Interactive Effects of Elevated CO_2 and Air Pollution on Wheat

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Atmospheric CO_2 enrichment typically enhances photosynthesis and biomass production in wheat (*Triticum aestivum* L.) under normal growing conditions. But what happens when environmental conditions are less than ideal? This Summary investigates this question as it pertains to the impact of air pollutants on the growth and development of wheat, as learned from a number of scientific studies published on this topic.

We begin with the work of Bender *et al.* (1999)[1], who analyzed the results of thirteen open-top chamber studies, wherein spring wheat was grown at ambient and twice ambient atmospheric CO_2 concentrations in combination with ambient and elevated ozone (O_3) concentrations. They found that the elevated O_3 treatment had little effect on growth and yield, suggesting that either the O_3 concentrations employed in the studies were not high enough to elicit a negative response in the specific cultivar tested (Minaret) or that the cultivar was highly tolerant of ozone. Consequently, elevated CO_2 was the primary variable that influenced growth and yield; and it proved very effective in this regard, increasing aboveground biomass by an average of 37% (with a range of 11 to 128%) and grain yield by an average of 35% (with a range of 11 to 121%).

Tiedemann and Firsching (2000)[2] grew spring wheat from germination to maturity in controlled environment chambers maintained at ambient (377 ppm) and enriched (612 ppm) atmospheric CO_2 concentrations and ambient (20 ppb) and enriched (61 ppb) atmospheric O_3 concentrations. The extra CO_2 increased mean photosynthetic rates at both O_3 concentrations, with the greatest absolute photosynthetic rates and the largest CO_2-induced percentage increases in photosynthesis being observed in the elevated CO_2/elevated O_3 treatment. Total grain yield was also greatest in the high CO_2/high O_3 treatment, with the elevated CO_2 increasing total grain yield at high O_3 by 38% relative to that observed at ambient CO_2 and elevated O_3. Moreover, the absolute value of total grain yield in the high CO_2/high O_3 treatment was not significantly different from that produced at ambient O_3, regardless of the atmospheric CO_2 concentration. Thus, the deleterious effects of ozone on

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[1] http://www.co2science.org/articles/V5/N25/B1.php
[2] http://www.co2science.org/articles/V3/N14/B2.php

photosynthesis and yield were completely ameliorated by atmospheric CO_2 enrichment in this study.

Pleijel *et al*. (2000)[3] grew spring wheat in open-top chambers maintained at atmospheric CO_2 concentrations of 340 and 680 ppm for three consecutive years. In addition, they exposed some plants in each CO_2 treatment to ambient, 1.5 x ambient and 2 x ambient O_3 concentrations. The elevated O_3 concentrations negatively influenced wheat yield at both atmospheric CO_2 concentrations. Nevertheless, grain yield was always higher for the plants grown in the CO_2-enriched air, averaging 13% greater over the three years of the study and leading the scientists to conclude that "the positive effect of elevated CO_2 could compensate for the yield losses due to O_3."

Working in the United Kingdom, Mckee *et al*. (2000)[4] also grew spring wheat in open-top chambers that were subjected to various atmospheric treatment combinations of CO_2 (380 and 690 ppm) and O_3 (27 and 61 ppb). Depending on the time of day and other environmental conditions, elevated CO_2 increased photosynthetic rates by 43 to 67%. Elevated CO_2 also reduced stomatal conductance by about 50% relative to rates measured in leaves of ambient-grown plants. Elevated O_3 severely reduced rubisco content in the youngest wheat leaves sampled. However, leaves of plants exposed to both elevated CO_2 and elevated O_3 displayed no such reductions in leaf rubisco content, indicating that elevated CO_2 ameliorated the negative effects of O_3 on leaf rubisco content. A similar ameliorating effect of elevated CO_2 was observed for rubisco activity, which was decreased by elevated O_3 under ambient CO_2 conditions.

As the atmospheric CO_2 concentration rises, it is therefore likely that spring wheat plants will exhibit greater photosynthetic rates than they currently do under ambient CO_2 concentrations. Moreover, it is likely that rising CO_2 concentrations will protect spring wheat plants from increasing O_3 concentrations, which commonly reduce photosynthetic rates. Indeed, as the work of Mckee *et al*. demonstrates, elevated CO_2 ameliorates elevated O_3-induced reductions in rubisco activity and content. In addition, CO_2-induced reductions in stomatal conductance will likely allow this important agricultural crop to better cope with water stress through improved plant water-use.

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[3] http://www.co2science.org/articles/V4/N16/B3.php
[4] http://www.co2science.org/articles/V3/N37/B2.php

Heagle *et al*. (2000)[5] grew several soft red winter wheat cultivars in open-top chambers at atmospheric CO_2 concentrations of 380, 540 and 700 ppm in combination with atmospheric ozone concentrations of 27, 45 and 90 ppb to determine the interactive effects of elevated CO_2 and O_3 on growth and yield in this agronomic cereal crop. Their work revealed that elevated CO_2 suppressed foliar injury caused by elevated O_3, especially in some of the more O_3-sensitive cultivars they examined. In addition, atmospheric CO_2 enrichment to 700 ppm almost completely protected such cultivars from the negative effects of elevated O_3 on seed yield. At ambient CO_2 concentrations, for example, elevated O_3 reduced seed yield by 48% in an O_3-sensitive cultivar. However, at an atmospheric CO_2 concentration of 700 ppm, yield reductions in this same O_3-susceptible variety were only 8%. Thus, atmospheric CO_2 enrichment had a strong ameliorating effect on the negative influences of elevated O_3 on growth and yield of O_3-susceptable winter wheat cultivars.

Vilhena-Cardoso and Barnes (2001)[6] grew spring wheat for two months in environmental chambers fumigated with air containing atmospheric CO_2 concentrations of 350 and 700 ppm at ambient and elevated (75 ppb) O_3 concentrations in soils of low, medium and high nitrogen content. They found that the elevated O_3 treatment reduced photosynthetic rates in the ambient-CO_2-grown plants, but it had no effect on the CO_2-enriched plants, which maintained enhanced photosynthetic rates even in the high O_3 treatments. With respect to biomass production, elevated CO_2 increased total plant dry weight by 44, 29 and 12% at high, medium and low soil nitrogen supply, respectively; and although elevated O_3 by itself reduced plant biomass, the simultaneous application of elevated CO_2 completely ameliorated this detrimental effect at all soil nitrogen concentrations.

Fangmeier and Bender (2002)[7] analyzed mean grain yields of spring wheat derived from the ESPACE-Wheat project of the European Stress Physiology and Climate Experiment - Project 1, which was conducted for three growing seasons at eight experimental field sites across Europe that employed atmospheric CO_2 concentrations of 380, 540 and 680 ppm and O_3 concentrations of 32.5 and 60.3 ppb for half-day periods (Jager *et al*., 1999). They found that the high O_3 stress reduced wheat yields by an average of about 12% at the ambient CO_2 concentration. However, as the air's CO_2 concentration was increased to 540 and 680 ppm, there were no significant reductions in yield due to the high O_3 stress. Hence, whereas wheat yield in ambient-O_3 air increased by 34% over the entire CO_2 enrichment range investigated (380 to 680 ppm), it increased by 46% in the high-O_3 air, more than compensating for the O3-alone-induced yield losses.

Focusing on another pollutant, sulfur dioxide (SO_2), Agrawal and Deepak (2003)[8] grew two cultivars of wheat (Malviya 234 and HP1209) in open-top chambers maintained at atmospheric CO_2 concentrations of 350 and 600 ppm in air of normal or increased (to 60 ppb) SO_2 concentration, finding that fumigation with elevated SO_2 did not significantly impact rates of photosynthesis in either cultivar. However, they determined that the extra SO_2 decreased plant water use efficiency by 16% and reduced leaf protein levels by 13%; but when the air was

[5] http://www.co2science.org/articles/V4/N23/B1.php
[6] http://www.co2science.org/articles/V5/N13/B1.php
[7] http://www.co2science.org/articles/V6/N37/B2.php
[8] http://www.co2science.org/articles/V6/N4/B1.php

simultaneously enriched with CO_2, plant water use efficiency rose by twice as much (32%) as it had previously fallen, while leaf protein levels dropped by only 3% in HP1209 and actually *increased* by 4% in M234.

One year later, and returning back to ozone, Cardoso-Vilhena *et al*. (2004)[9] grew individual spring wheat (cv. Hanno) plants in 3-dm^3 pots in controlled environment chambers for 77 days at atmospheric CO_2 concentrations of either 350 or 700 ppm and at ozone concentrations of either less than 5 or 75 ppb, while gas exchange measurements of leaves 4 and 7 on the plants' main shoots were made at regular intervals throughout the study, after which the plants were harvested and their total dry weights determined. In parallel with the gas exchange measurements, Rubisco activity and chlorophyll fluorescence were also assessed throughout the experiment. And what did their work reveal?

In air of less than 5 ppb O_3, the doubling of the air's CO_2 concentration increased total plant dry weight by 66%; while in air of 75 ppb O_3, it increased total plant dry weight by 189%. Over the lifespans of leaves 4 and 7, elevated CO_2 also reduced cumulative O_3 uptake by 10 and 35%, respectively, due to the decrease it caused in leaf stomatal conductance, while it protected against the decline in apparent quantum yield of CO_2 assimilation caused by high O_3 in the ambient CO_2 treatment. In addition, elevated CO_2 protected against the reduction in the maximum in vivo rate of Rubisco carboxylation induced by high O_3 in both leaves 4 and 7.

In light of such findings, Cardoso-Vilhena *et al*. concluded their data "revealed that rising atmospheric CO_2 concentrations are likely to afford protection against the adverse effects of O_3 on plant growth and photosynthesis, with the effect due, at least in part, to the decline in stomatal conductance triggered by increases in atmospheric CO_2." In addition, they report that their study "suggested that rising atmospheric CO_2 concentrations may also enhance the tolerance of leaf tissue to O_3-induced oxidative stress," and that "this finding is consistent with reported shifts in the antioxidant status of leaves under the combined influence of elevated CO_2 + O_3 (Rao *et al*., 1995)."

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Working at the Oak Park Research Center at Carlow, Ireland, Donnelly *et al*. (2005)[10] grew well-watered and fertilized wheat plants from seed to maturity in pots recessed into the ground out-

[9] http://www.co2science.org/articles/V7/N25/B2.php
[10] http://www.co2science.org/articles/V10/N29/B2.php

of-doors in open-top chambers in ambient air and air to which 90 ppb ozone was added at two different atmospheric CO_2 concentrations: ambient (366 ppm) and elevated (681 ppm). They report that "elevated O_3 caused an overall reduction in both grain yield and the 1000-grain weight," but that "elevated CO_2 produced an overall increase in grain yield, 1000-grain weight, number of ears and number of grains." In air of ambient O_3 and CO_2, for example, the grain yield of wheat was 2770 g/m^2; but in the presence of the extra 90 ppb of ozone, the grain yield was cut to 1587 g/m^2, or only 57% of what is was in ambient air. However, when the air's CO_2 concentration was simultaneously increased (along with the O_3 concentration), the grain yield of the wheat was raised to 2984 g/m^2, which actually more than compensated for the deleterious effects of the extra ozone, boosting the grain yield to 8% above what it was in ambient air, and to fully 88% more than what it was in the O_3-polluted ambient-CO_2 air.

Donnelly *et al*.'s study reveals that ozone pollution can dramatically reduce the grain yield of wheat, but that atmospheric CO_2 enrichment can just as dramatically reverse its adverse effects and actually lead to a modest increase in grain yield. Consequently, in the words of the researchers, "elevated CO_2 can be seen as protecting some yield components from the damaging effects of O_3," and that "the overall effect of increasing concentration of CO_2 will be positive for wheat production in Ireland."

In conclusion, when considering the several results described above, it would appear that enriching the air with CO_2 goes a long way, if not *all* the way, towards ameliorating a variety of negative influences of various types of air pollution (particularly ozone, which has been studied most extensively in this regard) on the well-being of wheat plants. Thus, wheat growers can anticipate greater yields in the future, due to this beneficial effect of the rising atmospheric CO_2 concentration.

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