THE EARTH

Carbon Emissions Reduce Nutrients

A 2014 study in the journal *Nature* offers the most direct evidence yet of a significant health threat associated with climate change: less-nutritious crops. Researchers led by Samuel Myers of the Harvard University School of Public Health looked at how rising levels of the greenhouse gas carbon dioxide will affect staple foods like wheat, maize and soy. They found that as CO_2 increases, the levels of vital minerals like zinc and iron will decline. Some 2 billion people around the world already suffer from zinc and iron deficiencies, resulting in a loss of 63 million life years annually. Elevated levels of CO_2 will make that malnutrition even worse.

Researchers grew crops at different test sites—some sites had CO_2 levels close to the levels we see today, while others had levels we're likely to reach by mid-century if the world keeps burning fossil fuels at an unsustainable rate. Elevated CO_2 levels affected different crops in different ways. Zinc, iron and protein concentrations in wheat grown at high-CO_2 sites fell by 9.3%, 5.1% and 6.3%. Field peas and soybeans also lost zinc and iron as CO_2 rose. Maize and sorghum plants showed less sensitivity to changing levels of CO_2.

Malnutrition will worsen if the staple crops that the world's poorest people depend on become less nutritious as CO_2 levels rise: one more reason to worry about climate change.

DIE OFF *Global warming could make crops less nutritious.*

ZINC, IRON AND PROTEIN CONCENTRATIONS IN WHEAT GROWN AT HIGH-CO_2 SITES FELL BY

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CO_2 Fertilization

Most plants use one of two mechanisms for photosynthesis, C3 or C4.[1] Doubling the concentration of CO_2, an input to photosynthesis, increases the yield of C3 plants by about thirty percent, with the exact amount varying with species, variety, and experiment. Some experimenters report no increase in yield of C4 plants with increasing concentration of CO_2, others find some but substantially less than with C3 plants.[2] Most crop plants are C3; the important exceptions are maize, sugarcane and sorghum.

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[1] A few plants, such as pineapple, use a third mechanism, Crassulacean acid metabolism, to deal with lack of water. Some use only CAV, others switch from CAV to C3 or C4 when water supply is adequate.

[2] "C4 plants like maize, sorghum or sugarcane are however, comparatively independent of changes in [CO2]. Their photosynthesis rate does increase similar to C3-plants toward today's [CO2] concentration, then, however, starts to quickly level out around 400 ppm" Jan F. Degener, "Atmospheric CO2 fertilization effects on biomass yields of 10 crops in northern Germany." But "Increases in seed yields of many C_3 crops range between 20% and 35%, [3] whereas increases for C_4 crops are only about 10% to 15%," Leon Hartwell Allen, Jr. and P. V. Vara Prasad "Crop Responses to Elevated Carbon Dioxide," in *Encyclopedia of Plant and Crop Science*.

Because increasing CO_2 concentration reduces the amount of air that a plant must pass through its leaves in order to get an adequate amount of carbon, it reduces loss of water. That effect applies to both C3 and C4 plants. Experiments on growing crops in water stressed environments show substantial increases in yield with increased CO_2 concentration for both C3 and C4 plants.[3]

CO_2 fertilization is a well-established effect from both enclosed and free air experiments, used for a long time to increase yield in greenhouses. Unlike other climate effects on agriculture it depends on only the first step in the causal chain, the increase in CO_2 concentration.

And Nutrition

The news story shown above is based on an article in *Nature,* Increasing CO_2 threatens human nutrition, which found that increasing CO_2 concentration from the ambient level, about 400 ppm when the research was done, to 546–586 ppm., reduced the concentration of zinc by 9.3% and of iron by 5.1% in wheat, with similar results for rice, field peas, soybeans and maize but not sorghum. For all except soybeans and sorghum they also found a reduction in the concentration of protein.

"Concentration" is not defined in the article but presumably means the ratio of the weight of the nutrient to the total weight of the crop.[4] The increase in yield is not reported in the article but can be found from other sources that used similar CO_2 increases. If the concentration of zinc declines by 9.3% and of iron by 5.1% while the amount of wheat produced per acre increases by 17%, as suggested by one source,[5] the amount of zinc produced per acre increases by about 8%, of iron by about 12%. For rice as well, but not for maize, nutrient concentration falls but nutrient yield rises.

That raises a question that the authors of the article do not consider: Is the constraint on nutrition how much food people want to eat or how much food is available, the size of the human stomach or the productivity of the fields? If people are sufficiently poor or food sufficiently expensive, we would expect an increase in yield to result in an increase in how much they eat. If they are sufficiently rich or food sufficiently cheap, we would expect it to produce a decrease in how much they plant. That suggests that nutrient concentration should be more relevant in richer countries, nutrient yield in poorer.

> The global distribution of the disease burden of IDA [iron deficiency anemia] is heavily concentrated in Africa and WHO region Southeast Asia-D (table 1). These regions bear 71% of the global mortality burden and 65% of the DALYs lost. By contrast, the DALYs lost to IDA in North America and Cuba amount to 1.4% of the global total.[6]

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[3] Elevated atmospheric [CO2] can dramatically increase wheat yields in semi-arid environments and buffer against heat waves, Fitzgerald et. al., Glob Chang Biol. 2016 Jun;22(6):2269-84.

[4] Another article by some of the same authors reported the ratio of nutrients to calories: "we believe the simplest approach is to model diets that are unchanged with respect to calories and composition."

[5] Jan F. Degener, "Atmospheric CO2 fertilization effects on biomass yields of 10 crops in northern Germany, used a concentration increase from 390 to 540, slightly less than the article's increase, and found a yield increase for wheat of 17%. Another article reported an increase in yield for rice with doubling of CO2 concentration as 44%, on the high end of estimates for wheat, which suggests at least 17% for the article's increase.
Sorghum is a C4 plant, so its yield may not increase with increased CO2. But its nutrient concentration does not change significantly with increased CO2, slightly lower for zinc, slightly higher for iron, in both cases with zero well within the uncertainty range.

[6] Iron deficiency: global prevalence and consequences, Rebecca J Stoltzfus, Food Nutr Bull. 2003 Dec;24(4 Suppl):S99-103.

> The percentage of the national population at risk for low zinc intake ranges from 1%–13% in countries of Europe and North America to 68%–95% in South and Southeast Asia, Africa, and the Eastern Mediterranean regions, …[7]

The quotes imply that iron and zinc deficiencies are a problem primarily in poor countries. The source of the second quote also gives calorie intake per capita by region; it ranges from 3546 in the U.S. and Canada down to 2351 in South Asia and 2203 in Sub-Saharan Africa. The less people eat, the more likely it is that amount of food available is an important constraint. Increasing CO_2 makes nutrition worse for some people, better for others; it would take more information than I have, probably more than exists, to know which group is larger.

All of this is for the world as it now is. Many who regard climate change as a serious threat to human welfare expect one of its effects to be a serious worsening of the food supply. If so, more people in the future will find their nutrition constrained by the availability of food, hence will be benefitted, not harmed, by changes that decrease nutrient concentration but increase nutrient yield.

Reducing the Problem

The article reports figures not only for crop species but for crop varieties. All the varieties of wheat tested had lower concentrations of zinc and iron with CO_2 fertilization, although the amount of the reduction varied substantially, but another source reported an increase in iron concentration in one variety.[8] Some varieties of rice reverse the effect for zinc and, in one case, for iron.

> Such differences between cultivars suggest a basis for breeding rice cultivars whose micronutrient levels are less vulnerable to increasing [CO_2]. Similar effects may occur in other crops, given that the statistical power of many of our other inter- cultivar tests was limited by sample size. We note, however, that such breeding programmes will not be a panacea for many reasons including the affordability of improved seeds and the numerous criteria used by farmers in making planting decisions that include taste, tradition, marketability, growing requirements and yield.[9]

The article does not discuss differences in yield among different varieties, but other sources do. As CO_2 concentration increases farmers can be expected to adjust their choice of varieties accordingly, shifting where practical to those with the highest yields under the new conditions. If nutrient concentration turns out to be an issue that consumers care about, they can be expected to take that into account as well. It follows that the results of articles like this should be taken as a

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[7] Kenneth H. Brown, Sara E. Wuehler, and Jan M. Peerson, "The importance of zinc in human nutrition and estimation of the global prevalence of zinc deficiency, *Food and Nutrition Bulletin*, vol. 22, no. 2 © 2001, The United Nations University.

[8] Rafael Martínez-Carrasco et. al., Action of elevated CO2 and high temperatures on the mineral chemical composition of two varieties of wheat , Agrochimica -Pisa- · September 2000. The variety, Rinconada, has a lower concentration of iron than Alcazar, the other variety tested, at both CO2 concentrations. Both varieties have higher concentrations of iron when grown at a temperature 4° higher, however.

[9] The information on varieties is Figure 2. Both it and the quote are on page 141 of Nature, vol. 5510, 5 June 2014. Additional information on variation in CO2 effect on yield and nutrients in varieties of beans and soybeans is found in Soares J et. al. Growth and Nutritional Responses of Bean and Soybean Genotypes to Elevated CO_2 in a Controlled Environment. *Plants (Basel)*. 2019;8(11):465. 2019 Oct 30.

lower bound on future nutrient and yield, since it ignores the effect of people adjusting the variables under their control to get the best possible results under changed conditions.

Throughout this chapter I have followed the article in using “nutrition” to refer to the specific nutrients discussed by the article. Increasing crop yield improves the most basic form of nutrition, availability of calories, for everyone. That fact, surely the most important consequence of CO_2 fertilization, is mentioned in neither the news story nor the article.