Assessing the Impacts of Climate Change on Global Nutrient Availability

Robert H. Beach, RTI International

Abstract

Climate change is affecting the agricultural sector through multiple pathways, influencing productivity as well as nutrient content of food crops. In this study, we explore the combined implications of both effects on global nutrient availability. Adjustments to productivity differ across crop-region combinations, altering the relative profitability of the production of different commodities across regions and resulting in shifts in which commodities are produced where. The changes in regional and global production and market prices lead consumers to alter their food consumption patterns. Changes in nutrient content due to elevated carbon dioxide levels are accounted for through post-processing adjustments to the consumption baskets consumed under each scenario. We focus on iron, zinc, and protein due to the substantial global impacts of deficiencies in those nutrients. While per capita availability of these nutrients is projected to increase through mid-century under all scenarios, we find that climate change is likely to slow global progress towards nutrition targets identified in the sustainable development goals.

Introduction

Global climate change has already been affecting agricultural production and is projected to have considerably larger impacts in the future. There have been several studies exploring potential implications for food security, but these assessments tend to focus only on changes in production of major grains and oilseeds due to productivity shocks. There has been growing interest in moving beyond a focus on the implications of climate change for agricultural production to an examination of the effects on health and nutrition as well. In addition, there have been several studies providing evidence that increasing concentrations of atmospheric CO2 results in crops that contain a higher proportion of carbon in their tissues and a reduced proportion of certain key macro- and micronutrients (e.g., Myers et al., 2014; Taub, Miller, and Allen, 2008; Loladze, 2014). This change in plant tissue composition would tend to make foods less nutritious and further contributes to the concerns surrounding nutrition and health effects under future climate projections (Beach et al., 2019). A shift towards less nutritious food also potentially contributes to the global double burden of malnutrition, which includes both undernutrition and obesity.

In this study, we incorporate both impacts on crop productivity as well as effects of elevated atmospheric carbon dioxide (CO_2) concentrations on nutrient content to explore the implications of alternative future climate scenarios for nutrient availability. We incorporate climate scenarios consistent with the IPCC Fifth Assessment Report (AR5) representative concentration pathways (RCPs) as implemented in multiple global circulation models (GCMs) such as the MIROC, GFDL, and HADGEM models, using a set of RCP-GCM combinations that provides a range of possible climate futures.

Background

In order to model the economic responses to changes in agricultural productivity, we incorporate changes in yields by crop and region relative to baseline projections. These adjustments differ across crop-region combinations, resulting in changes in the relative profitability of individual crop production across regions. This results in adjustments in which commodities are produced in which parts of the world and impacts on regional and global production, consumption, and prices. As a result, consumers alter their consumption baskets in response to changing prices. In addition to changes in the quantities of different food commodities that are consumed, these foods are expected to experience changes in nutrient content due to elevated CO_2 levels. We account for these effects through post-processing adjustments consistent with the Loladze (2014) and Myers et al. (2014) estimates to calculate changes in nutrient content per kg for different food commodities. We also make use of data from the GENuS dataset at Harvard to disaggregate the sources of key nutrients consistent with baseline diets across different regions of the world.

We focus on iron, zinc, and protein for this assessment due to the substantial global impacts of deficiencies in those nutrients. Iron and zinc are available from many different types of commodities, including both livestock and crop products. However, the bioavailability of these nutrients varies across regions based on the allocation of nutrient sources in the diet. Thus, we make use of estimated recommended nutrient intake (RNI) data provided by Matthew Smith to approximate the daily requirements for nutrient intake across different regions of the world and assess availability relative to those RNIs.

Methods

The model used for this analysis is the Applied Dynamic Analysis of the Global Economy (ADAGE) model, a recursive dynamic, multi-region, and multi-sector CGE model. ADAGE follows the classical Arrow-Debreu general equilibrium framework covering all aspects of the economy, including production, consumption, trade, and investment. Households can distinguish between domestic or imported consumption goods, including personal and purchased transportation services. Producers maximize profits subject to technology constraints in a nested constant elasticity of substitution (CES) structure. The dynamics in ADAGE are represented by: (i) growth in the available effective labor supply from population growth and changes in labor productivity, (ii) capital accumulation through savings and investment, (iii) changes in stocks of natural resources, and (iv) technological change from improvements in manufacturing, energy efficiency and land productivity. ADAGE is simulated for the period 2010-2050 with a five-year time step.

The key underlying database used in ADAGE is the Global Trade Analysis Project (GTAP) database version 7.1 (Narayanan and Walmsley, Ed., 2008), which was updated from 2004 to the baseline year 2010 using secondary data from World Energy Outlook (WEO, 2010) and International Energy Outlook (IEO 2010) and Food and Agricultural Organization. The model has rich details in energy and electricity generation, agriculture, biofuel, and land. ADAGE also has full GHG accounting where baseline data for GHGs (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulfur hexafluoride, SF_6) are from U.S. EPA historical inventory data and projections. ADAGE has been undergoing continuous enhancement since 2009 and has been applied for various economic, energy, and environmental policies analyses, including renewable fuel policy analysis, evaluation of climate change impacts, and food, energy and climate mitigation analysis.

We improve upon past accounting for food quality (in terms of caloric and nutrient content of alternative food commodities) and generate several measures of food security, including measures of average dietary energy supply adequacy; total value of food production; regional availability of iron, zinc, and protein per capita; cereal import dependency ratio; and other measures of food security.

Results and Discussion

Our findings suggest that climate change is likely to have important effects on nutrient availability as global climate impacts affect the relative competitiveness of agricultural production across regions of the globe and lead to shifting production patterns over time. This leads to changes in the mix of food commodities consumed and tends to reduce global availability of iron, zinc, and protein over time relative to a no climate change scenario. The effects of elevated atmospheric CO_2 levels tend to have an even larger effect on nutrient availability than climate change through mid-century. Our primary GCM scenarios include CO_2 fertilization, which offsets much of the negative impact of climate change on yields in our primary climate scenarios. Scenarios assuming no CO_2 fertilization suggest considerably more negative effects on nutrient availability, with yields declining for all major crops globally and contributing to reductions in iron and zinc availability of around 5-10%.

Conclusions

This study provides important insights into the potential combined effects of climate change on nutrient availability through both effects on crop productivity and nutrient content per kg of output. This information is important for considering appropriate mitigation and adaptation policies to reduce negative impacts on nutrient availability and associated effects on health outcomes. We find one of the key effects of climate change is likely to be a reduction in global progress towards nutrition targets identified by the sustainable development goals and other major global efforts.

References

Beach, R.H., T.B. Sulser, A. Crimmins, N. Cenacchi, J. Cole, N.K. Fukagawa, D. Mason-D'Croz, S. Myers, M.C. Sarofim, M. Smith, and L.H. Ziska. (2019). Combining the effects of increased atmospheric carbon dioxide on protein, iron, and zinc availability and projected climate change on global diets: a modelling study. *The Lancet Planetary Health* 3(7):e307-e317. https://doi.org/10.1016/S2542-5196(19)30094-4.

Loladze, I. (2014). Hidden shift of the ionome of plants exposed to elevated CO2 depletes minerals at the base of human nutrition. *eLife* 3:e03356. doi:10.7554/eLife.02245

Myers, S.S., et al. (2014). Increasing CO2 threatens human nutrition. *Nature* 510:139-142. doi:10.1038/nature13179

Taub, D.R., B. Miller, and H. Allen. (2008). Effects of elevated CO2 on the protein concentration of food crops: A meta-analysis. *Global Change Biology* 14: 565-575. doi:10.1111/j.1365-2486.2007.01511.x