# CO<sub>2</sub> Levels and Plants: What's So Wrong with a Greenhouse?

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# Introduction

If you have ever enjoyed a locally grown tomato in November or bought a poinsettia in December, these plants were most likely grown in greenhouses. Greenhouses give us the ability to grow plants during seasons in which they would not otherwise grow. With glass walls and ceilings that trap infrared radiation (heat), greenhouses are an ideal environment in which to grow many different kinds of plants. In fact, some greenhouse growers even increase the CO<sub>2</sub> levels in their greenhouses to help their plants grow faster. But do we really want to impose this environment on the whole planet?

Human activities have increased atmospheric  $CO_2$  levels in recent history. It is possible that we have had an impact on  $CO_2$  levels since we began clearing forests in Europe and cultivating rice in China 5000 to 8000 years ago.  $CO_2$  levels were estimated at below 200 ppm (parts per million) during the last glacial maximum, approximately 20 000 years ago. The levels increased at the beginning of the Holocene to about 280 ppm, between 12 000 and 10 000 years ago. Current  $CO_2$  levels are about 385 ppm (see Figure 1) and are predicted to increase to 550 ppm by the year 2050.

The greenhouse effect is caused by  $CO_2$ , water vapour, and other greenhouse gases present in the atmosphere. These gases absorb much of the infrared radiation Earth emits and reflects some of it back (the same way a greenhouse does), keeping the average temperature from dropping and preventing our planet from turning into a giant snowball. This natural greenhouse effect is very important to every living organism on Earth. But too much of a good thing can be a problem. As the concentration of atmospheric  $CO_2$  and other greenhouse gases increases, global temperatures rise, with the greatest warming occurring in the polar regions. This regional disparity is similar to the warming event seen during the Holocene Climate Optimum between 9000 and 5000 years ago. Researchers estimate that during the Holocene Climate Optimum, the increase in Arctic and Antarctic temperatures was about 4°C as opposed to the estimated increase of 1°C in the tropics.

Rolf Matthews from Simon Fraser University and Francine McCarthy from Brock University are investigating post-glacial climate change in Canada using **palynology**, the study of the deposition of pollen, spores, and other particulate organic matter that accumulate over time in sediment, such as on lake bottoms. Changes in the distribution of plant species over time can be inferred by the pollen and spore record and may be attributable to changes in climate. This type of research is a form of paleoclimatic reconstruction.

#### **KEY CONCEPTS**

- The accumulation of greenhouse gases is increasing.
- The Calvin cycle uses ATP and NADPH to convert CO<sub>2</sub> to sugar.
- Alternative mechanisms of carbon fixation have evolved in hot, arid climates.
- Human activities now dominate most chemical cycles on Earth.

#### FIGURE 1. The yearly average atmospheric CO<sub>2</sub> levels for Nunavut,

Canada.

The data in this graph were collected at Alert, Nunavut. The yearly average atmospheric  $CO_2$  levels in 1975 was 334 ppm. This increased to 387 ppm in 2008.

Sources: Meteorological Service of Canada, Environment Canada, and Earth System Research Laboratory, Global Monitoring Division.



Global warming causes greater temperature increases in polar regions for four main reasons. First, as polar snow and ice melts, darker land and ocean surfaces lose their reflective covering and absorb more solar energy. With more land exposed, a greater proportion of solar energy will go directly into warming land masses. Second, in polar regions, the atmospheric layer must warm before the surface does. Because the atmosphere is shallower there, the surface will warm more quickly than in other regions. Third, the ocean surface is exposed as sea ice retreats, and the solar heat absorbed by the oceans is more easily transferred to the atmosphere. Fourth, predicted changes in atmospheric and oceanic circulation could also increase warming by bringing warmer currents and air masses further north to the Arctic and further south to the Antarctic.

### The Canadian Boreal Forest

The boreal forest of Canada functions as a major **carbon sink** by extracting and storing a lot of carbon in its biomass—primarily in its trees. The boreal forest is continuing to grow and is actively removing  $CO_2$  from the atmosphere through photosynthesis. With



PHOTO A. The Canadian boreal forest. Source: © Dale Wilson/ Masterfile. increased temperatures in northern Canada, we have recently seen the expansion of the boreal forest into adjacent tundra zones; however, since the 1990s, data from remote sensing has shown an increase in the losses of stored carbon in the Canadian boreal forest because of disturbances by fires and insects. Werner Kurz and his colleagues from the Canadian Forest Service suggest that the Canadian boreal forest may change from a carbon sink to a **net carbon source**, releasing more  $CO_2$  into the atmosphere if climate change increases the intensity and frequency of forest fires, the damage from insects, and the respiration of soil-dwelling organisms.

What effect will an increase in atmospheric  $CO_2$  have on the boreal forest? One prediction is that photosynthesis in the boreal forest will increase as  $CO_2$  levels increase, resulting in the absorption of even more  $CO_2$ . This could happen because carbon from  $CO_2$  is the essential building block of organic molecules produced by photosynthesis. Increased  $CO_2$  should mean increased photosynthesis, right? Not necessarily. Experiments at Free Air Carbon Dioxide Enrichment (FACE) found that plant growth rates can increase with elevated atmospheric  $CO_2$ , but the growth is less than predicted. The reduced growth is due to a lack of nitrogen, an essential nutrient for plants. As a result, increases in plant growth from elevated  $CO_2$  may be limited by nutrient availability.

# Increased CO<sub>2</sub> Will Affect C<sub>3</sub> and C<sub>4</sub> Plants Differently

With sufficient nutrients, the plants in the boreal forest, which are almost all  $C_3$  plants, could increase their photosynthetic activity with increased atmospheric  $CO_2$ .  $C_3$  plants directly fix atmospheric  $CO_2$  in the Calvin cycle using the enzyme RuBisCO. Most studies indicate  $C_3$  carbon fixation can be increased by elevated  $CO_2$ . This is not the same for plants that use the alternative  $C_4$  photosynthetic pathway.  $C_4$  plants use the enzyme PEP carboxylase to fix atmospheric  $CO_2$  into a four-carbon organic acid first, and then the enzyme RuBisCO uses this organic acid as its carbon source in the Calvin cycle.

Adapted to hot, dry climates, C<sub>4</sub> plants are rare in cool climates because of their poor photosynthetic performance at low temperatures relative to C<sub>3</sub> species. In hot, dry conditions, C<sub>4</sub> plants lose less water through transpiration than C<sub>3</sub> plants. During the stress of drought and high temperatures, plants normally close most of their stomata, and the concentration of CO<sub>2</sub> in the plant becomes extremely low. The unique **kranz anatomy** of C<sub>4</sub> plants (the enzyme RuBisCO is found only in bundle-sheath cells, special cells that form a ring around the vascular bundles in the leaves) allows CO<sub>2</sub> to be concentrated around RuBisCO, even when stomata are closed, and photosynthesis keeps going. By contrast, under similar conditions of drought and high temperatures, C<sub>3</sub> plants experience photorespiration. Photorespiration occurs when RuBisCO uses oxygen as an alternate substrate to carbon, which severely reduces the photosynthetic rates in C<sub>3</sub> plants; therefore, C<sub>4</sub> plants have a competitive advantage under conditions of drought, high temperature, and low CO<sub>2</sub>. So, while elevated CO<sub>2</sub> increases photosynthesis in C<sub>3</sub> plants under most conditions, C<sub>4</sub> plants benefit from elevated CO<sub>2</sub> only when under drought stress (see Figure 2).

As  $CO_2$  levels increase, temperatures in Canada are predicted to increase, which will also affect photosynthesis in plants. Because increased atmospheric  $CO_2$  decreases photorespiration in  $C_3$  plants even during heat stress,  $C_3$  plants may have a competitive advantage over  $C_4$  plants in a warmer climate with high  $CO_2$  levels. In the  $C_3$ -dominated boreal forest, competition between  $C_3$  and  $C_4$  plants may not be an issue; but, the Canadian prairies are a mix of  $C_3$  and  $C_4$  grasses that constantly compete with one another for resources. The predicted changes in temperature and  $CO_2$  levels may change the

#### FIGURE 2. Temperature and CO<sub>2</sub> influences the predicted superiority of different photosynthetic pathways.

Modelled CO<sub>2</sub> uptake for C<sub>3</sub> and C<sub>4</sub> plants as a function of atmospheric CO2 concentrations: upper bar is 550 ppm CO<sub>2</sub>—the predicted levels we will have by 2050 (and those seen during the Miosine), current CO<sub>2</sub> concentrations (middle bar), and CO<sub>2</sub> levels of 200 ppm estimated at last glacial maximum (lower bar). Source: Adapted with kind permission from Springer Science + Business Media: Ehleringer JR, Cerling TE, and Helliker BE. 1997. C4 photosynthesis, atmospheric CO<sub>2</sub>, and climate. Oecologia 112(3):285-299. Copyright © 1997, Springer Berlin/Heidelberg.



distribution of  $C_3$  and  $C_4$  plants as certain plants out-compete others. Increased  $CO_2$  levels will also have an impact on agriculture in Canada, with  $C_3$  weeds possibly gaining a competitive advantage over  $C_4$  crops, such as corn. Canada thistle (*Cirsium arvense*) is an example of a noxious weed that grows more roots when  $CO_2$  levels are increased, which makes herbicides less effective.

# Conclusions

The complexity of the interactions between organisms and their environment makes it difficult to be sure how all the different ecosystems in Canada will respond to the predicted increases in atmospheric  $CO_2$ . Biologists continue their efforts to better understand how a future hotter planet will affect life everywhere.

### **Critical Thinking Questions**

- 1. Why is it difficult for scientists to predict the rate of warming that Arctic regions will experience?
- 2. Why are C<sub>4</sub> plants considered to be adapted for hot, dry conditions?
- 3. How will increases in atmospheric CO<sub>2</sub> alter the distribution of C<sub>3</sub> and C<sub>4</sub> grasses in the Canadian prairies?

### Further Research Question

How could changing CO<sub>2</sub> levels—from their low level during the last ice age to the high levels predicted by the year 2050—affect C<sub>3</sub> and C<sub>4</sub> plants (see Ward et al., 2008)?

### References

- \*Ainsworth EA, Long SP. 2005. What have we learned from 15 years of free-air CO<sub>2</sub> enrichment (FACE)? a meta-analytic review of the responses of photosynthesis, canopy properties, and plant production to rising CO<sub>2</sub>. *New Phytol.* 165:351–372.
- Archambault DJ, Li X, Robinson D, O'Donovan JT, Klein KK. 2001. The effects of elevated CO<sub>2</sub> and temperature on herbicide efficacy and weed/crop competition [Internet]. Final Report Prepared for the Prairie Adaptation Research Collaborative. [cited 2010 Apr 12]. Available from: http://www.parc.ca/pdf/research\_publications/agriculture2.pdf
- Bonan GB. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Sci.* 320:144–1449.
- Ehleringer JR, Cerling TE, Helliker BR. 1997. C<sub>4</sub> photosynthesis, atmospheric CO<sub>2</sub>, and climate. *Oecol.* 112:285–299.
- Kubien DS, Sage RF. 2004. Low-temperature photosynthetic performance of a  $C_4$  grass and a co-occurring  $C_3$  grass native to high latitudes. *Plant Cell Environ*. 27:907–916.
- Kurz WA, Stinson G, Rampley G. 2008. Could increased boreal forest ecosystem productivity offset carbon losses from increased disturbances? *Philos. Trans. R. Soc. Biol.* 363:2259–2268.
- Leakey ADB. 2009. Rising atmospheric carbon dioxide concentration and the future of C<sub>4</sub> crops for food and fuel. *Proc. R. Soc. Biol.* 276:2333–2343.
- Logan AJ, Régnière J, Powellet JA. 2003. Assessing the impacts of global warming on forest pest dynamics. *Front Ecol. Environ.* 1(3):130–137.
- Wang D, Heckathorn SA, Barua D, Joshi P, Hamilton EW, LaCroix JL. 2008. Effects of elevated CO<sub>2</sub> on the tolerance of photosynthesis to acute heat stress in C<sub>3</sub>, C<sub>4</sub>, and CAM species. Am. J. Bot. 95:165–176.
- \*Ward JK, Myers DA, Thomas RB. 2008. Physiological and growth responses of C<sub>3</sub> and C<sub>4</sub> plants to reduced temperature when grown at low CO<sub>2</sub> of the last ice age. *J. Integr. Plant Biol.* 50:1388–1395.