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Features

The Rise & Fall of Carbon Dioxide

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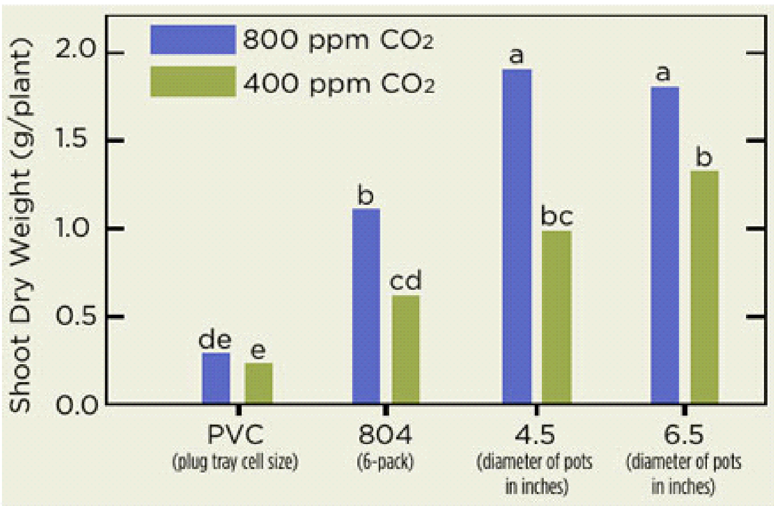

Figure 1. Vinca shoot dry weight with and without supplemental CO_2 in different container sizes. The influence of CO_2 on plant growth increased as container size increased. Different letters indicate significant difference in mean dry weight based on Tukey's multiple comparison of means ($P<0.05$).

In the winter production cycle, many of us are heating our greenhouses to maintain set points. We've focused on sealing up gaps in an effort to decrease air infiltration and cut our heating bills substantially along the way. While making these changes or upgrades, we may have noticed humidity inside rising, too, and perhaps even implemented a few changes like anti-condensation glazing to cut back on drips over the plants. But more often than not, we're ignoring something that's more difficult to see but could be having a profound effect on our plant growth: carbon dioxide (CO_2).

CO2 101

To quickly review basic plant biology, plants require CO_2 for photosynthesis and they release oxygen as a result of this process. At night (for most plants), plants release CO_2 as a result of respiration; respiration happens all the time, but during the daytime, the uptake of CO_2 is greater than its release, so we can't measure CO_2 rising except when photosynthesis isn't occurring.

In a closed greenhouse during the day, the plants are feeding on the available CO_2, but how well they feed and, therefore, how quickly they grow, depends on how much CO_2 is available. The more there is, the faster they photosynthesize, and the less there is, the less they grow. Outside CO_2 concentrations average nearly 400 parts per million (ppm) in the wintertime, but most plants can benefit from elevated CO_2, up to about 1,000 ppm. We generally assume that plants inside greenhouses experience something close to outside or "ambient" conditions. But is this a good assumption? In a normal commercial greenhouse, how quickly can CO_2 become low?

Calculating levels of CO2

We can estimate how quickly CO_2 can drop from initial conditions through a few assumptions, most of which are pulled straight from textbooks or measured in a greenhouse. Knowing the dimensions of a greenhouse (for example, a 150 x 30-ft., single span greenhouse with 12-ft. sidewalls and a 16-ft. center height), we can calculate the volume of air within the greenhouse and, therefore, the amount of CO_2 within that greenhouse (63,000 cu. ft. of air and just over 3 lbs. of CO_2 in this example). If we have a sunny day and we've filled our greenhouse with about 80% of capacity, we can calculate that photosynthesis will remove 1.5 lbs. of CO_2 in one hour from that greenhouse or about half the starting amount! That would decrease the original value from 400 to about 200 ppm or a concentration that definitely would impact photosynthesis. Of course, greenhouses are leaky and, as CO_2 decreases, so does photosynthesis, so it's likely that the actual drop would be closer to 100 ppm in one hour. How does this theoretical calculation, filled with assumptions, compare with real-world measurements?

The Real World: In the greenhouse

A couple of years ago, I carried a CO_2 sensor while I visited a handful of greenhouses during the winter, when everything was sealed up tightly. On this relatively cloudy day, I routinely found that CO_2 concentrations inside greenhouses were in the 300 to 330 ppm range. In one case, I even found CO_2 as low as 175 ppm. So in this small survey, even in the "best" case, CO_2 was lower than outside air by about 20%. In this CO_2 range, that's effectively cutting growth by about 20%, too!

Increased ventilation would certainly help boost CO_2 and make low CO_2 not as big a problem, but that adds to the cost of heating since we would need to heat that outside air. In fact, most cost estimates for the heating performed as a result of greater air infiltration to boost inside CO_2 are nearly an order of magnitude higher than the cost of adding supplemental CO_2 from either a burner or a liquid CO_2 source (actual costs depend on CO_2 supply type and weather at your location). Elevated CO_2 (supplementing CO_2 to above ambient or outside conditions) is commonly done in the vegetable production industry, but is not as widely done in the ornamental industry. If people were to boost CO_2 to above ambient conditions, what could be expected?

In plants grown for finishing, it's not unusual to notice larger plants earlier as a result of faster growth. There are inconsistent reports about faster development; in some crops, flowers appear earlier, but in others, there's no difference in the rate of flowering. In our own research, we've noticed plants reaching "full size" earlier when given supplemental CO_2, but then the ambient or low- CO_2-grown plants catch up. In these cases, we believe the supplemental CO_2 plants maximize their growth earlier and reach an upper limit to their size as determined by their container size. Indeed, when compared across container sizes, the effect of CO_2 increases as container size increases.

A CO2 case study

So what should we do about this? Is it a problem? One approach is to ventilate, but that certainly impacts your heating bill. Adding CO_2 with a "burner" system is also an approach, as long as the water that's generated in the combustion process is dealt with, not to mention the issues of incomplete combustion products like ethylene. Adding CO_2 via a liquid CO_2 source is yet another solution, but can have higher set-up costs. Is it worth adding CO_2? If CO_2 is low, the growth of plants will be affected, so adding CO_2 may accelerate growth. Dropping temperatures can save money and energy—about 3% for every one degree Fahrenheit lower set point—but also slows growth and development. Can additional CO_2 compensate for growth at lower temperatures and what is the cost of such a system and strategy?

Partnering with Don Schmidlin of Schmidlin Greenhouses in Delta, Ohio, we were able to test the first step to this strategy in a commercial setting. There are two essentially identical single-span, double-poly houses at Schmidlin's, each 29 ft. x 184 ft. In one, we set up a CO_2 controller ($599, model iGS-061 from www.SpecialtyLights.com) and a solenoid ($113, model SV122 from www.Omega.com), purchased a tank of liquid CO_2 ($68 per tank, plus a one-time delivery fee of $15 from Airgas www.airgas.com), set the CO_2 controller to maintain day-time CO_2 at a concentration of 500 ppm, and a temperature of 62F (16C). The other greenhouse was left uncontrolled for CO_2 and a temperature set point of 65F (18C).

Stock geranium plants were grown in both greenhouses and five lettuce seedlings (for destructive harvest and comparison purposes) were put into each house. Then we waited. During this time, we measured CO_2 and temperature periodically in both houses. CO_2 in the uncontrolled house was between 200 and 300 on sunny or partly sunny days, and always at least 100 ppm lower and at least three degrees warmer than the CO_2-controlled house.

A round of cuttings was the first data collected. Attempts were made to quantify total cuttings per pot and assess cutting quality. The cooler, CO_2-controlled house produced about 0.5 more cuttings per pot that the warmer, uncontrolled house and the stem diameter of the cuttings in the cooler, CO_2-controlled house was noticeable larger. The lettuce plants were harvested later. Fresh and dry weight was substantially greater in plants from the cooler, CO_2-controlled house. There were also about two more leaves per plant in those plants, suggesting that development—even though they were grown in a cooler environment—was compensated by higher CO_2.

What was the cost, and since we were adding a "greenhouse gas" of CO_2, what was the environmental impact of this strategy? Using the software Virtual Grower (www.virtualgrower.net), we can calculate how much fuel was used in heating the two different greenhouses and we know how much CO_2 was used for the heating season. Reducing the temperature by three degrees Fahrenheit saved $959 in propane over three months, assuming $2 per gallon cost, while adding CO_2 cost (including all parts, delivery and three months of liquid CO_2) $931, or essentially a break-even for a single, three-month season. The solenoid and CO_2 controller should last several years and could be scalable to different-sized greenhouses. The additional fuel used in the warmer greenhouse contributed nearly 5,000 lbs. more of CO_2 over this three-month period than the cooler greenhouse, while the CO_2 addition added 1,200 lbs. of CO_2 in the same time period. So supplementing this cooler greenhouse with CO_2 actually contributed 3,800 lbs. less CO_2 to the environment than the traditional production method.

These results are an encouraging step forward to design heating/control systems in a production environment in a more economical and environmentally friendly manner. The results in the case of CO_2 and environmental impacts may be counter-intuitive. The plants used in this test were vegetative (cuttings for propagation and lettuce production). We must do similar tests to determine if adding CO_2 can offset developmental delays for flower induction caused by cooler temperatures. As results continue to be collected, we will share strategies on managing the often-ignored "problem" of tight greenhouses leading to CO_2 starvation.

Having low CO_2 is a mixed blessing. If you have low CO_2, you've probably done an excellent job in sealing up the gaps in your facility. But consider adding CO_2 back into your greenhouses to take advantage of the greater control during this time. **GT**

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