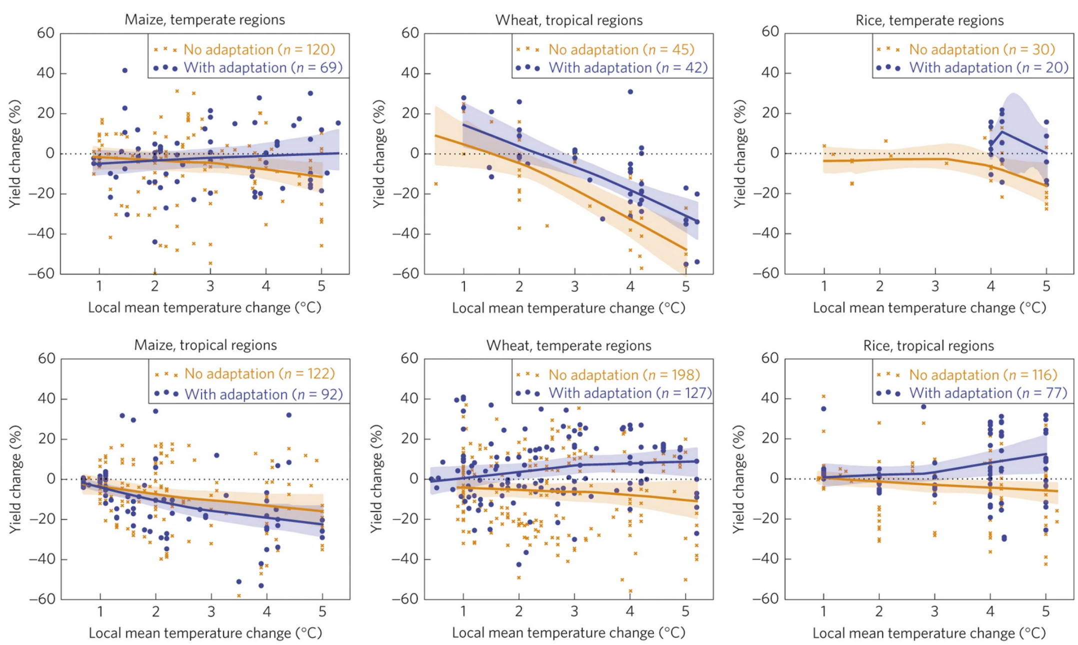
Climate Change and Food Supply

> "Overall, climate change could make it more difficult to grow crops, raise animals, and catch fish in the same ways and same places as we have done in the past." (EPA Page)

Estimates of the effect of climate change are sometimes calculated on the assumption that people affected by climate change make no attempt to adapt what they are doing to take account of it. For the slow change projected that is implausible, but sometimes it is all your data can tell you.

Suppose, for example, you want to know how crop yields change with temperature. You look at yields in a location where annual temperature averages thirteen degrees centigrade and observe that in years when it happened to be a little higher yield was a little less than average. It is tempting to use that information to calculate by how much yield falls for each degree of warming. That has the advantage, compared to the alternative of comparing yields in different places, that you are holding everything but temperature constant — the same farmers, the same soil, the same technology.

It also has the disadvantage that you are holding everything constant. If temperature averages thirteen degrees farmers will plant crop varieties suited to that temperature. By the time they know that this year happens to be warmer than average the seed is already in the ground and many of the decisions for the year have been made. If, on the other hand, temperature is rising at two or three tenths of a degree per decade, farmers will take account of the changed circumstances in their decisions, shift crop varieties, irrigate more or less, change what they are doing to adapt to the changed circumstances.[1] The result without adaptation ignores all that, hence overestimates the loss. It might even find a loss where there is actually a gain.



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[1] The problem was recognized in Lobell et. al. 2011: "Since our models are non-linear, both year-to-year variations in historical weather as well as the average climate are used for the identification of the coefficients (unlike a linear panel which only uses deviations from the average). However, we do not directly estimate the full set of adaptation possibilities that might occur in the long-term under climate change."

These graphs, from Challinor et. al. 2014, show the effect of temperature on yield for wheat, rice and maize in both temperate and tropical regions. Without adaptation yield falls with increased temperature in all cases. With adaptation it rises with temperature for wheat in temperate regions, where most wheat is grown, rice in tropical regions, where most rice is grown, and maize in temperate regions, where about 70% of maize is grown.

Why Global Temperature may not Matter for Global Crop Yield

Crop yields depend, among other things, on temperature, with an optimal average temperature for each crop — about 15°C for wheat, for example (Lobell 2012). If temperature goes up by a degree, yield in an area that used to be 15° and is now 16° goes down a little. That is one of the effects that goes into estimates of reduced yield as a result of climate change.[2]

But it shouldn't. The same warming that shifts 15° up to 16° also, somewhere a little farther north in the northern hemisphere or south in the southern, warms 14° to 15°, 13° to 14°, and so on. If wheat was being grown between, say, 13° and 17°, the area of cultivation can shift towards the pole by a distance that changes average temperature by one degree, roughly two degrees of latitude, and continue to have a temperature range of 13°-17° and the same temperature-related yield as before.[3]

I see two possible objections to this argument. The first is that the land a little closer to the pole may be less well suited to growing wheat in respects other than temperature, have worse soil, too much or too little water. That is possible but why should we expect it? Is there any reason why land that happens to have the ideal temperature for growing wheat is also more likely than other land to have the ideal soil or the ideal amount of rain? If not, then on average the shift is to land about as well suited in other ways and now ideally suited in temperature.[4]

The second objection is that shifting the area of cultivation is costly. Farms have irrigation systems and farm machinery suitable to growing what they are currently growing, are owned or managed by people experienced in doing so. You cannot just pick all that up and shift it a hundred miles further north.

How serious an issue this is depends on how fast the shift happens. Looking at maps showing average temperature, it seems to go down as you move towards the poles by about a degree every hundred miles, with a good deal of variation. At current rates of climate change, global temperature should be going up by about a degree every thirty years. So shifting the area of cultivation to keep the temperature at which wheat is being grown constant should require moving it by about three miles a year, with farms at the warm edge of the zone shifting to crops with a higher optimal temperature such as maize (18°) while farms at the cold edge are shifting from barley or vegetables to wheat.

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[2] See, for example, Zhao et. al. "Temperature increase reduces global yields of major crops in four independent estimates," PNAS August 15, 2017.

[3] I am oversimplifying in two respects. The closer land is to the pole, the more it warms — arctic temperatures go up by about three degrees for every degree increase in global temperatures. And the closer to the pole you are, the shorter the distance around the world at that latitude. Both effects mean that you lose slightly more land in a given temperature range than you gain, all else held constant.

[4] One commenter on my blog pointed out two other effects, working in opposite directions. The closer you are to the pole the less intense the sunlight, because it is coming in at a greater angle. On the other hand, the closer you are to the pole the longer the day in the summer, which is when it matters for crop growth. Since three hundred miles is only about one twentieth the distance from the equator to the pole, I would expect both effects to be small.

If that argument is correct, reduced yield with warming should not be included in the predictable effects of climate change on agriculture. That is one example of the problem of calculating effects of climate change on the implicit assumption that people make no attempt to take account of it in their decisions.

If there is substantial climate change we will not continue to "raise animals, and catch fish" — or grow wheat — "in the same ways and same places as we have done in the past." As I commented on the same problem decades ago in response to the book *Limits to Growth*, it is like trying to extrapolate the path of an automobile on the assumption that the driver has his eyes closed.

CO_2 Fertilization

Most plants use one of two mechanisms for photosynthesis, C3 or C4.[5] Doubling the concentration of CO_2, an input to photosynthesis, increases the yield of C3 plants by more than twenty percent,[6] with the exact increase 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. Most crop plants are C3; the important exceptions are maize, sugarcane and sorghum.

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.[7]

CO_2 fertilization is a well-established effect measured in both enclosed and free air experiments and used for a long time to increase yield in greenhouses. Unlike other predicted climate effects on agriculture it depends on only the first step in the causal chain, the increase in CO_2 concentration. It implies a large increase in crop yield — a fact frequently ignored in discussion of the effects of climate change.

And Nutrition

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

[6] "Yields of C3 grain crops were increased on average about 19%" by increasing CO2 from 353 ppm to 550. "to a first approximation growth responses by plants to elevated CO2 are generally linear between 300 and 900 ppm" which implies a 23% increase for a doubling. Kimball, Bruce A. (2016) Crop responses to elevated CO_2 and interactions with H_2O, N, and temperature, *Current Opinion in Plant Biology*, Vol. 31, pp. 36-43.

[7] 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.

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

9.3%, 5.1%, 6.3%

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.[8] The increase in yield due to the increased concentration is not reported in the article but can be found from other experiments 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,[9] the amount of zinc produced

[8] 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."

[9] 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. Other sources give lower increases. 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.

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.

Iron and zinc deficiencies are a problem primarily in poor countries.

> 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.[10]

> 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, …[11]

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 but it is pretty clear that the second group is poorer.

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.

That brings us back to the subject of adaptation. If CO2 fertilization reduces the amount of iron and zinc people get, they can adapt by consuming fortified foods, as many in the developed world already do, or taking supplements.

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

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

[11] 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.

variety.[12] Some varieties of rice reverse the effect for zinc, increasing concentration with CO_2 fertilization, and, in one case, for iron. As the article says:

> 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.[13]

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, shifting towards those with higher 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 lower bound on future nutrient and yield, again because they ignore adaptation.

I have been following the article in using "nutrition" to refer to the specific nutrients it discusses. Increasing crop yield improves the most fundamental 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.

Judging by a quick look at mineral supplements online, a year's RDA of either zinc or iron costs about ten dollars. A year's worth of calories costs considerably more than that.

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[12] 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.

[13] 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.

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