HEAVY METAL SOIL TOXICITY IN A CO_2-ENRICHED WORLD

Are plants at greater risk or better protected from the dangers of soil toxicity?

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Noting that copper (Cu) is "an essential micronutrient [that] plays a vital role in maintaining normal metabolism in higher plants," but that it "is toxic to plant cells at higher concentrations and causes the inhibition of plant growth or even death," Jia *et al*. (2007)[1] grew a Japonica rice cultivar in control and Cu-contaminated soil for one full season at ambient and elevated atmospheric CO_2 concentrations (370 vs. 570 ppm), while measuring leaf Cu concentrations at the tillering, jointing, heading and ripening stages of the crop.

At the *tillering* stage of the plants' progression, results indicated that leaf Cu concentrations in the plants growing in the Cu-contaminated soil of *both* CO_2 treatments were about 90% greater than those in the plants growing in the uncontaminated soil of both CO_2 treatments. By the time the plants had reached the *jointing* stage, however, the mean leaf Cu concentration in the plants growing in the Cu-contaminated soil in the *CO_2-enriched air* had dropped all the way down to the same level as that of the plants growing in uncontaminated soil in ambient air; and this equivalency was maintained throughout the plants' subsequent *heading* and *ripening* stages. For the plants growing in contaminated soil in *ambient air*, however, leaf Cu concentrations were still 50% greater than those of the plants growing in contaminated soil in CO_2-enriched air at the end of the experiment.

Thus, the negative effect of a *more-than-five-fold increase* in soil Cu concentration, which increased *leaf* Cu concentration by approximately 90% at the crop tillering stage, was *completely ameliorated* throughout the rest of the crop's development by a mere 54% increase in the atmosphere's CO_2 concentration.

The negative effect of a *more-than-five-fold increase* in soil Cu concentration, which increased *leaf* Cu concentration by approximately 90% at the crop tillering stage, was *completely ameliorated* throughout the rest of the crop's development by a mere 54% increase in the atmosphere's CO_2 concentration.

Noting that "mining and smelting, disposal of sewage sludge and use of cadmium (Cd) rich phosphate fertilizers have contaminated large areas throughout the world, causing an increase in the Cd content of the soil (Liu *et al*., 2007)," which they indicate is an unfortunate development because "cadmium is a non-essential element that negatively affects plant growth and development processes, such as respiration and photosynthesis (Vega *et al*., 2006), water and mineral uptake (Singh and Tewari, 2003), cell division (Fojtova *et al*., 2002) and cellular redox homoeostasis (Romero-Puertas *et al*., 2004),"

[1] http://www.co2science.org/articles/V11/N8/B3.php.

Jia *et al*. (2011a)[2] set out to investigate the interactive effects of Cd contamination with atmospheric CO_2 enrichment on a perennial ryegrass (*Lolium perenne*). More specifically, they grew *L. perenne* from seed hydroponically in half-strength Hoagland solution for 3 days, which was followed by growth in full-strength Hoagland solution for 5 and 20 days and at a range of Cd concentrations ranging from 0 to 160 µmol/liter, while the five researchers monitored plant growth and development. And what did they learn?

The scientists report that regardless of Cd treatment, they found that "the Cd concentration was much lower under elevated CO_2 than under ambient CO_2," most likely due to the "fast growth triggered by elevated CO_2," such that in their experiment "the dry biomass increased by 81.2% for shoots and 55.2% for roots under non-Cd stress, and an average of 99.1% for shoots and 68.5% for roots under Cd stress, respectively." As a result of such findings the five Chinese scientists conclude that "under elevated CO_2, *L. perenne* may be better protected against Cd stress with higher biomass, lower Cd concentration and better detoxification by phytochelatins." In addition, they state that "lower Cd concentration in plants under elevated CO_2 may relieve the Cd toxicity to plants and reduce the risk of Cd transport in the food chain."

> *Total Cd uptake per pot, calculated on the basis of biomass, was significantly greater under elevated levels of CO_2 than under ambient CO_2, increasing by 42-73% in plant shoots. Yet at the same time, there was a reduction of Cd concentration within the plants' tissues at elevated CO_2.*

Similar results were obtained in a contemporaneous study by Jia *et al*. (2011b)[3], who hydroponically grew two important forage crops (*Lolium perenne* and *Lolium multiflorum*) at three different Cd (0, 4 and 16 mg/L) and two different atmospheric CO_2 (360 or 1000 ppm) concentrations in individual pots in controlled environment chambers for three weeks. Their results indicated that "root morphological parameters, including root length, surface area, volume, tip number, and fine roots, all decreased under Cd exposure," while "by contrast, elevated levels of CO_2 significantly increased all those parameters in the presence of Cd, compared to the CO_2 control, suggesting that elevated levels of CO_2 had an ameliorating effect on Cd-induced stress." The extra 640 ppm of CO_2 also increased the shoot dry weight of *L. multiflorum* by 68%, 92% and 90% and that of *L. perenne* by 65%, 61% and 67% at low, medium and high (0, 4, and 16 mg/L) cadmium concentrations, while it increased the root dry weight of *L. multiflorum* by 65%, 54% and 50% and that of *L. perenne* by 47%, 67% and 10%, under the same respective set of conditions. In addition, the authors report that "total Cd uptake per pot, calculated on the basis of biomass, was significantly greater under elevated levels of CO_2 than under ambient CO_2," increasing by 42-73% in plant

2 http://www.co2science.org/articles/V15/N4/B3.php.
3 http://www.co2science.org/articles/V14/N22/B3.php.

shoots. Yet at the same time, they report there was a *reduction* of Cd *concentration* within the plants' tissues at elevated CO_2.

Based on such findings, the seven scientists noted that due to high Cd uptake under CO_2-enriched conditions, the two *Lolium* species show great potential for use in the phytoremediation of Cd contaminated soils in a CO_2-enriched world of the future. And at the same time, because of much greater biomass production, the Cd concentration reduction in their tissues suggests that the ongoing rise in the air's CO_2 content could well improve the *safety* of these forage crops in decades to come, much as was demonstrated by Guo *et al*. (2006), who according to Jia *et al*. (2011b), "reported decreased Cd accumulation in leaves, stems, roots and grains of rice at elevated CO_2," and by Zheng *et al*. (2008), who "showed that *Pteridium revolutum* and *Pteridium aquilinum* grown on Cu-contaminated soils accumulated less Cu in plant tissues at elevated levels of CO_2 than at ambient CO_2," and by Li *et al*. (2010), who working with rice also "found that elevated levels of CO_2 diluted grain Cd concentration."

In one final study, Tukaj *et al*. (2007)[4] report that cadmium has been demonstrated to cause "inhibition or inactivation of many enzymes, thereby disturbing the growth, respiration, or photosynthesis in plant cells and algae (Tukendorf and Baszynski, 1991; Sanita di Toppi and Gabbrielli, 1999; Prasad *et al*., 2001; Faller *et al*., 2005)." Against this backdrop, the group of four Polish scientists grew the unicellular green alga *Scenedesmus armatus* for periods of one, two and three days in batch cultures that contained a 93µM concentration of cadmium and were continuously bubbled with air of either 0.1% or 2% (v/v) CO_2 - equivalent to approximately 1,000 and 20,000 ppm CO_2, respectively - while making a number of measurements of algal properties and physiological processes. So what did the experiment reveal?

It showed that the density of the cultures grown for 3 days at 2% CO_2 "was markedly higher in comparison to cultures grown at 0.1% CO_2 concentration mainly due to the growth rate acceleration during the first day of culture." After 24 hours of cadmium exposure, for example, they found that "growth was inhibited to about 49% at 0.1% CO_2, whereas at 2% CO_2 only to about 74% of the controls." In addition, they report that "cadmium inhibited the rate of oxygen evolution (70% of control) of cells cultured at 0.1% CO_2 [but] had no effect on the rate of oxygen evolution of cells cultured at 2% CO_2."

Algae living in conditions of elevated CO_2 are better protected against cadmium than those at ordinary CO_2 level.

Based on these findings, the researchers say their results suggest that the protective mechanism(s) directed against cadmium was (were) "more efficient in algae cultured under elevated CO_2 than algae cultured under low level of CO_2." In further support of this suggestion, they also note that "the main detoxifying strategy of plants contaminated by heavy metals is the production of phytochelatins (PCs)," as described by Cobbett (2000); and in this regard they report that "cells grown at 2% CO_2 - after 24 hours of exposure - produced much more PCs than cells cultured at 0.1% CO_2." In fact, their data

[4] http://www.co2science.org/articles/V10/N40/B3.php.

indicate that the CO_2-induced phytochelatin enhancement of their study was *in excess of ten-fold*. Consequently, they conclude that "algae living in conditions of elevated CO_2 are better protected against cadmium than those at ordinary CO_2 level."

Taken together, the above results bode well indeed for the ability of plants in a CO_2-enriched world of the future to better deal with the problem of heavy metal soil toxicity.

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