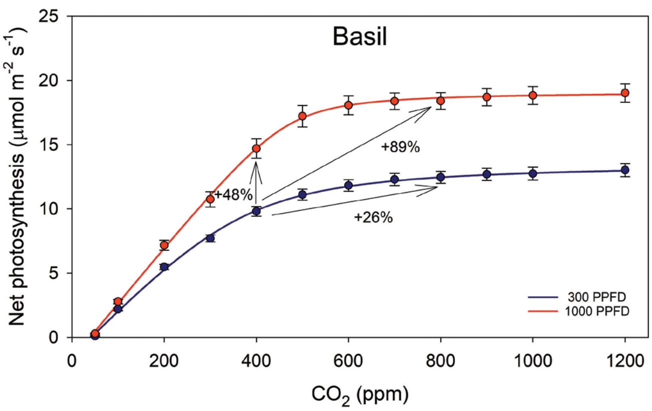

Figure 2. A photosynthesis CO_2 response curve for basil. Increasing the light intensity from 300 to 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD increased instantaneous photosynthesis by 48%. Increasing the CO_2 concentration from 400 to 800 ppm increased photosynthesis by 26%. Increasing light intensity and CO_2 together increased photosynthesis by 89% and exhibited a synergistic response.

the plant canopy, as plants use CO_2 for photosynthesis. Based on our response curves for the culinary herbs, decreasing the CO_2 from 400 to 300 ppm decreased photosynthesis by 18% to 22% at "moderate" light (blue line in the graphs) and decreased photosynthesis by 21% to 26% at "high" light (orange line in the graphs). Cilantro was the least sensitive to the decrease in CO_2.

This highlights two findings. One, the impact of below-ambient CO_2 was more severe at high light. And two, keeping CO_2 levels as close to ambient as possible will minimize unintentionally limiting photosynthesis.

This can be achieved by using fans to increase air flow around the plant canopy. Venting the greenhouse to bring in fresh air is another good option, but it must be considered in combination with temperature and humidity management.

How beneficial is supplemental CO_2?

The "moderate" light intensity of 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD is realistic in the greenhouse during springtime on sunny days or with supplemental lighting on cloudy days, and the "high" light intensity (1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD) is realistic on sunny days in the greenhouse.

Increasing CO_2 from 400 to 600 ppm increased photosynthesis by 18% to 26% at moderate light and by 22% to 34% at high light. Doubling the CO_2 concentration from 400 to 800 ppm increased photosynthesis by 26% to 39% at moderate light and by 27% to 48% at high light.

From this, there are two pieces of good news. First, supplementing CO_2 above ambient levels increased photosynthesis. And second, the increase in photosynthesis with additional CO_2 was greater at the higher light intensity. The additional CO_2 allowed the plants to use more photons of light that otherwise would have been unusable at the high light intensity.

However, as we look at the response curves, we'd like to point out that the lines are already starting to curve as we move from 400 to 800 ppm CO_2. Thus, a 50% increase in CO_2 (from 400 to 600 ppm) provided less than a 50% increase in photosynthesis. The increase from 600 to 800 ppm was even less of a return, only boosting photosynthesis an additional 8% to 14%.

This doesn't mean that adding CO_2 isn't a good idea. It means that the largest benefits of adding CO_2 occur as we move from below-ambient to ambient levels. As we supplement CO_2 above ambient levels, we will see additional gains, but they will not be a 1-to-1 return. For example, doubling the CO_2 concentration will not double the harvestable biomass.

Lastly, we mentioned earlier that photosynthesis can only occur as fast as the most rate-limiting step or input. When photosynthesis is limited, adding more light or adding more CO_2 can boost it. Often, adding light and CO_2 together will provide a synergistic effect. This means that adding both at the same time can give a greater response than the sum of adding each one individually.

Using basil as an example, increasing the light intensity from moderate to high light at ambient CO_2 (400 ppm) increased photosynthesis by almost 50% (**Figure 2**). At moderate light, doubling the CO_2 level from 400 to 800 ppm increased photosynthesis by roughly 25%.

Thus, we might expect that adding both light and CO_2 at the same time would increase photosynthesis by about 75% if the effects were additive. Instead, adding light and CO_2 increased photosynthesis by almost 90%.

Take-home messages

Monitoring your greenhouse CO_2 levels can be a good starting point to see if they are lower or higher than expected. If greenhouse CO_2 levels are consistently below ambient, strategies that increase air movement around the plant canopy or increase the air exchange rate in the greenhouse can help minimize the CO_2 drawdown, especially during periods of rapid plant growth.

Adding supplemental CO_2 to increase levels above ambient can also increase plant growth, but the increase in photosynthesis per increase in CO_2 will incrementally decrease the further above ambient that you go. Supplementing to maintain ambient CO_2 levels or to boost CO_2 to about 600 ppm would provide the highest efficiencies.

However, if maximizing photosynthesis is the key target, then supplementing to 800 to 1,000 ppm CO_2 would be an appropriate range to target. Supplemental CO_2 can be provided through gas cylinders or tanks, CO_2 burners or CO_2 generation systems.

The five herbs that we evaluated — basil, cilantro, mint, parsley and sage — all had similarly shaped response curves. This means that one general approach to CO_2 management, rather than individualized plans, will be suitable. Just remember… *lights, CO_2, grow.* GM

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