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# THE IMPACT OF RISING CARBON DIOXIDE LEVELS ON CROP NUTRIENTS AND HUMAN HEALTH

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Carbon dioxide ($CO_2$) levels are rising globally at a rapid pace, on track to surpass 550 parts per million (ppm) by midcentury. Studies have found that, when grown under elevated $CO_2$ concentrations of 546–586 ppm, many food crops—including wheat, rice, barley, and soybeans—have lowered concentrations of nutrients, including many that are important for overall health, such as iron, zinc, and protein. Elevated $CO_2$ also affects both the quantity and quality of forage, thereby affecting animal performance and production and, consequently, the availability of nutrients from animal-source foods, such as meat, milk, and eggs. This loss of dietary nutrients in foods could translate to increased nutritional deficiency for hundreds of millions of people already on the brink of deficiency—mainly developing countries in Asia, the Middle East, and North Africa based on dietary preferences for the commodities most affected. This policy note examines the link between rising $CO_2$ levels and declining nutritional content for a number of major crops, as well as forage. The discussion includes a comparison of the varying effects by crop, and strategies to address this challenge in the context of climate change.

## The Crucial Role of Nutrients for Health, and the Impact of Rising Carbon Dioxide Levels

In addition to calories, dietary macro- and micronutrients are essential to human life. The roles that nutrients play in our bodies are crucial, irreplaceable, and manifold, ranging from human growth and metabolism, neurodevelopment, bone health, hormone and enzyme production, reproductive health, cell creation, gene expression, immune functioning, oxygen delivery to muscles and organs, and many more. Many vital nutrients are usually delivered adequately through the diet, but others—including iron, zinc, vitamin A, and iodine—have become scarce for many populations identified as targets for global health intervention. Furthermore, persistent malnutrition of dietary energy and protein continues to lead to stunting, wasting, and low birth weight for poorer populations globally (Black et al. 2008). Despite advances in improving global nutritional status over the past several decades, progress has been uneven, with many developing regions seeing only modest improvement (such as India) or stagnating entirely (such as Africa south of the Sahara).

## Rising Carbon Dioxide Levels

$CO_2$ emissions from fossil-fuel combustion, industry, and land-use change continue to rise, with each year regularly exceeding the last to produce the highest yearly atmospheric $CO_2$ levels ever measured (Le Quéré et al. 2018). In 1960, some of the earliest direct measurements of atmospheric $CO_2$ from the Mauna Loa Observatory in Hawaii recorded a concentration of 317 parts per million (ppm) $CO_2$ (0.01 percent is equal to 100 ppm). In 2015, levels surpassed 400 ppm globally, and are now following an accelerating trajectory to reach 550 ppm by roughly 2050. Higher $CO_2$ levels and their climate impacts are predicted to cause disruptions to crop and livestock production in



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many dramatic and visible ways: extreme heat causing crop failure; warming and more acidic oceans, reducing the abundance and range of fish; and rising sea levels, inundating coastal wetlands used for rice farming and aquaculture. However, a more hidden, but no less serious effect, is the impact on plant nutrients.

In open-field experiments in Australia, Japan, and the United States, the major food crops wheat, rice, barley, maize, peas, soybeans, and sorghum were observed in free air $CO_2$ enhancement (FACE) experiments (Myers et al. 2014), which allow identical cultivars of the same crop to be grown inside and outside a ring of $CO_2$-emitting jets. In this way, crops are exposed to identical soil, weather, and biological conditions, but the crops grown inside the ring are exposed to elevated $CO_2$ concentrations (in this case, 546–586 ppm). When the crops were harvested and analyzed, it was found that those grown under elevated $CO_2$ levels had lower concentrations of important nutrients (iron, zinc, and protein), with declines of 3–17 percent compared with those grown nearby under regular $CO_2$ levels. This collection of 143 side-by-side comparisons was the largest-ever collection of data to have found this effect in high-quality open-field experiments.

## Varying Impacts by Crop

The effect was not the same across all nutrients and crops. The most consistent results were among the major grain crops wheat, rice, and barley, for which declines were significant across all important nutrients: iron, zinc, and protein. Results were more mixed for other crops. Zinc and iron content also declined in peas and soybeans, but these crops experienced little or no loss of protein. This might be because they can harvest nitrogen directly from the air, which they then convert to protein, regardless of $CO_2$ levels. Other grain crops must absorb nitrogen from the soil through their roots, as they do for iron and zinc, which is controlled to some degree by plant evapotranspiration and $CO_2$. Maize and sorghum showed less or no response across these nutrients when grown under higher $CO_2$ levels. Although seemingly strange, this is explained by the ways in which these and other biologically similar crops (for example, sugarcane and millet) perform photosynthesis differently (called $C_4$ photosynthesis). $C_4$ crops keep an artificially high internal $CO_2$ concentration during photosynthesis, even under regular conditions, so the addition of more $CO_2$ does little to affect their uptake of nutrients. As a result, these crops are more immune to the negative impacts of higher $CO_2$ on nutrient levels.

## Grazing Livestock Potentially Also Affected

Forage quantity and quality are also affected by elevated $CO_2$ concentrations. In some situations, increased temperatures and $CO_2$ concentrations may increase herbaceous growth and favor legumes more than grasses in mixed pastures. These effects may be modified by a range of factors, however, including changes in rainfall patterns, plant competition, perennial growth habits, and plant–animal interactions, for example. The cumulative impact of these factors on forage quality and quantity is not easy to predict. Current research is helping to untangle these complex relationships. Recently, for example, large and persistent declines in forage quality have been found under elevated $CO_2$ conditions in North American grasslands (Augustine et al. 2018).

$CO_2$ effects may thus translate into changes in the amount, type, and quality of forage available to grazing animals, which in turn may result in greater nutritional stress for animals, as well as reduced growth rates, reproductive performance, and production. These effects may result in changes in the nutrients available from animal-source foods, particularly in resource-poor rural farming households in low- and middle-income countries. The $CO_2$-related forage effects can be addressed through a range of options, such as modifying animal stocking rates or planting different forage species to enhance forage quality, or via dietary diversification, for example. Very little information is available as to whether elevated $CO_2$ has more direct effects on animal physiology, including interactions with heat stress that may affect the nutrient composition of animal-source foods. Any effects that may exist are likely to be small, however.

## Rising Nutrient Deficiency Based on Dietary Composition

On average, people around the world receive most of their nutrition from plants, including 63 percent of total dietary protein, 68 percent of zinc, and 81 percent of iron (Smith 2016). Because so much of the world's population gets its nutrition from plants, and because plants are uniquely affected by higher $CO_2$ concentrations—without significant measures to counteract nutrient leaching—it is likely that significant numbers of people will consume less protein, iron, and zinc from crops in 2050. Also, because any reduction in these nutrients would not necessarily be immediately noticeable, unlike a loss of calories, which is felt as perceptible hunger, people are less likely to adapt without direct intervention. The clearest health implication would be a rise in nutritional deficiencies. As of 2015, iron and zinc deficiencies together accounted for 5.7 percent of all life-years lost to death and disability. Protein deficiency is not typically measured on its own, but combined protein-calorie deficiency contributes an additional 1.7 percent of total life-years lost. Over time, these values have improved consistently with declining overall malnutrition, but nutritional deficiencies are an ongoing threat to public health globally, which rising $CO_2$ may worsen.

To identify the potential size of the effect of $CO_2$ levels on future nutritional deficiencies, recent studies estimated the size of the population newly at risk of deficiency under 550 ppm $CO_2$ by comparing national diets with nutritional needs, and assessing how the nutrient content of each major food responded to $CO_2$ levels (Myers et al. 2015; Medek, Schwartz, and Myers 2017; and Smith, Golden, and Myers 2017). Results indicated that, in 2050, the number of people at risk of becoming zinc deficient could increase by 138 million globally, and the number at risk of becoming protein deficient could increase by 148 million globally. Iron deficiency could not be predicted in the same way because the link between diet and deficiency is poor. Nevertheless, it was estimated that roughly 1.4 billion women and children—those most vulnerable to the adverse effects of iron deficiency—live in countries at highest risk of increased iron deficiency due to rising $CO_2$ levels. Even worse, these increases are in addition to the roughly two billion people already deficient in one or more of these nutrients, whose deficiencies could become more severe without intervention. It should be noted that the downstream effects of forage quality and quantity on animal-source foods have not yet been fully estimated, increasing the likely underestimation of the potential nutritional and health consequences.

It is clear that, because crops respond differently to increasing $CO_2$ levels, populations around the world will be affected unequally. Higher-income countries with high intakes of animal-source foods may be more insulated from these health impacts, although it is possible that the effects of forage on animal-source food availability and quality may ultimately affect nutritional status in these countries as well. Low- and middle-income countries that consume less-affected crops, such as maize, sorghum, and millet, have lower vulnerability than those with wheat- or rice-dominant diets. This means that many maize-eating countries in Central and South America, as well as major swaths of Africa south of the Sahara, where a combination of both affected and unaffected grains is consumed, could be less affected by increased $CO_2$ levels. Note, however, that maize is threatened from increased aflatoxin levels under climate change, as described in another recent GCAN policy note (Brown 2018).

Overall, the most susceptible regions would be those with large populations on the brink of nutritional deficiencies who are also high consumers of wheat and rice: India and South Asia, Southeast Asia, China, and the Middle East and North Africa. India alone constitutes some of the highest burden under higher $CO_2$ levels with an estimated 53 million people newly protein-deficient and 48 million people newly zinc-deficient. These countries are not necessarily destined to see growth in nutritional deficiencies as $CO_2$ rises, however. Changes in diets or nutritional status between now and 2050 could act either to protect them from or further exacerbate the impacts on health, depending on other factors that control the composition of diets: income levels, dietary preferences, and growing access to a wider range of foods. Importantly, the regions most at risk from nutritional deficiencies due to increased $CO_2$ levels would be best served by heightened monitoring of both public health and crop nutrition.

## Strategies to Address this Challenge

Countries have many ways to act to protect themselves now. For some crops, breeding programs could choose cultivars based on reduced $CO_2$ sensitivity alongside other typically beneficial characteristics, such as high yields, heat tolerance, and drought and pest resistance. Many international organizations, in particular the CGIAR, are actively working to create crop breeds with higher overall micronutrient contents, which would also work to offset these declines in nutrient density if adopted in the regions that need them.

Other techniques directly tackle the issue of nutritional deficiency. One way would be for countries to adopt or expand flour fortification policies, which mandate adding certain amounts of necessary nutrients to grain flours. Another path is increased nutritional monitoring, along with the promotion of carefully conceived supplementation plans to provide targeted nutrients to those most in need. Finally, the most direct and clear path to reduce the nutritional impact of higher $CO_2$ levels is to redouble efforts to curb $CO_2$ emissions and lower the emissions trajectory.

## Moving Forward

Despite the work undertaken so far, many pieces of this story remain uncertain. The trajectory of future global $CO_2$ emissions, changes in dietary habits, and the response of global food systems to climate change remain largely unknown in any forecasts of the global health costs of rising $CO_2$ levels on crop nutrition. Each of these systems is complex, difficult to predict, and interdependent, which makes any effort to increase their precision challenging.

Nevertheless, many avenues of research could shed light on this issue and begin the process of crafting ways to avoid some of the worst effects. Additional FACE experiments to examine a wider range of crops and forages could fill gaps around the variable impact of nutrient leaching on plants. Increased direct monitoring of both food intake and micronutrient status, globally, would help to improve targeting of any future interventions to the most vulnerable populations. Finally, donors may strengthen investments toward breeding programs that focus on cultivating beneficial characteristics, such as resistance to $CO_2$-related leaching and higher micronutrient content, to provide dietary remedies to this effect.

## References

Augustine, D., D. Blumenthal, T. Springer, D. LeCain, S. Gunter, and J. Derner. 2018. "Elevated $CO_2$ Induces Substantial and Persistent Declines in Forage Quality Irrespective of Warming in Mixedgrass Prairie." *Ecological Applications* 28 (3): 721–735.

Black, R., L. Allen, Z. Bhutta, L. Caulfield, M. de Onis, and M. Ezzati. 2008. "Maternal and Child Undernutrition: Global and Regional Exposures and Health Consequences." *Lancet* 371: 243–260. doi: 10.1016/S0140-6736(07)61690-0.

Brown, L. 2018. *Aflatoxins in Food and Feed: Impacts, Risks, and Management Strategies*. GCAN Policy Note 9. Washington, DC: International Food Policy Research Institute.

Le Quéré, C., R. Andrew, P. Friedlingstein, S. Sitch, J. Pongratz, A. Manning, et al. 2018. "Global Carbon Budget 2017." *Earth System Science Data* 10: 405–448. doi: 10.5194/essd-10-405-2018.

Medek, D., J. Schwartz, and S. Myers. 2017. "Estimated Effects of Future Atmospheric $CO_2$ Concentrations on Protein Intake and the Risk of Protein Deficiency by Country and Region." *Environmental Health Perspectives* 125 (8): 087002. doi: 10.1289/EHP41.

Myers, S., K. Wessells, I. Kloog, A. Zanobetti, and J. Schwartz. 2015. "Effect of Increased Concentrations of Atmospheric Carbon Dioxide on the Global Threat of Zinc Deficiency: A Modeling Study." *Lancet Global Health* 3 (10): e639–e645.

Myers, S., A. Zanobetti, I. Kloog, P. Huybers, A. Leakey, A. Bloom, E. Carlisle, et al. 2014. "Increasing $CO_2$ Threatens Human Nutrition." *Nature* 510: 139¬142. doi: 10.1038/nature13179.

Smith, M. 2016. "Nutrient Supplies by Food and Country (2011)." Harvard Dataverse, v3. https://doi.org/10.7910/DVN/UZW5S3.

Smith, M., C. Golden, and S. Myers. 2017. "Anthropogenic Carbon Dioxide Emissions May Increase the Risk of Global Iron Deficiency." *GeoHealth* 1 (6): 248–257. doi: 10.1002/2016GH000018.

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