FOOD SECURITY

Fertilizing hidden hunger

Atmospheric CO_2 fertilization may go some way to compensating the negative impact of climatic changes on crop yields, but it comes at the expense of a deterioration of the current nutritional value of food.

Christoph Müller, Joshua Elliott and Anders Levermann

A healthy meal is a complex cocktail of macro- and micro-nutrients. Yet, when it comes to discussing diets, we typically consider calories to be the central drivers of hunger and obesity, disregarding other factors. The threat that climate change poses to agricultural productivity and food security around the world, especially in the tropics and sub-tropics, is also usually analysed only in terms of yields and calories[1]. The primary driver of anthropogenic climate change — the emission of CO_2 into the atmosphere — has long been known to stimulate photosynthesis and plant growth, an effect that has the potential to compensate much of the negative impact of climate change. This so-called CO_2 fertilization increases nitrogen use efficiency, reduces water use[2], and is especially relevant for stimulating photosynthesis in the large group of C_3-plants, which include important crops like wheat, rice and soy. A focus on calories, however, may be greatly misleading when judging whether the effects of CO_2 fertilization are beneficial for food security. In a Letter published in *Nature*, Myers *et al.*[3] present compelling evidence, based on a large meta-analysis of published studies, that CO_2 fertilization will have negative effects on the nutritional value of many key food crops by reducing the concentrations of essential minerals and protein. This could have serious implications for hunger and health in many parts of the world where the quality of food is just as important as its quantity.

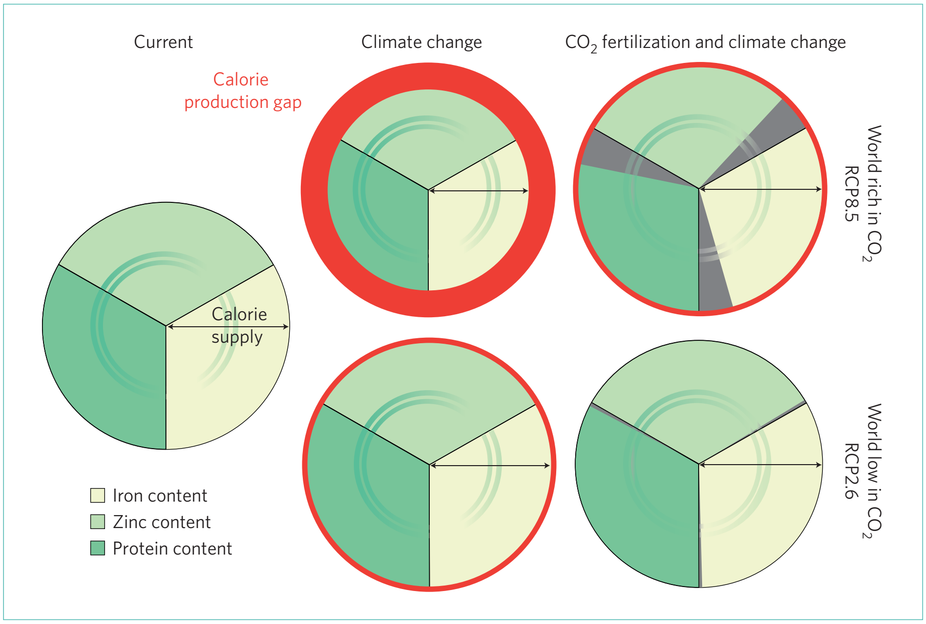

Figure 1 | Currently, the C_3-crops wheat, rice and soy provide almost 40% of the world's food calorie supply (left) as well as significant shares of iron, zinc and proteins (current levels represented as thirds of the plate area). Under climate change (middle), production quantities are projected to decline[1], especially in warm worlds rich in CO_2, leaving a calorie production gap (represented by the reduction in plate radius; red) to be filled by intensification, cropland expansion and trade[8]. Two potential CO_2 scenarios are considered: RCP8.5 (top right) and RCP2.6 (bottom right). CO_2 fertilization can reduce the negative climate change effects considerably so that they are comparable to climate change impacts in a cooler world low in CO_2 (bottom right). Assuming a linear decline of the minerals iron and zinc, as well as protein, with rising atmospheric CO_2 concentrations[3], production compensation leads to significant decreases in nutritional values (grey wedges). All data are based on median ISI-MIP projections for the end of the twenty-first century of EPIC, GEPIC, LPJ-GUESS, LPJmL, PEGASUS and pDSSAT[1].

Myers *et al.*[3] compiled data from free-air carbon dioxide enrichment (FACE) trials in which different crops and varieties were grown under ambient and elevated atmospheric CO_2 concentrations. Focusing on the edible part of the plants, they found that zinc and iron contents decrease significantly under CO_2 fertilization in all C_3-crops studied, whereas C_4-crops, like maize and sorghum, are less responsive. Protein content was also found to decrease in all C_3-crops that cannot fix additional nitrogen from the atmosphere. Concentrations of other micro-nutrients are affected as well, but the picture is more diverse and hints at complex interactions yet to be understood. Owing to the complexity of plant growth mechanisms and their dependence on environmental conditions and farm management practices, the extent to which CO_2 fertilization can help farmers to increase food production remains highly uncertain[4]. The altered chemical composition of food crops under elevated CO_2 can also affect food quantities, through hormone-controlled growth effects[5]. In addition, the increased feeding rates of herbivorous insects[6] may lead to greater crop damage. However, threats to the nutritional value of crops are perhaps the most worrisome and yet are typically neglected in assessments of future food security. This leads to the possibility that assessments that focus on food quantity could be comparing apples to oranges. In other words, even if CO_2 fertilization has the potential to compensate much of the negative climate change effects on agricultural yield, nutritional value may nevertheless be compromised. To illustrate this, we draw on global gridded crop model simulations from the large and open-access database of the Inter-Sectoral Impact Model Intercomparison Project (www.ISI-MIP.org; ref. 7). Using the simplest possible assumption of a linear decline in iron and zinc for the C_3-crops wheat, rice and soy, and also in the protein content of wheat and rice, increased atmospheric CO_2 leads to a substantially lower supply of all three nutrients compared with a world implementing strong climate change mitigation, even though food quantities are comparable if farmers are able to fully exploit the effects of CO_2 fertilization (Fig. 1).

As long as food commodities are priced by weight or volume and only rough categories are used to distinguish quality (for example, the use of protein content to determine baking quality in wheat), a decrease in essential minerals will go largely unnoticed by consumers and effectively increase the prices of nutrients essential to human nutrition. Hidden hunger, that is, the insufficient supply of vitamins and minerals like zinc or iron in diets with sufficient calorie content, currently affects about two billion people and the problem is amplified by food price volatility[9]. Both CO_2 fertilization and climate change — which is expected to increase food prices and volatility[8] — will presumably exacerbate hidden hunger and jeopardize one of the central millennium development goals, even in the long term. Myers *et al.*[3] present evidence that crop breeding could alleviate some of the negative effects of increased atmospheric CO_2, especially for rice, which shows relatively high variation in the CO_2–nutrient response among the different cultivars evaluated. Much work is already underway, through breeding or transgenic methods, to produce variants of staple crops with increased nutrient concentrations[10], but much more work is still needed to understand how these cultivars would perform under the very different conditions induced by high atmospheric CO_2 concentrations.

To improve our understanding of risks to food quality, two central challenges need to be tackled. First, CO_2 fertilization and its multiple, ambivalent effects on food security need to be better understood and represented in crop models. Myers *et al.*[3] provide evidence that reduced mineral contents are not only caused by dilution through increased carbohydrate production, thus highlighting the deficiency in our current understanding of the processes of plant response to enhanced CO_2. To improve this situation, crop modellers, breeders, physiologists and human health and nutrition researchers will need to work together to understand future climate-driven challenges in food security. The Agricultural Model Intercomparison and Improvement Project (www.AgMIP.org) and ISI-MIP could and should serve as platforms to facilitate this interaction. Second, we need to broaden the scope of modelling to elucidate hidden hunger. This requires moving from a quantities-only perspective to one that includes impacts on nutritional quality, which will involve a new look at non-staple crops — for which models have often never been developed — that may become increasingly important in a world of high-calorie, low-quality grains and legumes. ❐

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AGRICULTURAL IMPACTS

Europe's diminishing bread basket

Global demand for wheat is projected to increase significantly with continuing population growth. Currently, Europe reliably produces about 29% of global wheat supply. However, this might be under threat from climate change if adaptive measures are not taken now.

Holger Meinke

By the middle of the twenty-first century, it is probable that climate change will result in more frequent wheat crop failures accross Europe[1]. There are many reasons why the frequency and severity of crop failures might increase in the future, albeit with large regional differences. Some adaptive measures to minimize yield losses show more promise than others, yet none of them seem to be sufficient to fully avoid the problem.

Assessments of the potential impact of climate change on agriculture have flooded the scientific literature over the past decade. They range from detailed laboratory or field experiments[2,3] to global impact studies[4]. In the majority of cases, these analyses account for probable crop physiological responses to either temperature, rainfall or CO_2. These factors are generally evaluated progressively, rarely considering changes in the extremes of climatic variables (such as intensive rainfall events or heatwaves) or the combined effect of extreme events on crop physiology and crop management practice. Thus, most studies examine climate change impacts from a monocausal, crop physiological perspective. Yet, as every farmer knows, producing an economically viable yield requires the effective management of a multitude of potential perils, combined with a fair amount of skill and luck.

As they report in *Nature Climate Change*, Trnka and colleagues[1] take a refreshingly different approach to this problem. Not only do they avoid the common monocausal trap, they also resist the temptation to 'over-quantify' climate change impacts on wheat yields by, for instance, using highly parameterized production models. Instead, the authors only simulate the bare essentials — the probable changes in crop development (phenology) over the next 50 years from the present period (1981–2010) to the middle of the twenty-first century (2051–2070) — for 14 locations across Europe. These simulations provide the necessary input dates (sowing, anthesis and maturity) for a carefully designed, multi-peril risk assessment.

Trnka *et al.*[1] selected 14 case study locations across 13 countries covering the major wheat-producing regions of the