ADVANCING GLOBAL FOOD SECURITY

IN THE FACE OF A CHANGING CLIMATE

Douglas Bereuter and Dan Glickman, cochairs
Gerald C. Nelson, principal author

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Advancing Global Food Security in the Face of a Changing Climate
The Chicago Council on Global Affairs

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May 2014

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Foreword

In the decades to come, our global food system will face unprecedented strains. On the one hand, demand for sustainable and nutritional food production will continue to increase as the world's population grows through midcentury and rapid economic development stimulates the rise of an ever-growing global middle class. On the other hand, climate change will produce higher temperatures, changes in rainfall patterns, and more frequent natural disasters that, if unaddressed, will reduce the growth in global food production by an estimated 2 percent per decade for the rest of this century.

Since 2009 the US government has taken steps to confront the first of these challenges through agricultural development. For the first time since the Green Revolution, empowering the world's poorest to improve their livelihoods is a high priority on the international agenda. But climate change puts the success of these efforts at risk.

Food systems in developing countries, many of which are located in tropical and low-lying coastal areas, will be hardest hit. These countries also lack the resources to adapt effectively to the multiple challenges climate change poses to food production. This report puts forward recommendations for how the US government can integrate climate change adaptation and mitigation into its global food security strategy. It presents evidence and analysis on how climate change could affect the global food system and puts forward strong arguments for urgent action. It builds on the 2013 Chicago Council report *Advancing Global Food Security: The Power of Science, Trade, and Business,* which laid out a broad strategy to prioritize science, increase trade flows for agriculture and food, and provide greater incentives for businesses to invest in low-income countries. The recommendations put forward in this report were developed by the project's cochairs—Dan Glickman and Doug Bereuter—through consultations with the principal author, the project's advisory group, and numerous subject-matter experts from government, business, civil society, and academia.

I would like to thank the advisory group cochairs for their skillful and dedicated leadership throughout this study's demanding process. The issues surrounding climate change and agricultural development are complex and require the expertise of individuals from a wide array of disciplines and backgrounds. It speaks to the stature, insight, and energy of Mr. Bereuter and Mr. Glickman that the study was able to assemble a diverse group with wide-ranging expertise and incorporate these perspectives into a thorough, well-founded report. I would also like to thank the other members of the advisory group. Each had distinct experiences and views on the issues considered, yet worked together effectively to achieve consensus on the report's recommendations.

I am very grateful to Jerry Nelson, who served as the principal author of this report. Dr. Nelson is a widely published and respected expert in food security and climate change. Dr. Nelson framed the study's agenda, led the research process, and skillfully wrote the findings and recommendations.

Finally, The Chicago Council would like to express its deep appreciation and thanks to The Bill & Melinda Gates Foundation and PepsiCo for the generous support that made this report possible.

Ivo H. Daalder
President
The Chicago Council on Global Affairs

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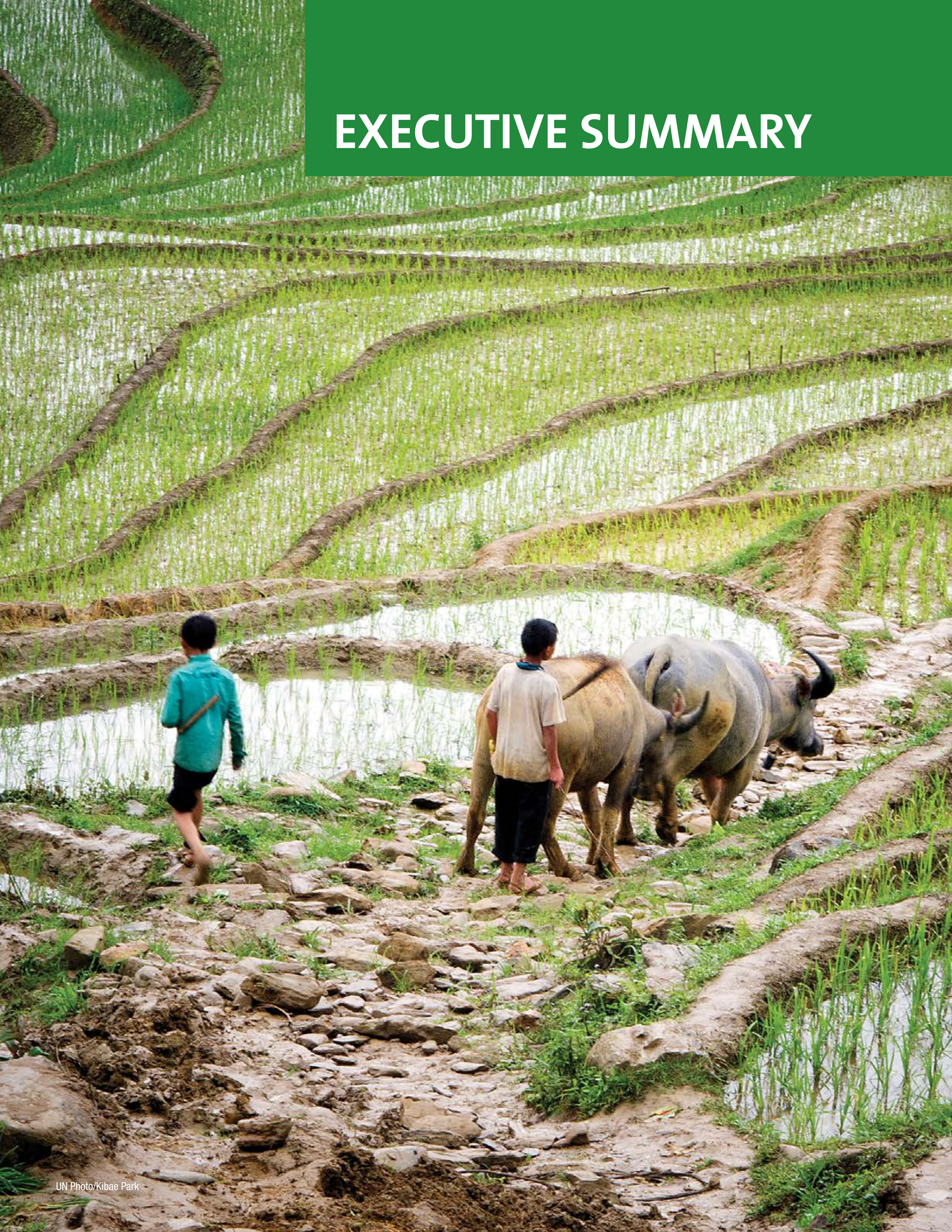
The Council would also like to thank the individuals who met with the research team: Ernie Shea and Fred Yoder from the 25x'25 Alliance; Joanna Syroka from African Risk Capacity; Stanley Wood from The Bill & Melinda Gates Foundation; Anthony Janetos from Boston University; Gregory Jaffe from the Center for Science in the Public Interest; Roger Thurow from The Chicago Council on Global Affairs; Pedro Sanchez from Columbia University; Jennifer Goldston from DuPont Pioneer; Sarah Gamino from the Economic Security Center; Steven Hamburg and Joe Rudek from the Environmental Defense Fund; Sarah Bittleman from the Environmental Protection Agency; Stephen Zebiak from the International Research Institute for Climate and Society; Edwin Chan-Lizardo from KickStart International; Jerry Hjelle and Jerry Steiner from Monsanto; Chris-Carolin Schön from Munich Technical University; Richard Engel from the National Intelligence Council; Christine Blackburn from the National Oceanic and Atmospheric Administration; Charles Liarakos, Joann Roskoski, and John Wingfield from the National Science Foundation; Joyce Coffee from the Notre Dame Global Adaptation Index; Nick Daniels from One Acre Fund; Fabian Laurier from the Office of Science and Technology Policy; Islam Siddiqui; Mary Louise Carlson, Sara Lopez, and Gordon Mengel from Peace Corps; William Easterling from Pennsylvania State University; Beth Sauerhaft from PepsiCo; Michael Smart from Rock Creek Global Advisors; Paul Weisenfeld from RTI International; Chris Field from Stanford University; Roger Beachy from the University of California, Davis; Ian Foster from the University of Chicago; John Roy Porter from the University of Copenhagen; John Hayes from the University of Florida; Donald Wuebbles from the University of Illinois; Cynthia Brady, Jenny Frankel-Reed, Jerry Glover, David Hegwood, Julie Howard, Tjada McKenna, Andre Mershon, Jami Montgomery, Moffatt Ngugi, Kyle Rearick, Erin Streurer, Ishani Sud, P.V. Sunddareshwar, and Sarah Tully from the USAID; Edward Buckler, William Hohenstein, Luis Tupas, Darci Vetter, Caren Wilcox, and Catherine Woteki from USDA; Robert Vallario from the US Department of Energy; Paul Koch, Oliva Lopez, Julia Meisel, David Reidmiller, Kate Russel, and Jonathan Shrier from the US Department of State; David Allen, Tom Armstrong, Samantha Brooks, Phil Duffy, Julie Morris, Emily Seyller, and Chris Weaver from the US Global Change Research Program; Marc Sadler from the World Bank; Lisa Dreier from the World Economic Forum; Chris Delgado from the World Resources Institute; and independent consultants Doug Clark and Scott Kilman.

Several members of The Chicago Council staff played key roles in bringing this report into fruition. Lisa Moon, vice president, Global Agriculture & Food, directed the study. Meagan Keefe, assistant director, expertly oversaw the day-to-day management of all aspects and participants in the report's development. Louise Iverson and Natalie Sheneman played key roles in the research and report drafting processes with unmatched dedication and accuracy. Taylor Gillings and Julian Medrano assisted with collecting report photos and references. Catherine Hug of Chicago Creative Group provided valuable editorial direction on the report.

EXECUTIVE SUMMARY



UN Photo/Kibae Park

To successfully advance global food security, the food system must be resilient to the effects of climate change. Science suggests that climate change will bring hotter temperatures, changing rainfall patterns, and more frequent natural disasters. These effects could slow the growth of food production by 2 percent each decade for the rest of the century.[1] Farmers everywhere will be affected, with those living in tropical and coastal areas initially hardest hit.

Climate change adds to a number of daunting challenges facing the world's food system. Today, more than 840 million people are chronically hungry.[2] In a business-as-usual future, it is predicted that by 2050, population growth, rising incomes, and changing diets will increase food demand by 60 percent.[3] Most production gains will have to occur using existing resources.

This is not an impossible task. Food production on all the world's farms can be increased through innovation, more sustainable practices, and reductions in food waste. In Sub-Saharan Africa and South Asia, yields can increase significantly if farmers are given access to training; tools to improve soil health; and productive resources such as improved seeds, fertilizers, and postharvest storage.

The international community has recognized this potential. Funding for agricultural development, especially in Sub-Saharan African and South Asia, has been on the rise after two decades of weak support, but not enough is being done to prepare for the added effects of climate change.[4] Food producers need more accurate information on how crops, livestock, and fisheries will be affected and more up-to-date information on weather. Innovations are needed to ensure agricultural productivity continues to grow and farmers use water, soil, and other resources more efficiently. The global trade regime needs to become more flexible, and farmers must have better tools to manage weather-related risks.

If these challenges are not addressed, consumers will need to be prepared for higher food prices and potential food shortages. The US Department of Defense has made clear that climate change could have wide-ranging implications for US national security due to social unrest spurred by reduced water availability, degraded agricultural production, higher food prices, damage to infrastructure, and changes in disease patterns.[5] The concern has modern precedent. The 2008 food price spikes led to unrest in at least 30 countries.[6]

History has shown that with adequate resources and support, agriculture can meet growing production demands and adapt to some changes in climate. But adaptation must begin now. Developing the necessary scientific breakthroughs and broadly disseminating them will require years, even decades of lead time.[7] Reducing barriers to global food trade to enable food to move more easily from areas of surplus to those of deficit will continue to be a difficult task.

As a global leader in agriculture, the United States should act now. It has much to gain by doing so: the continued productivity of the US farm sector, strong international agricultural markets, more stable societies, and demonstration of its national commitment to food and nutrition security for the world's people. It has much to lose by delay.

This report puts forward recommendations for how the US government can better address climate change through its policies on global agricultural development. It argues for the United States to rally international resources and deploy its agricultural research enterprise—its universities, research institutes, and agrifood businesses—to gather more information about how climate change will affect the global food system and develop the innovations to manage its impacts. It presents evidence that by enhancing the public sector's partnerships with businesses and civil society, solutions that benefit populations around the world, from farmers in Africa to those in the United States, can be found.

Recommendation 1: Make global food security one of the highest priorities of US economic and foreign development policy

The long-term nature of food and nutrition security challenges associated with climate change requires an enduring commitment from the US government. This recommendation calls for:

- Congress to pass authorizing legislation that commits the United States to a global food and nutrition security strategy.
- The Feed the Future and the Global Climate Change initiatives to integrate their activities on climate change related to agriculture. The US government should ramp up support for research institutions in developing countries and their scientists.
- The US government to make food security central to international negotiations on climate change and instigate an international effort to identify strategies for more efficient water use in food production.

Recommendation 2: Bolster research on climate change impacts and solutions, increase funding for data collection, and partner widely

The US government should increase funding for agricultural research to promote climate change adaptation and mitigation. This recommendation calls on the government to work in partnership with universities, business, and civil society to:

- Increase funding on adaptation and mitigation. Research priorities should include improving crop and livestock tolerance to higher temperatures and resilience to variable weather; engendering efficient use of natural resources; exploring varied crops and farming practices that exploit system dynamics; developing management strategies for combating pests and disease; and reducing food waste.
- Develop more sophisticated models and collect better data on climate change and food security. Top priorities for collection should be data about weather, water availability, crop performance, land use, and consumer preferences. Better models and data are crucial for developing solutions that will help increase productivity, enhance nutrition, increase resilience to the effects of climate change, and contribute to reduced greenhouse gas concentrations.

Recommendation 3: Include climate change adaptation in trade negotiations

With increasing weather variability and more extreme natural disasters, the international trade system must support the unimpeded short-term movement of food to compensate. Policies to support these trade flows should be a priority in international trade negotiations. This recommendation calls for:

- Including controls on export restrictions in the Trans-Pacific Partnership and Transatlantic Trade and Investment Partnership negotiations.
- Incorporating climate change adaptation and resilience in the World Trade Organization work program on food security.

Recommendation 4: Advance climate change adaptation and mitigation through partnerships

Partnerships between the public and private sectors are of critical importance, and US agencies such as the Millennium Challenge Corporation, the Overseas Private Investment Corporation, and the US Department of Agriculture can play valuable roles in supporting these efforts. This recommendation calls for:

- Reinvigorating extension programs in low-income countries to improve adaptation and information-sharing, capitalizing on digital technologies.
- Developing insurance product strategies to manage weather risk.
- Strengthening the resilience of infrastructure to climate change and reducing food waste.

These recommendations make suggestions for how to improve the efficiency of current funding for agricultural development, food and nutrition security, agriculture and food research, and climate change. But some increases in spending are necessary. Policymakers can and must find the will to make these investments happen. For its part, the American public is favorably disposed toward initiatives related to hunger and climate change. A 2012 Chicago Council survey found that 91 percent of Americans considered "combating global hunger" and 79 percent of Americans considered "limiting climate change" to be important foreign policy objectives.[8] With such support, the United States has the opportunity to lead the way in improving life not just for its own citizens, but for humanity.

PART I

Climate Change Poses Risks to Global Food Security

Reuters/David Mercado

The global food system contributed to unprecedented improvements in human well-being during the 20th century. Increased productivity from the expansion of cropland and irrigation along with scientific breakthroughs in breeding, soil management, and other farming techniques helped feed the world's rapidly growing population and brought decades of declining food prices.[9] Life expectancy rose from below 40 years for much of the world's population of two billion people at the beginning of the century to over 60 years for many of the world's six billion people by its end.[10] Mounting challenges, however, are putting these successes at risk in the 21st century.

Population numbers continue their march towards 9 billion or more by 2050. Rising incomes among people in developing countries are increasing demand for food of higher quality and diversity.[11] The majority of the world's population already lives in cities, and urbanization will continue.[12] Resources needed for sustainable food security—fresh water, productive soils, key nutrients, genetic diversity—are becoming increasingly scarce.[13] The dramatic successes of the past have led to complacency about the potential for challenges in the future, resulting in reduced public-sector investments in agricultural productivity.[14] To those already daunting problems, climate change adds more, including higher temperatures, changes in water availability, increases in weather extremes, a broader range of pests and diseases, and rising sea levels.

The warning signs were evident in the 1990s, when global growth in major grain yields stalled.[15] The food price spikes of 2008—caused by a combination of droughts and disease in grain-producing nations, rising oil prices, increased demand, inappropriate export controls, and falling global stocks—were a wake-up call.[16] Civil unrest spread across at least 30 countries. Several countries underwent changes in government.[17] In 2010 excessive heat and drought in Russia led to wildfires and a grain embargo. This, coupled with unprecedented floods in Pakistan, was a stark reminder of the impact that extreme weather events have on the food system.

Without an immediate plan of action, food and nutrition security challenges will only intensify, with dire global consequences, ranging from greater numbers of hungry and malnourished people, to economic losses, to growing instability of national governments, and even to international security concerns.[18]

While a few might initially benefit from climate change, all farmers will face challenges to productivity and more difficulties in managing the additional variability in production and markets.[19] Coupled with population and income growth, the food system will struggle to deliver adequate quantities of food without substantial price increases, which in turn raises the potential for increased food insecurity in vulnerable populations, migration, and civil disobedience.

The challenges posed by climate change extend well beyond the farm—challenges affect national governments, which must establish the environment for policy and infrastructure; businesses, which must respond to climate-related issues along the value chain; and the global trading regime, which must ensure that potentially rapid swings in comparative advantage translate into unimpeded trade flows to balance world supply and demand.

The effects of climate change on agriculture will also not be limited to countries in the tropics or those living on coastal areas. They will impact the US food system. The 2014 National Climate Assessment finds that climate disruptions to US agriculture have been increasing and are projected to become more severe over this century. While some US regions and some types of agricultural production will be relatively resilient to climate change over the next 25 years or so, others will increasingly suffer from stresses due to extreme heat, drought, disease, and heavy downpours.[20] Agrifood businesses will need to continuously adapt to climate and resource-related challenges.

Despite the mounting challenges, meeting the world's food and nutrition needs in a way that protects the environment is possible as long as efforts to reduce global greenhouse gas emissions begin soon. Ramping up research, leveraging the innovative power of business, removing barriers to trade, providing a level playing field in the mar-

Box 1 – Definitions

Weather and climate

"Climate" is usually defined as average weather. The United Nations Framework Convention on Climate Change (UNFCCC) defines "climate change" as changes in climate caused directly or indirectly by human activity.* People do many things to cause local changes in climate. For example, "heat islands" are caused by higher temperatures in cities compared to the surrounding countryside. Deforestation can cause local increases in temperature and changes in rainfall patterns. This report, however, focuses on *global* changes in climate.

Food security

This report uses the term "food security" to refer to an outcome where people worldwide have regular access to a sufficient quantity of nutritious food stuffs that are produced by a food system that manages natural resources sustainably; sustainability, nutrition, and security are essential elements of food security.

* Article 1 of the UNFCCC defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Simon Rawles/The Image Bank/Getty Images


Alexey Sazonov/AFP/Getty Images

ketplace, and giving all farmers access to practices and innovations that enhance their productivity and resilience will transform the global food system to support a growing population with higher incomes. In the past five years there has been renewed energy directed towards advancing global food and nutrition security. The US government has played a critical role in supporting governments, farmers, and businesses to improve food production sustainably and nutritiously in underperforming economies. These are important first steps. Now, the United States and the international community must build on this foundation to achieve lasting change.

This report assesses how a changing climate threatens global food and nutrition security over the next several decades. It focuses on the challenges of dealing with the slow but inexorable increase in the effects of climate change that require a longer-term perspective. Successful implementation of the recommendations in this report will help alleviate some of the effects of weather variability in the short-term, but most importantly, will strengthen the resilience of the global food system to withstand the consequences of climate change, which will be most pronounced in the decades to come.

This report's publication coincides with a period of growing attention to these issues. The Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change, was established by the United Nations Environment Program and the World Meteorological Organization to provide the world with a clear scientific view on climate change and its potential impacts. The IPCC released two reports of a four-part series in March and April 2014 that comprises the Fifth Assessment Report. It plans to complete its final synthesis in October 2014.

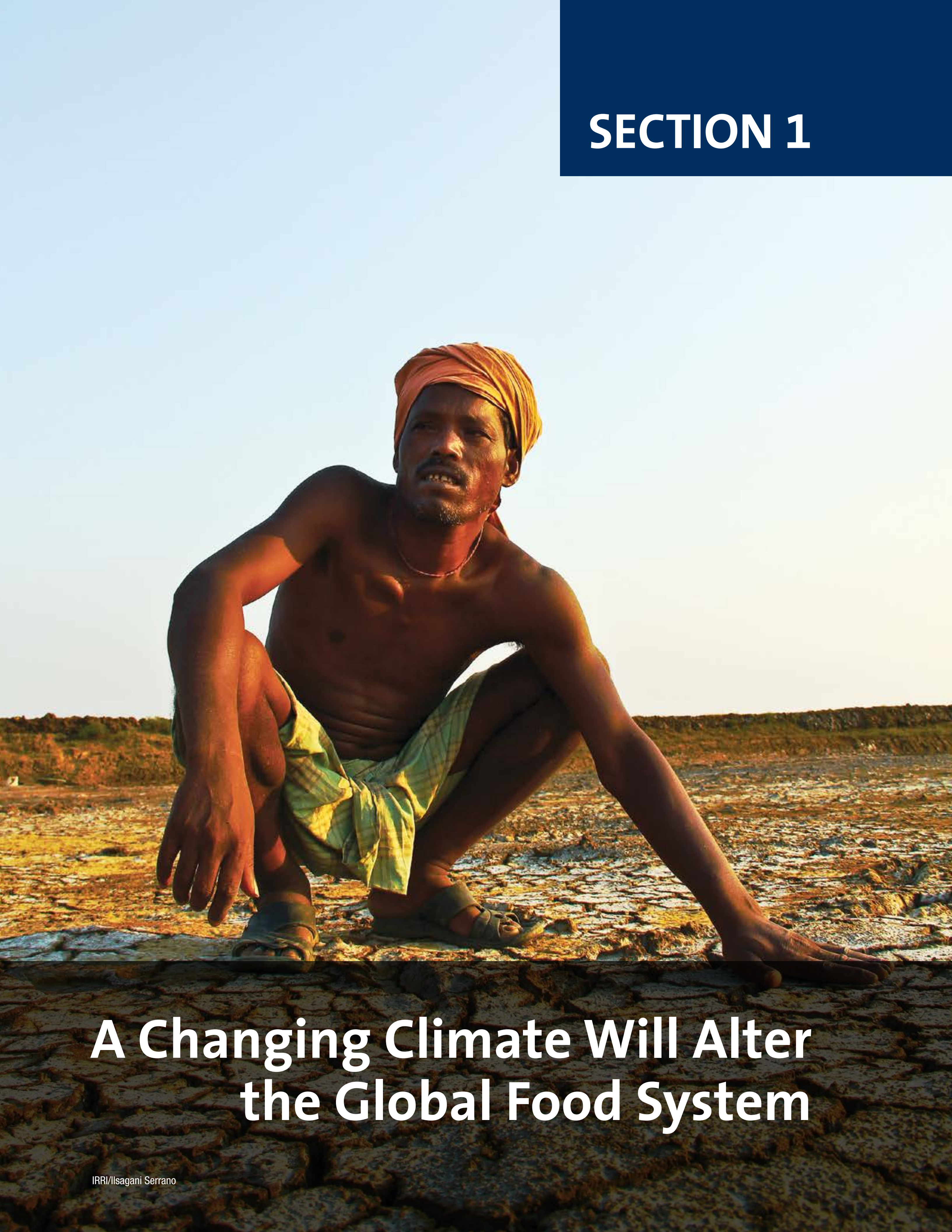
The IPCC reports highlight the urgency of climate change and have sparked calls for the international community to take immediate action to address this issue. The IPCC reports suggest that temperature increases can be contained with near-term action that significantly reduces greenhouse gas emissions. This report focuses primarily on the opportunities to adapt food systems to a changing climate, which the IPCC recognizes are necessary, even if greenhouse gas emissions slow immediately. It reviews agriculture's contributions to climate change and identifies mitigation opportunities within the food system that would also boost productivity and improve resilience.

Most importantly, this report recommends actions that the US government should take—in partnership with other countries, businesses, international organizations, and nongovernmental organizations—to build food systems that are resilient to climate change and advance global food and nutrition security. It pays special attention to lower-income countries and their small- and medium-scale farmers in particular, where the challenges will likely be most pronounced and the resources to deal with them limited. But given that the problems are global, with both domestic and international consequences, they must be addressed with a global perspective.

In the final section, this report discusses four sets of policy recommendations. They include efforts to increase climate change resilience and mitigation. The four recommendations are:

- Make global food security one of the highest priorities for US economic and foreign development policy. The recommendation proposes major new legislation that would make permanent the US food security activities currently funded and administered across US government agencies and enhance their effectiveness.
- Bolster research on climate change impacts and solutions, increase funding for data collection, and partner widely. The recommendation highlights research and data priorities and makes the case for investing in research institutions and scientists in low-income countries.
- Include climate change adaptation in trade negotiations. The recommendation makes specific suggestions for identifying solutions that improve the global trading regime.
- Advance climate change adaptation and mitigation through partnerships. The recommendation presents a variety of possible partnerships.

SECTION 1



A Changing Climate Will Alter the Global Food System

IRRI/Isagani Serrano

While population growth, rising incomes, and food price shocks have focused greater attention on the state of global agriculture in recent years, the added impacts of climate change on production have received less emphasis in the United States. Yet rising temperatures, changes in precipitation, and increasing weather extremes will impact the food system. Changes are already evident in the United States and other countries and will only accelerate in the future.[20] While the precise impacts of climate change are difficult to predict, scientists, researchers, and other observers do know a great deal about the kinds of changes that the world can expect and the impending consequences for the food system.

Food production and food prices are inextricably linked to weather

Farmers have always prepared for unpredictable and varied weather. Most farmers plan agricultural production based on rainfall, anticipating both good and bad years as part of the farming cycle. Occasionally, extreme weather has caused unusual devastation. For example, the Indian famine of 1899 to 1900 brought on by the failure of the summer monsoons in 1899 caused large crop losses.[22] When the colonial British government did not bring grain to the affected regions, mass starvation followed, and at least a million people died.[23] The Dust Bowl in the United States in the 1930s left more than 500,000 Americans homeless and forced tens of thousands of families to abandon their farms in the midst of the Great Depression. By 1940, 3.5 million people had moved out of the Plains states in the largest short-term migration in American history.[24]

More recently, in 2010 monsoons in Pakistan, which depends greatly on farming, caused devastating flooding. The floods submerged about 17 million acres of the country's most fertile croplands. The flooding also killed over 200,000 head of livestock and washed away large quantities of stored commodities that would ordinarily feed millions of people throughout the year.[25]

While these sorts of extreme events have typically been rare, the likelihood, duration, and intensity of such events are expected to increase due to climate change. Even more frequent small weather events can still cause significant harm. In 2008 the Mississippi River flooded as crops were just beginning to grow, causing an estimated $8 billion in losses for farmers.[26]

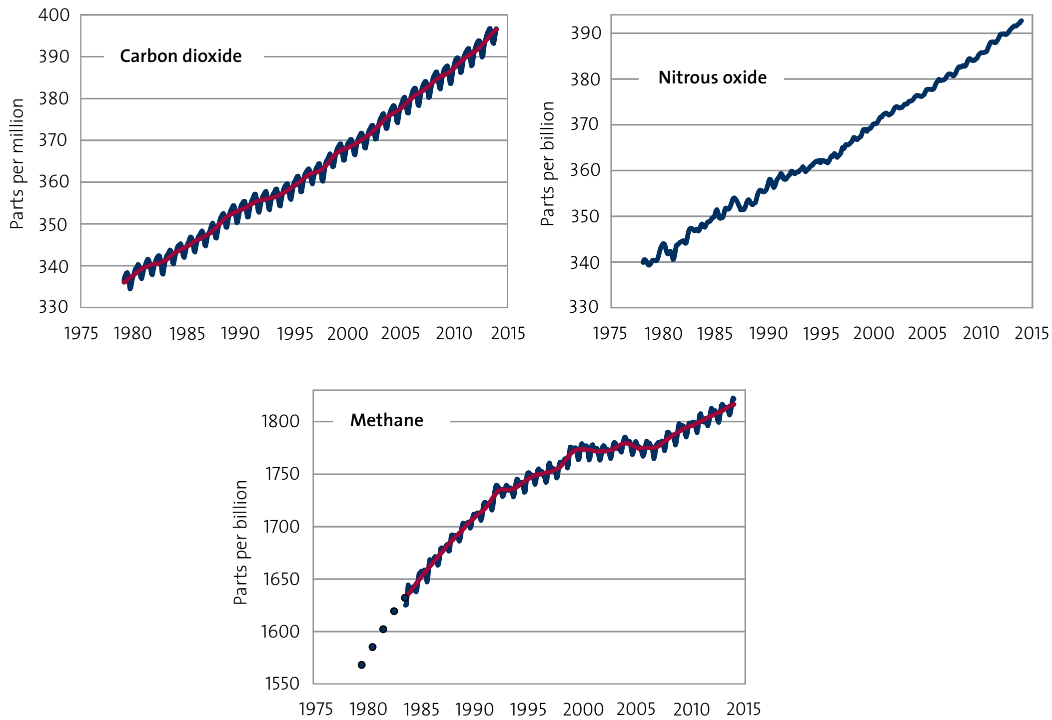
Agricultural losses due to weather events, when combined with other critical factors, can have a domino effect on the food system, leading to commodity shortages, food price spikes, and price increases for animal feed and other inputs, eventually pushing up retail food prices. In addition to the immediate devastation, high and volatile food prices driven by extreme weather jeopardize the ability of the global food system to deliver adequate food and nutrition to the world's people.

Global temperatures are rising along with greenhouse gas emissions

Physicists and atmospheric scientists have known for more than 100 years that greenhouse gases in the atmosphere convert sunlight into heat, warming the air. Major

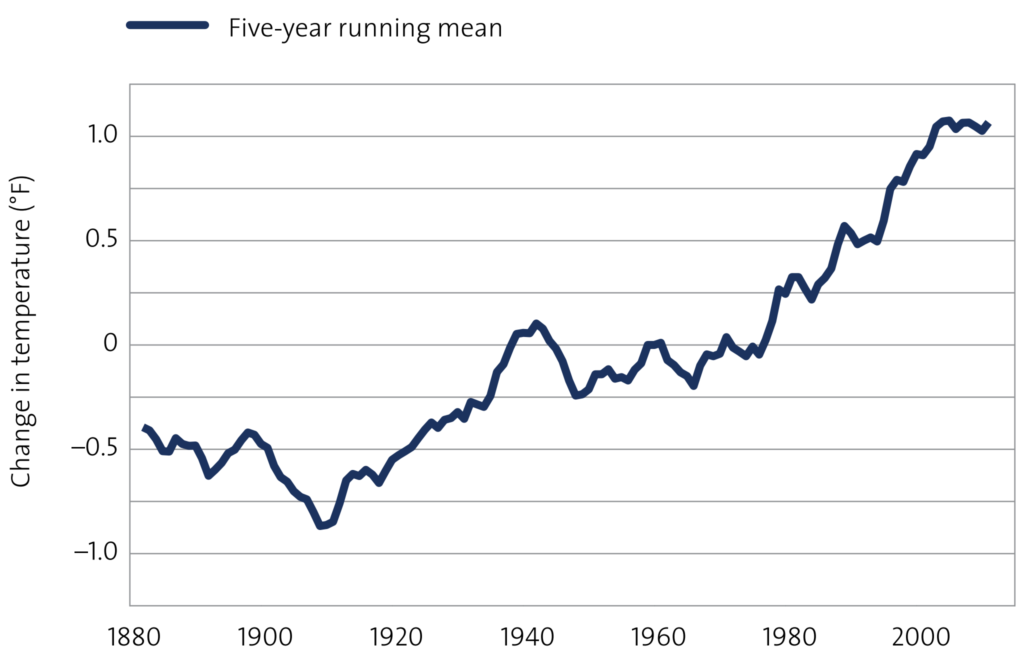
Note: For more information about climate change, please see the technical appendix by Gerald C. Nelson, available at thechicagocouncil.org/globalagdevelopment.

Figure 1 – Atmospheric concentrations of major greenhouse gases continue to rise (1978 to 2013)



Source: Butler and Montzka 2014.

Figure 2 – Average global temperatures have been rising for the past century (1880 to 2013)



Note: Figure shows differences with average global temperature during the base period 1951 to 1980.

Source: NASA GISS Surface Temperature Analysis 2014.

greenhouse gases like carbon dioxide, nitrous oxide, and methane have all been on a steady upward trend over the past century (figure 1). Unlike other major greenhouse gases that disappear from the atmosphere relatively quickly, carbon dioxide stays put for hundreds to thousands of years, making increased concentrations in the atmosphere difficult to reverse.

The initial effect of increased greenhouse gas concentrations is higher temperatures. Concurrent with the rise in greenhouse gas emissions, the average global temperature rose by about 1.4°F (0.8°C) from the mid-19th century to the early 21st century (figure 2). The current rise in temperature is notable because it is happening at a rate unprecedented in at least the past 1,300 years.[27]

The World Meteorological Organization reports that 1998, 2005, and 2010 were the warmest years globally on record since modern records began in 1850. Thirteen of the 14 warmest years on record have all occurred in the 21st century. For the United States, 2012 was the warmest year on record. For Australia, it was 2013.[28]

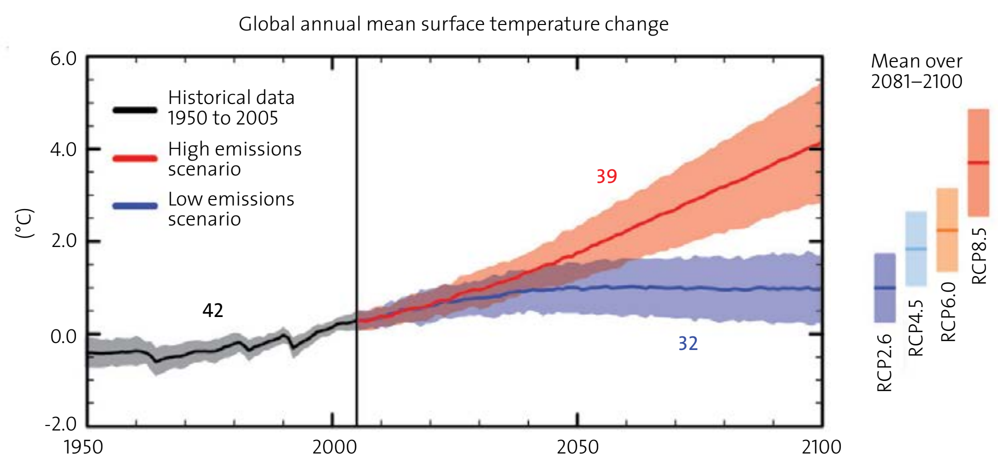
Weather changes are on the horizon

Temperatures are expected to continue rising throughout this century, bringing about a host of weather-related consequences.[29]

Temperatures will continue to climb

Model results from the Fifth Assessment Report of the IPCC, the most recent assessment of the scientific literature on climate change, predict global mean temperature increases of 2°F to 8°F (1°C to 4°C) from the middle of the last century to the end of this century based on a range of plausible increases in greenhouse gas concentrations (figure 3).[30] Currently, growth in greenhouse gas concentrations is at the high end of the

Figure 3 – Average global temperatures are expected to continue rising (IPCC scenarios, 1950 to 2100)



Note: Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel simulated time series from 1950 to 2100 for change in global annual mean surface temperature relative to 1986–2005. This figure depicts scenarios RCP8.5 (high emissions scenario) and RCP2.6 (low emissions scenario) from the IPCC's Fifth Assessment Report. The numbers in the graph indicate how many climate models were used to generate the mean values (lines) and the uncertainty estimates (shaded area). The figure (IPCC's figure 7 (a) from Working Group I Summary for Policymakers) has been reprinted with a modified legend with permission from the IPCC.

Source: IPCC 2013.

Box 2 – Is climate change responsible for today's extreme weather events?

For Californians who are suffering through the drought of 2013-14, Floridians who experienced unprecedented rainfall in the spring of 2014, farmers and ranchers in Texas and throughout the Midwest that faced drought and unprecedented heat in 2011-12, and grape growers in Colorado's wine district who lost merlot in an extended cold snap during the winter of 2013-14, the question of whether climate change played a role in these events is frequently asked.

While no single weather event can be attributed to climate change, it is likely that extreme events are occurring more frequently. The IPCC's special report on extreme events states:

> It is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale. There is medium confidence that anthropogenic influences have contributed to intensification of extreme precipitation at the global scale. It is likely that there has been an anthropogenic influence on increasing extreme coastal high water due to an increase in mean sea level.

Source: IPCC 2012.

IPCC's emissions scenarios, which suggests the temperature increases by the end of this century will be closer to 8°F than 2°F. And these values represent average temperatures across land and oceans. Land temperature increases will be greater.[31] The IPCC provides this assessment of the changes to come:

> It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase. It is very likely that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur.[32]

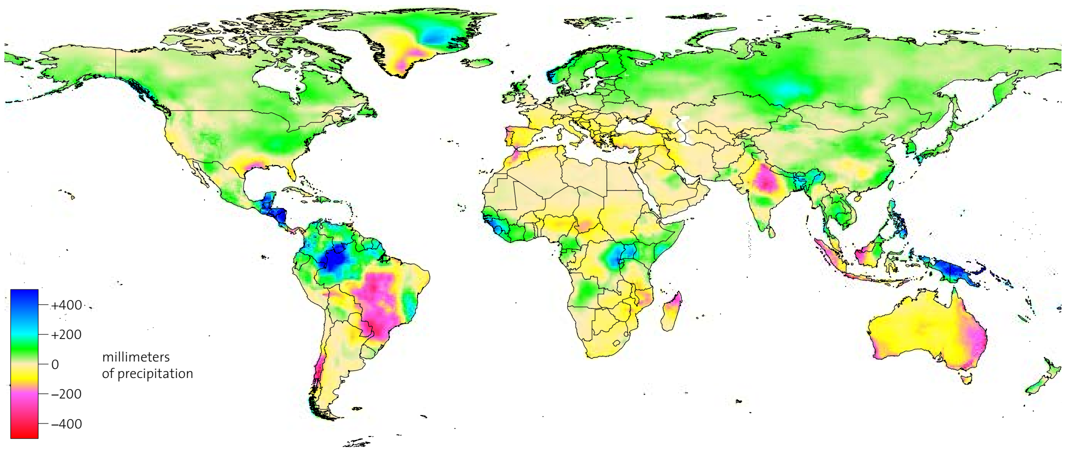
More varied rains and weather extremes are expected

Higher temperatures will bring more evaporation and ultimately higher average rainfall across the globe. With more energy in the climate system, variability in local weather is expected to increase. While exact changes in precipitation are difficult to predict, it is certain that weather extremes will increase in many regions. It is possible that some regions will see substantial increases in rainfall and flooding, while others experience increased drought. And even regions with more rain might experience drought-like conditions as higher temperatures result in more evaporation and transpiration. Figure 4 shows potential precipitation changes globally from two different climate models.

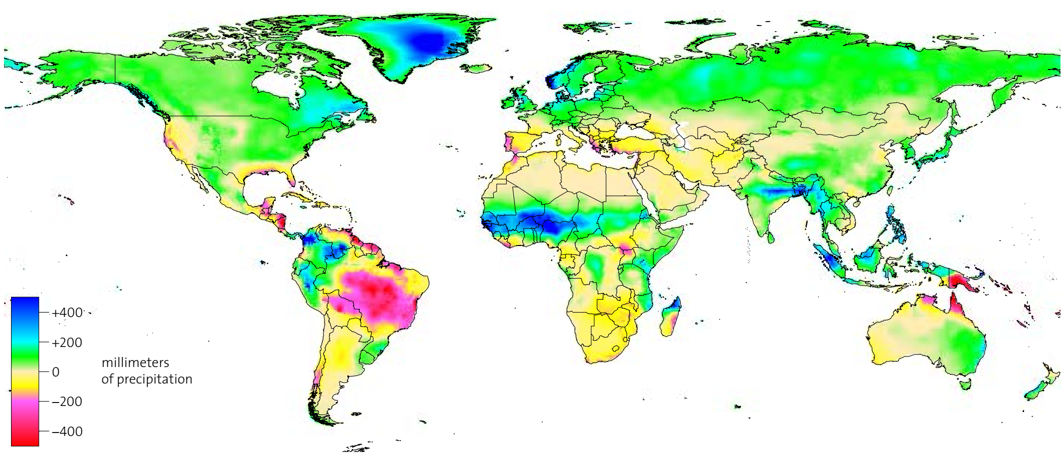
Climate change does not and will not affect all regions of the world equally.[33] And within a region its effects will not be uniform. In hard hit regions, the poor are likely to bear the brunt of the effects, at least initially.[34] Farmers and agricultural workers, whose livelihoods depend on agriculture, will likely suffer more direct effects than the rich and city dwellers, who have access to imports. But the impacts of climate change on food production will be far-reaching and will affect everyone.

Figure 4 – Predicted changes in average annual rainfall between 2000 and 2050 from two climate models

GFDL*



MIROC†



* The GFDL model is a general circulation model developed by the Geophysical Fluid Dynamics Laboratory (GFDL) in the United States National Oceanic and Atmospheric Administration.

† MIROC (Model for Interdisciplinary Research on Climate) is a general circulation model produced by the Center for Climate System Research, University of Tokyo; the National Institute for Environmental Studies; and the Frontier Research Center for Global Change in Japan.

The GFDL and the MIROC models use the same high greenhouse gas emissions scenario (RCP8.5) but differ because the models have differing climate sensitivities.

Source: Robertson 2014a.

Box 3 – Agriculture contributes to and can reduce greenhouse gas emissions

Growing use of fossil fuels is the single largest contributor to the increase in carbon dioxide concentrations, but agricultural activities are also significant.[35] When grasslands and forests are converted to agriculture, the loss of vegetation above ground results in large carbon dioxide emissions. As the figure below shows, this land use change accounts for about 6 percent of the warming potential from total greenhouse gas emissions annually, mainly through deforestation in tropical regions.[36] In addition, without careful management practices, soils in the newly converted lands lose about 50 percent of the initial soil organic carbon in the top surface layer in 25 to 50 years in temperate climates and in five to 10 years in the tropics, making land less productive.[37]

Agriculture also emits large amounts of methane and nitrous oxide, which are greenhouse gases that trap more heat than carbon dioxide.[38] Irrigated agriculture, especially rice, produces large amounts of methane.[39] Digestion and decomposition of manure from ruminants (livestock that extract nutrients from grasses such as cattle, goats, and sheep) also generate large quantities of methane.[40] Fertilizer use can also release large amounts of nitrous oxide when not properly managed.[41] Together these emissions account for about 14 percent of the increase in total warming potential annually.[42] Food systems also generate emissions beyond the farm, in storage, transport, and processing.

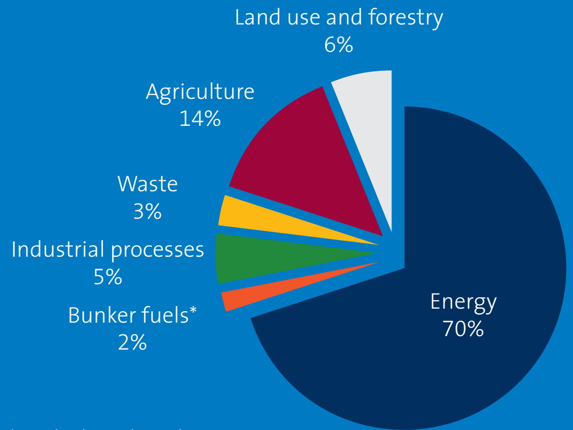
Projected increases in future agricultural emissions

As incomes rise and the population grows, agricultural-related emissions could rise dramatically unless low-emissions growth strategies for agriculture are implemented. Increases in agricultural methane emissions are likely to come mostly from increasing numbers of livestock, driven by increased meat and milk consumption.[43] By 2050 emissions of nitrous oxide are expected to triple from 1900 levels without interventions to increase the efficiency of fertilizer use.[44] Since the harvested area of irrigated rice is expected to grow slowly as demand for rice falls in the increasingly well-off countries of East and South Asia and as cultivation methods improve, these contributions to methane emissions growth will slow.[45]

Reducing emissions through agricultural practices

Plant-based agriculture also removes carbon dioxide from the air and stores the carbon initially in living plants.[46] By adopting good management practices, farmers can increase soil organic carbon and become a net sink for carbon dioxide. Many, if not all, of these practices also enhance resilience to climate change. Examples of such practices are identified in section 3.

Global warming potential from greenhouse gas emissions by sector (2009)



* Fuel oil used on ships.

Shares based on the global warming potential of the gases emitted from each source.

Source: World Resources Institute 2014.

Change is the new normal in agriculture

While the effects of climate change on the food system remain difficult to disentangle from other forces of change in the short term, it is apparent that the global agricultural landscape will be altered. The unpredictability of weather impacts on agriculture has always been a constant of farming. Farmers choose crops and animals that perform well under "normal" weather conditions, recognizing that normal doesn't mean identical. What is new is that climate change further contributes to unpredictability. As temperatures rise, rainfall patterns change, and variability increases, farmers will need to figure out what their new normal might become, and in fact whether change is the new normal. They will need to grow different crops, plant at different times, use different inputs, raise different animals, and be ready for ongoing changes.

Comparative advantage for crop production will move

Historically, crops grow best in the climate conditions in which they evolved—corn grows best in humid semitropical regions, potatoes in cool, dry environments, wheat in temperate regions, and rice in the humid tropics, for example. Over time, humans have transported these crops around the world to areas with similar climatic conditions and adapted them to local needs through formal and informal breeding. While breeding can help crops adapt to changing conditions, climate change will fundamentally alter

> *During the last several years, we've seen an increase in rains that exceed three inches per hour or dump six to eight inches per day on our fields. This has caused erosion in our no-till system where we hadn't had it before. This past spring we received a four-inch rain in one hour and 10 minutes. While our steeper no-till fields saw significant erosion, we observed almost no erosion in our no-till plus cover crop fields. We seem to be in a cycle of extreme weather and rain events. We need to adapt our management and conservation practices to what is happening in our fields.*
>
> Ray Gaesser, Iowa grain farmer
>
> Source: The 25x'25 Alliance 2013

current environments, shifting regions for optimal growing conditions for crops and increasing variability in yields. Average growing season temperatures in many countries are already above the optimum in the regions where many of the world's most important crops now grow, including wheat, rice, corn, barley, sorghum, and soy.[47]

Recent research strongly suggests that temperature increases since 1980 and accompanying changes in precipitation have already had demonstrable but varying effects on agriculture across the globe.[48] The horizontal bars in figure 5 show how climate change has affected yield growth over the past three decades. For most countries climate change has been a drag on yields. A conspicuous exception is the United States, where corn, wheat, and soybean yield growth has been thus far almost unaffected. This is expected to change with future warming.[49] Figure 6 shows potential changes through 2050 in yields of major crops from two climate models.

Crop production in regions of some countries has already begun to shift. For example, corn production in North America, rice production in China, and wheat production

Box 4 – How climate change affects crop growth

Temperature

In general, as *average* temperatures increase to between 68°F (20°C) (for crops that evolved in temperate regions such as wheat) and 86°F (30°C) (for crops from tropical regions such as cassava and rice), growth accelerates for plants. Above 88°F (31°C) the productivity of most crops drops rapidly. Especially when combined with moisture deficits, increases in *maximum* temperatures can lead to severe yield reductions and reproductive failure in many crops.[50] In corn, for example, each day spent above 86°F (30°C) can reduce yield by 1.7 percent under drought conditions.[51]

Increased *nighttime* temperatures reduce rice yields by up to 10 percent for each 1.8°F (1°C) increase in current *minimum* temperature in the dry season in the humid tropics.[52] Nighttime minimums above 68°F (20°C) constrain the initial development of potatoes. Temperate fruit crops require a period of extended cold temperatures to flower in the spring. Vegetables are generally sensitive to environmental extremes, especially high temperatures.[53]

Water

The global average water footprint per ton of crop varies substantially. Sugar crops use roughly 6,400 cubic feet per ton (ft^3/ton) (200 cubic meters per ton (m^3/ton)), vegetables use roughly 9,600 ft^3/ton (300 m^3/ton), roots and tubers use 12,800 ft^3/ton (400 m^3/ton), cereals use about 51,300 ft^3/ton (1,600 m^3/ton), oil crops use 76,900 ft^3/ton (2,400 m^3/ton), and pulses use as much as 128,100 ft^3/ton (4,000 m^3/ton).[54] Higher temperatures require more water for the same production.

Forty percent of worldwide agricultural production today comes from irrigated lands.[55] Future production growth will likely depend on irrigation, but fresh water supplies for irrigation are increasingly scarce. Many of the major rivers and groundwater aquifers throughout the world are suffering from overexploitation.

Irregular precipitation already affects productivity—and the livelihoods of many rural families around the globe—and will likely become more problematic as the climate changes.[56]

The timing of rainfall will also change in many locations, requiring management adjustments for farmers. The start of the growing season requires adequate soil moisture and warmth. Pollination and grain development are affected by moisture and temperature at key points in plant growth. A dry period at harvest improves grain quality. Shifts in rainfall timing and intensity can reduce productivity of existing practices even when average precipitation doesn't change. In sequential cropping systems, changes in rainfall patterns can alter the likelihood that a second or third crop is possible.[57]

Carbon dioxide

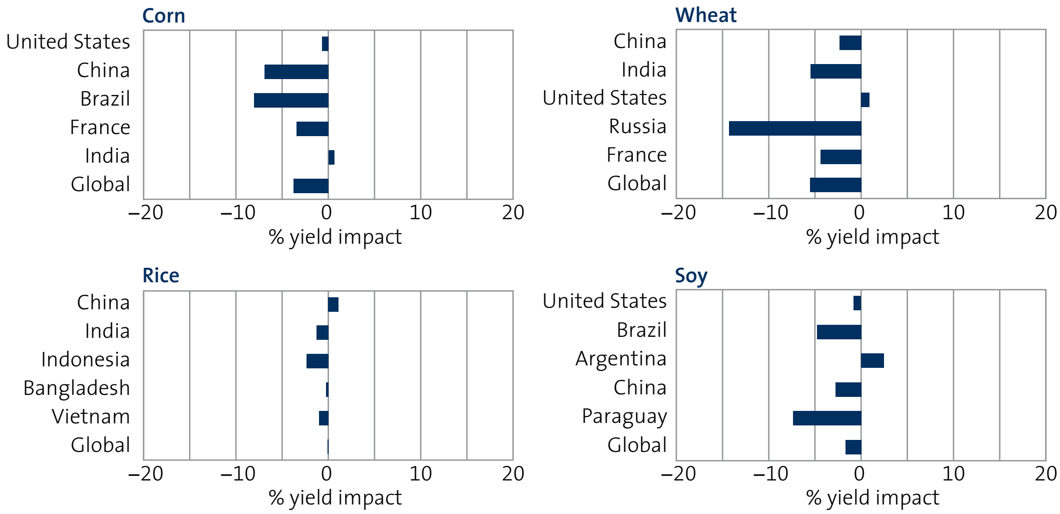
There remains considerable uncertainty about the impact of increased carbon dioxide concentrations on plant growth under typical field conditions. Plants have evolved two mechanisms for converting carbon dioxide into useful plant material, called the C_3 and C_4 metabolic pathways. In the laboratory, greater carbon dioxide concentrations benefit plants that use the less efficient C_3 metabolic pathway (most food crops, including rice and wheat, and most plants considered to be weeds). But plants that use carbon dioxide more efficiently through the C_4 metabolic pathway—such as corn, sugarcane, and sorghum—benefit little.

Elevated levels of carbon dioxide, however, can negatively affect the nutritional makeup of the crop (see "Food quality will be harmed" on page 22). The impact of carbon dioxide also depends on whether plant growth is affected by other factors such as lack of water or nutrients. In some crops, genetic differences in plant response to carbon dioxide have been found, and these could be exploited through breeding.[58]

Ozone

Higher temperatures and increases in methane concentrations are associated with higher ground-level ozone concentrations. While ozone is harmful to all plants, soybeans, wheat, oats, green beans, peppers, and some types of cotton are particularly susceptible. Exposure of perennial crops to ozone can have multiyear effects.[59]

Figure 5 – Climate change is already dragging down yields



Estimated net impact of climate trends for 1980-2008 on crop yields, divided by the overall yield trend.

Source: Adapted from Figure 3 in Lobell, Schlenker, and Costa-Roberts 2011.

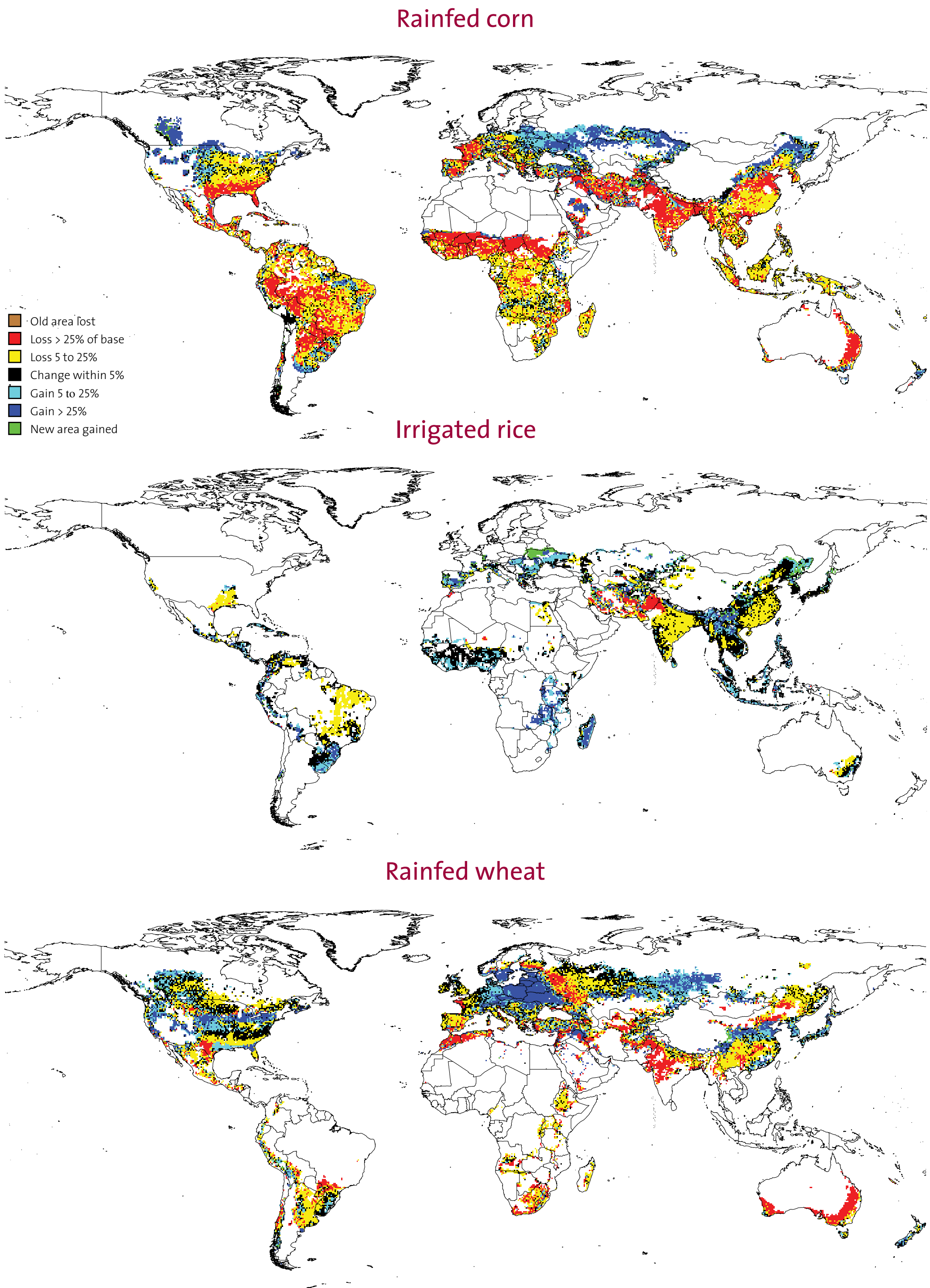
in Russia are already shifting north.[60] Coffee production is shifting to higher elevations; 100,000 jobs have already been lost in Guatemala's coffee industry due to a fungus brought on by climate change that has crippled production.[61] Factors unrelated to climate change such as technical innovations, agricultural policies, and changing diets also contribute to these shifts, but climate is a major factor. These kinds of changes will occur in all countries. And these types of shifts will run into natural limits, e.g., the tops of mountains in the case of coffee and other tropical crops, inadequate soil conditions for corn and wheat production in much of the far north of the northern hemisphere, and, ultimately, continental limits.

Although early scientific research suggested that crop production would benefit from climate change in some regions of the world, the IPCC now states that growing zones for specific crops will shift, with agricultural production everywhere eventually being negatively impacted by climate change.[62]

Variability in crop yields will increase

Climate change will also increase variability in production.[63] More extreme weather events will cause agricultural "good" and "bad" years to shift from country to country more frequently and increase the likelihood of simultaneous "bad" years in many countries. Consequently, the likelihood of more severe and more frequent food supply disruptions will increase.[64] An efficient and flexible global food production and distribution/trading system is essential for people everywhere to get the food they need when they need it.

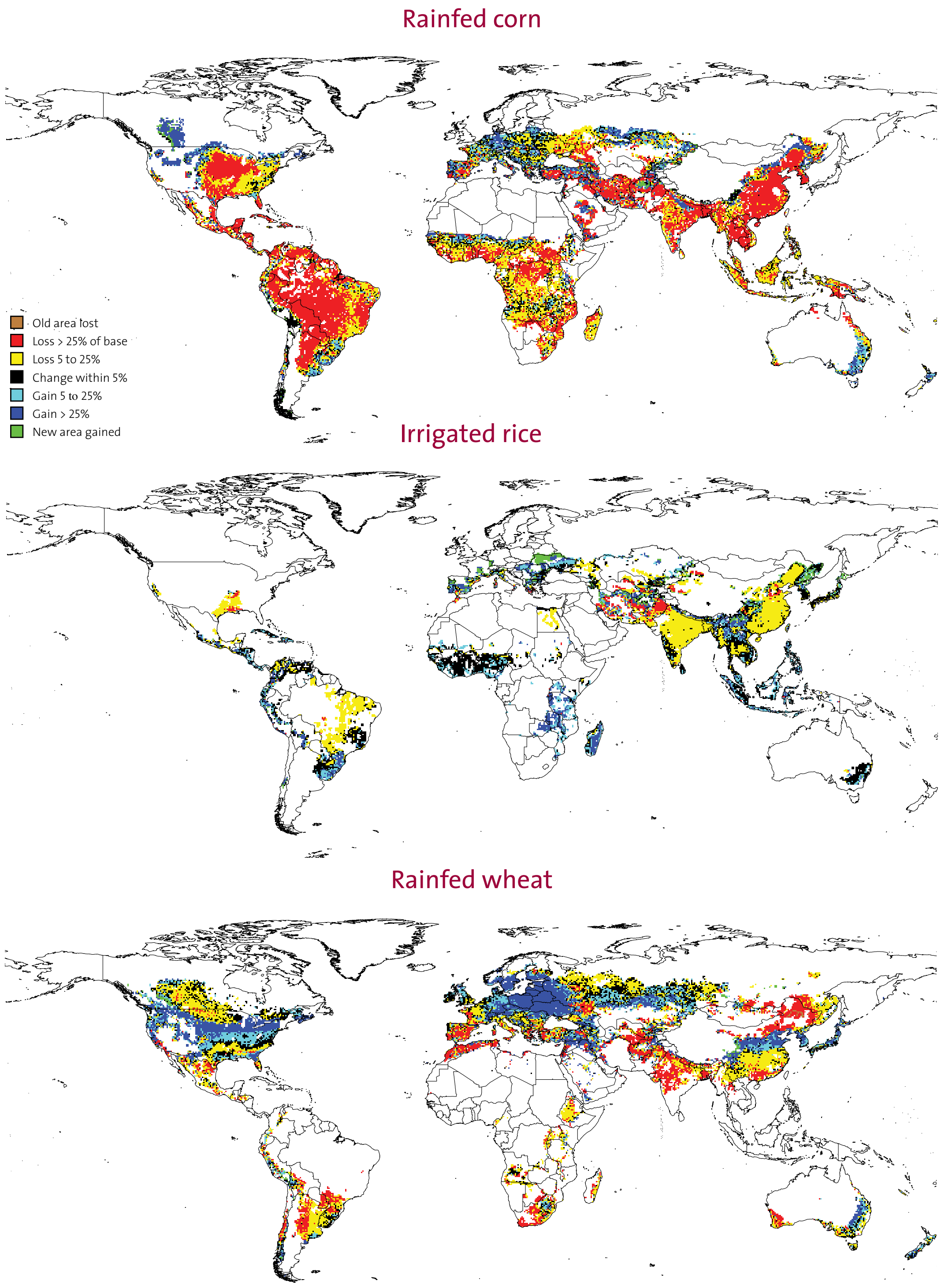
Figure 6a – Predicted changes in rainfed corn, irrigated rice, and rainfed wheat yields between 2000 and 2050 using the GFDL model.*



* The GFDL model is a general circulation model developed by the Geophysical Fluid Dynamics Laboratory (GFDL) in the United States National Oceanic and Atmospheric Administration. The base year for changes is 2000. The GFDL and the MIROC models use the same high greenhouse gas emissions scenario (RCP8.5) but differ because the models have differing climate sensitivities.

Source: Robertson 2014b.

Figure 6b – Predicted changes in rainfed corn, irrigated rice, and rainfed wheat yields between 2000 and 2050 using the MIROC model.*



* MIROC (Model for Interdisciplinary Research on Climate) is a general circulation model produced by the Center for Climate System Research, University of Tokyo; the National Institute for Environmental Studies; and the Frontier Research Center for Global Change in Japan. The base year for changes is 2000. The GFDL and the MIROC models use the same high greenhouse gas emissions scenario (RCP8.5) but differ because the models have differing climate sensitivities.

Source: Robertson 2014c.

New threats from native pests and diseases and invasive species will emerge

Climate change may have a substantial impact on pests and diseases that affect crops and livestock, but the science regarding this impact is currently in its infancy.[65] Within some limits, insects reproduce more rapidly with higher temperatures and are more likely to overwinter in temperate locations. Most weeds grow more vigorously with increased carbon dioxide concentrations.[66]

Crop losses from pests and diseases can offset the gains made from adopting crops with increased climate resilience. For example, yams and cassava are known to be well adapted to drought and heat stress,[67] but their pest and disease susceptibility in a changing climate could severely affect their productivity and range in the future.[68] Potato is another crop for which the pest and disease complex is very important.[69] How such crops may be affected by pests and diseases is not well understood. Yet the already high susceptibility of many crops to pests and diseases leaves them even more vulnerable in the face of climate change.

Climate change may also facilitate the introduction of invasive pests and diseases. For example, Asian soybean rust, which reproduces on many plants, was found in Brazil in 2001. It can be carried to the United States by weather patterns. Since it requires live, green tissues to survive, cold winters provide a natural barrier. As winters become shorter, the chances of the rust surviving and affecting Midwest soybean production grow.[70]

> *The longer growing season and warmer weather have introduced new weeds and insects that now survive winter in greater numbers. "We are getting bugs up here that used to be a problem just for Missouri and farther south," John says. While this initially led him to use stronger insecticides, a shift to genetically modified crops has helped to reduce the need for chemicals. Nonetheless, he finds that there is a need to sometimes spray the fields twice a year in order to account for the longer growing season.*
>
> John Vrieze, Wisconsin dairy farmer
>
> Source: The 25x'25 Alliance 2013

Food quality will be harmed

Most studies of the biological effects of climate change on crop production have focused on yield.[71] A second impact, much less studied, is how the *quality* of food is affected by climate change. As crops and animals respond to changing weather, a change in the nutrient value of crops as well as a change in the mix of available foods is likely. Grains have received the most attention, with both higher carbon dioxide levels and temperature affecting grain quality. For example, research shows that protein content in wheat is reduced by high carbon dioxide levels.[72] Experiments in the United States and China have shown that in nonleguminous grain crops, protein and mineral content such as iron and zinc are substantially reduced when carbon dioxide concentrations reach levels likely to occur by midcentury.[73] Yield increases in wheat due to doubling of carbon dioxide come from more grains rather than larger grains, resulting in lower protein and higher starch content.[74] According to the International Rice Research Institute, higher temperatures will negatively affect rice quality.[75]

Box 5 – A changing climate is already affecting farmers in the heart of the US corn belt

Weather data in Iowa cover over 100 years. These data serve as a record for Iowa farmers of how their climate has been changing. The story is complicated: averages mask important changes in seasonal patterns and extreme events that affect productivity.

Increases in precipitation

Annual precipitation has trended gradually upward, with increases in eastern Iowa that are somewhat greater than rest of the state. Most of the increase occurs in the first half of the calendar year, leading to wetter springs and drier autumns. For farmers, this means more water-logged soils, difficulty preparing fields, and delayed planting in spring. But this also means improved crop dry-down conditions in fall. Iowa rainstorms have become more intense, leading to serious soil erosion problems. In Des Moines, for example, by the end of the 20th century the number of intense rain events annually was more than three times what it was at the beginning of the century.

Humidity has also been rising. The summertime dew-point temperature increase in the last 35 years has led to about 13 percent more moisture in the air today, raising the probability of crop damage from disease due to longer periods of dew on crops. The higher humidity also fuels the thunderstorms that provide abundant summer precipitation. There is growing evidence that summer storm systems may be stronger. Trends in extreme events such as tornadoes, however, are difficult to quantify.

Changes in temperature

Iowa's annual average temperature has increased at a rather modest rate, but seasonal and day-night temperature changes are large and have a greater impact. Winter temperatures have increased six times more than summer temperatures, raising the odds that pests and diseases survive through the winter. Nighttime temperatures are also increasing more than daytime temperatures, which puts additional stress on crops.

Daily minimum temperatures have increased in both summer and winter in Iowa. Daily maximum temperatures have risen in winter but declined substantially in summer.

Iowa now has longer frost-free periods than it did in the past, but the number of growing degree days has changed very little over the last 40 years. Rising nighttime temperatures have offset declining daytime temperatures, resulting in little change in daily mean temperature and growing degree days.

This "pause" in temperature increases in Iowa overall, including fewer extreme high temperatures in summer, runs counter to global and continental trends. There is some evidence that an increase in summer cloudiness has caused this trend. More soil moisture may explain this anomaly. It is also possible that recent temperature increases over the Rockies result in more high pressure to the west of Iowa and a consequent increase in airflow from the north during the warm season.

The negative effects of additional springtime rain have been offset by larger planting equipment, more subsurface drainage, and new seed treatments that prolong viability in waterlogged soil. The pause in temperature increases, the decrease in extremely high summer temperatures, and improved crop dry-down conditions in fall has been highly favorable to corn production in Iowa and likely have been contributing factors to the current upward trends in corn yields of three bushels per acre per year, compared to two bushels per acre per year before 1995. Results of global climate models, however, do not project this pause in the warming to continue. If the flow of moisture from the Gulf stops earlier in the season, pollination and grain filling could be hurt and the recent trend of yield growth slowed.

Source: IPCC 2013; Takle, personal communication, 2014.

Livestock productivity will be reduced

Livestock production has expanded rapidly as global meat and milk consumption has grown due to increases in population and income. This trend is expected to continue.[76] The Food and Agriculture Organization of the United Nations (FAO) projects that by 2050, average meat consumption per person globally will be 40 percent higher than it was in 2010, with a 70 percent increase in developing countries.[77]

Climate change presents a number of challenges for livestock production.[78] The direct effects of higher temperatures are likely to be negative, with the vulnerability to heat stress varying according to species, genetic potential, life stage, and nutritional status. Most livestock species have comfort zones between 50° and 86°F (10° and 30°C). At higher temperatures they reduce their feed intake 1.5 to 2.5 percent for each one-degree increase. Higher temperatures also negatively affect fertility. Livestock are also harmed by increases in ground-level ozone.[79]

Climate change will also affect forage quantity and quality. A sustained increase in temperatures combined with higher levels of carbon dioxide results in a changing mix of grasses in native and managed pastures, but the net effects are uncertain. And changes in the nutritional makeup of grasses will affect feed quality.[80]

> *We have been working hard on the genetics of our animals over the last 25 years to build ones that use less resources. We are now using less grain to produce a better product at a younger age. This means less demand for land and water and less carbon dioxide and methane emissions.*
>
> Steve Irsik, Kansas rancher
>
> Source: The 25x'25 Alliance 2013

Rising sea levels will harm coastal agriculture

Sea level rise has been occurring for some time. According to the IPCC, the global mean sea level rose by about 0.62 feet (0.19 meters) from 1901 to 2010.[81] Climate change is likely to accelerate the increase. The IPCC estimates that by 2100 sea level rise will be between 0.92 and 3.22 feet (0.28 and 0.98 meters).[82]

Since nearly one-third of the world's population is located in coastal areas, sea level is a significant concern. Rising seas are expected to harm coastal agriculture and the livelihoods of coastal communities, and some island countries may even be submerged entirely. Crop production in the world's expansive coastal wetland areas and delta croplands may also suffer from saltwater intrusions. The effects of rising sea levels will be particularly pronounced in developing countries, notably in countries such as Egypt, Vietnam, and Bangladesh, where a great deal of agricultural production is in river deltas. Egypt, for example, is quite vulnerable since nearly 20 percent of the population and farmlands are less than seven feet (two meters) above sea level. Similarly, a 3.28 foot (one meter) rise in the sea level could submerge as much as 15 percent of the land area in Bangladesh, damage the Mekong delta rice fields in Vietnam, and submerge several small island states.[83]

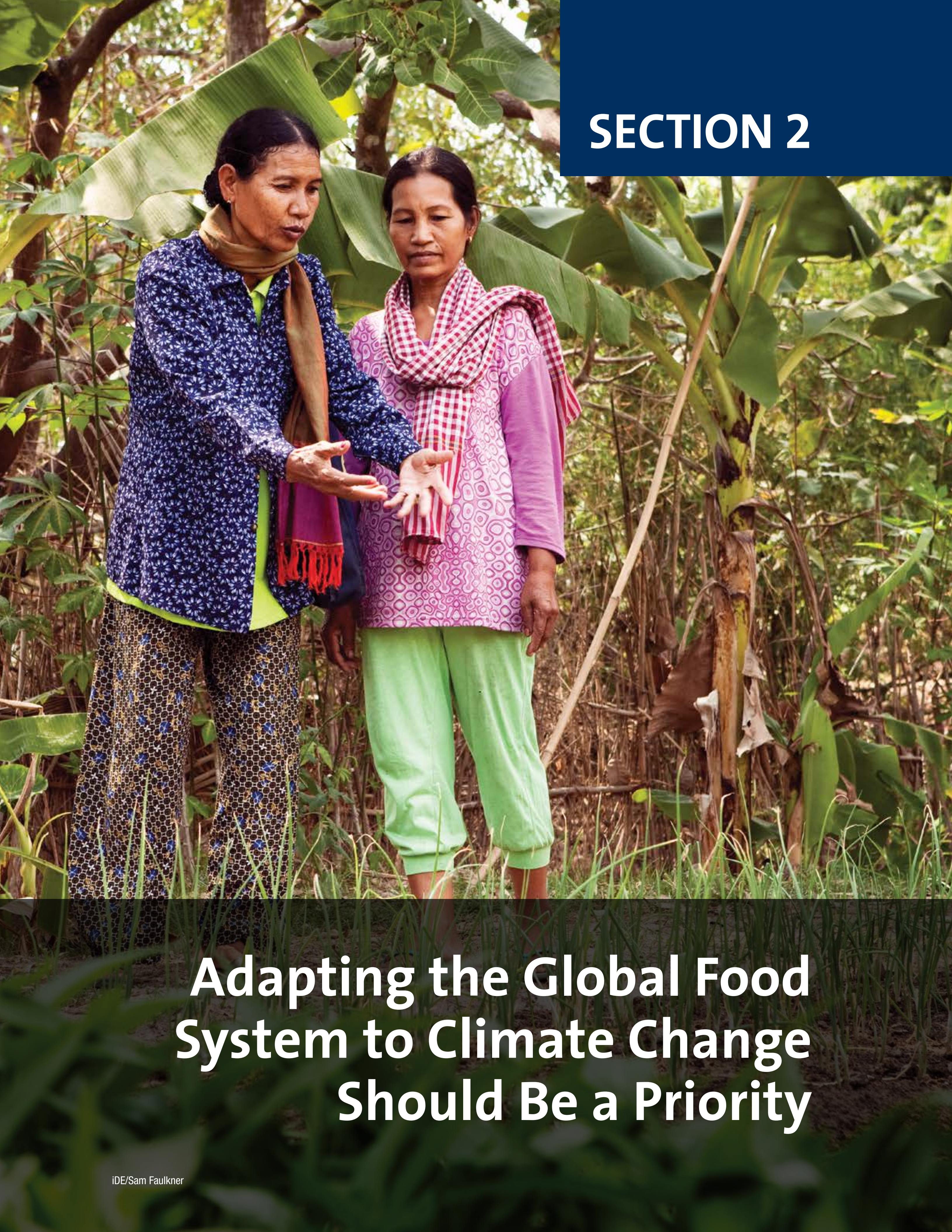
Transportation costs will rise

Agricultural products travel from the farm to the consumer in a myriad of ways—carried by hand and beasts of burden, by trucks of all sizes, and across the water in everything from small sailing ships to giant oceangoing cargo vessels. Climate change will increase costs for all of these. Higher temperatures reduce the efficiency of human and animal transport, require roads to be built to higher standards, and increase the costs of cooling for sensitive produce.

Navigable inland waterways are crucial for commodity movements. In the United States, farms in the Mississippi River basin produce over 90 percent of the nation's agricultural exports, almost 80 percent of the world's exports in feed grains and soybeans, and most of the nation's livestock and hogs. Sixty percent of all grain exported from the United States is shipped on the Mississippi River through the Port of New Orleans and the Port of South Louisiana.[84] Greater weather variability, whether extended droughts or extreme rain, raises shipping costs in the short term. In the longer term, rising sea levels threaten existing port infrastructure, and floods and sediment buildup alter the physical structure of the river.

SECTION 2

Adapting the Global Food System to Climate Change Should Be a Priority



iDE/Sam Faulkner

No one will escape the consequences of climate change and its effect on food production if we fail to act. Rising temperatures and weather variability will eventually impact everyone through higher prices, food shortages, and security threats. By 2100 climate change is expected to create climate conditions in many places outside the range of observations seen or recorded over the last 100 years.[85]

Science confirms the threats to food security

The continued rise in temperatures will "challenge the physiological limits of crops and exacerbate the global food challenge."[86] The following excerpts from the 2014 report by the IPCC's working group on impacts summarize the most recent scientific research on potential outcomes:

> Without adaptation, local temperature increase in excess of about [2°F] 1°C … is projected to have negative effects on yields for the major crops … in both tropical and temperate regions…. With or without adaptation, negative impacts on average yields become likely from the 2030s with median yield impacts of 0 to -2% per decade projected for the rest of the century, and after 2050 the risk of more severe impacts increases….[87]
>
> Under scenarios … leading to local mean temperature increases of [6 to 8°F] 3 to 4°C or higher, models … suggest large negative impacts on agricultural productivity and substantial risks to global food production…. Such risks will be greatest for tropical countries….[88]
>
> Global temperature increases of approximately [8°F] 4°C or more above late-20th-century levels, combined with increasing food demand, would pose large risks to food security globally and regionally (high confidence). Risks to food security are generally greater in low-latitude areas.[89]

As discussed in section 3, the state of the science in global models of agriculture likely underestimates the impacts of climate change. Since the IPCC reports must rely on currently available peer-reviewed results, the quantitative estimates summarized above also likely underestimate the effects due to factors missing from the models. The IPCC reports do recognize and acknowledge the importance of such factors, including the damaging impacts of increasingly extreme weather events, pests and diseases, ground level ozone, and changes in the nutrient composition of food.

As explained in box 6, one study finds that the demands on the food system from population and income growth through 2050 are of roughly the same magnitude as the negative effects of climate change. After 2050, however, climate change effects supersede the effects from population and income growth. Given the long lead times needed to advance scientific research and transfer new technologies and farming practices to the field, action must be taken now to meet the increasingly difficult challenges of climate change.

World prices are a useful indicator of the future of food security because they combine the effects of growing demand from population and income, resource scarcity, and national policies as well as the effects of climate change on supply. One modeling exercise, based on the effects of growing population and income alone, projects price increases from 2010 to 2050 to be about 33 percent for corn, 23 percent for wheat, and 19 percent for rice. Climate change causes these price increases to roughly double.[90]

Box 6 – Climate change impacts worsen with time

Models used by the IPCC to look at the impact of climate change on food and nutrition security also account for the impacts of two other challenges to food security: population growth and rising incomes. The models do not, however, break down these impacts separately, which would allow an assessment of the relative magnitude of climate change to these other challenges.

To do this, authors of a separate study developed plausible scenarios for each effect. They estimated market outcomes as if there were no climate effects and then added climate back in, with some automatic adjustments made by farmers to higher prices. They estimated these effects for three future worldviews—an optimistic world with high income and low population growth, a pessimistic world with low income and high population growth, and a baseline in between these two. They assumed a much slower growth rate for today's rich countries in all scenarios.

Their results suggest that for the period until 2050, climate change effects are of roughly the same magnitude as the food security challenges globally from population and income growth. Beyond 2050 that assessment likely changes as population growth slows or stops, but income growth and climate change continue. Biophysical effects of climate change become much worse after 2050. For example, in South Asia, where irrigated wheat will likely remain an important source of calories and protein, the estimate of yield decline solely from climate change is a 12 percent loss between 2000 and 2050 but a 29 percent loss by 2080. This climate change drag on yields will make it that much more difficult for breeders and farmers to produce the increases needed to feed a growing and more affluent population.

Source: Nelson et al. 2010.

Neil Palmer/CIAT

Farmers, countries, and humanity will feel the economic impact

Increased weather variability and greater frequency of extreme rainfalls or drought will make the economics of farming increasingly difficult to manage. Farmers who must adapt to climate shifts by changing crops, purchasing new inputs, or implementing new farming techniques will need to divert resources that might have been used for other farming upgrades. Displacement may result in areas where conditions are simply no longer suitable for production. Upheaval in the farm sector brings economic, social, and human challenges.

Climate change will not only push up prices, but increase price variability. Weather extremes have been a precursor to many of the food price spikes of the last decade. In 2011 alone catastrophic crop losses around the world caused significant economic consequences: Australia ($6 billion from flooding), Pakistan ($5 billion from flooding), Russia ($5 billion from extreme heat).[91] While there is not enough evidence to attribute any of these specific weather events to climate change instead of naturally occurring weather variability, they clearly illustrate the economic impacts of extreme weather events, which will increase in frequency and intensity in a warming climate.

High food prices and food shortages are felt most among the world's poorest people. Today, approximately 842 million people suffer chronic hunger.[92] Over half of these people are smallholder farmers living in rural parts of Sub-Saharan Africa and South Asia. If the international community wants a world without hunger, it must equip the world's food producers to grow more food using fewer resources in the face of climate change.

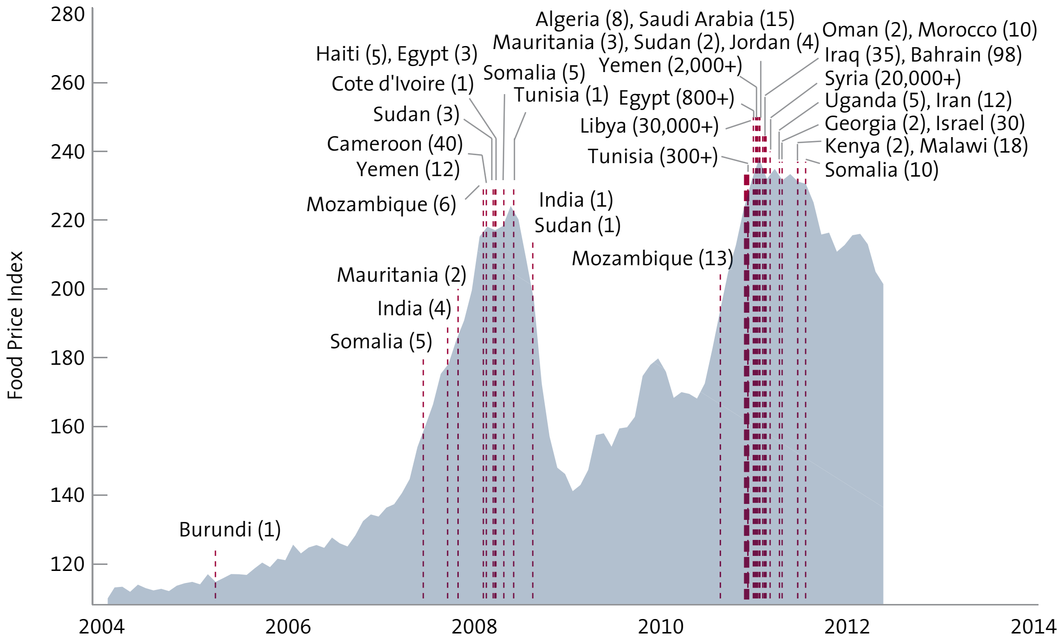
> *Nowadays, we don't enjoy farming like we used to. How am I coping? I plant fast-growing varieties for maize, beans, and sweet potatoes.*
>
> Ruth Marigu Njue, Kururumo, Kenya — Source: CGIAR CCAFS 2010

National and international security will also be at risk

For all of human history, food shortages and higher food prices have been linked to civil unrest that threatens national governments and international stability. The reaction to the food price spikes of 2008, which spurred civil unrest in more than 30 different countries, provide a graphic example (figure 7).[93] In Sub-Saharan Africa, agriculture is so crucial for stability that drought and high food prices are a leading indicator for civil conflict.[94]

There is compelling evidence that suggests food insecurity is a risk to America's national security interests and global stability. The 2014 Quadrennial Defense Review, which provides an overview of the threats and challenges that the US Department of Defense must be prepared to address, found that climate change pressures will increase competition for resources such as water and land and lead to rising food costs. These effects, it reports, will put additional pressure on economies, societies, and government institutions worldwide, thereby functioning as "threat multipliers that will aggregate stressors abroad such as poverty, environmental degradation, political instability, and

Figure 7 – Increases in the food price index correlate with social unrest (2004 to 2012)



Red dashed lines correspond to the beginning dates of "food riots" and protests in North Africa and the Middle East between 2004 and 2011. The overall death toll is indicated in parentheses next to each country.

Source: Lagi, Bertand, Bar-Yam 2011.

social tensions—conditions that can enable terrorist activity and other forms of violence."[95] This finding echoed a recent National Intelligence Council assessment, which stated that climate change would have wide-ranging implications for US national security interests in the coming decades due to reduced water availability, degraded agricultural production, damage to infrastructure, and changes in disease patterns.[96]

Our nation has a strong interest in preventing the sorts of conflicts that open the way for civil wars or turn weakened states into sanctuaries for terror groups that pledge harm to the United States and its allies. When events spiral out of control, US intervention in the form of emergency food assistance—or even more costly military engagement—becomes more likely.

Box 7 – Drought contributed to recent conflicts in the Middle East

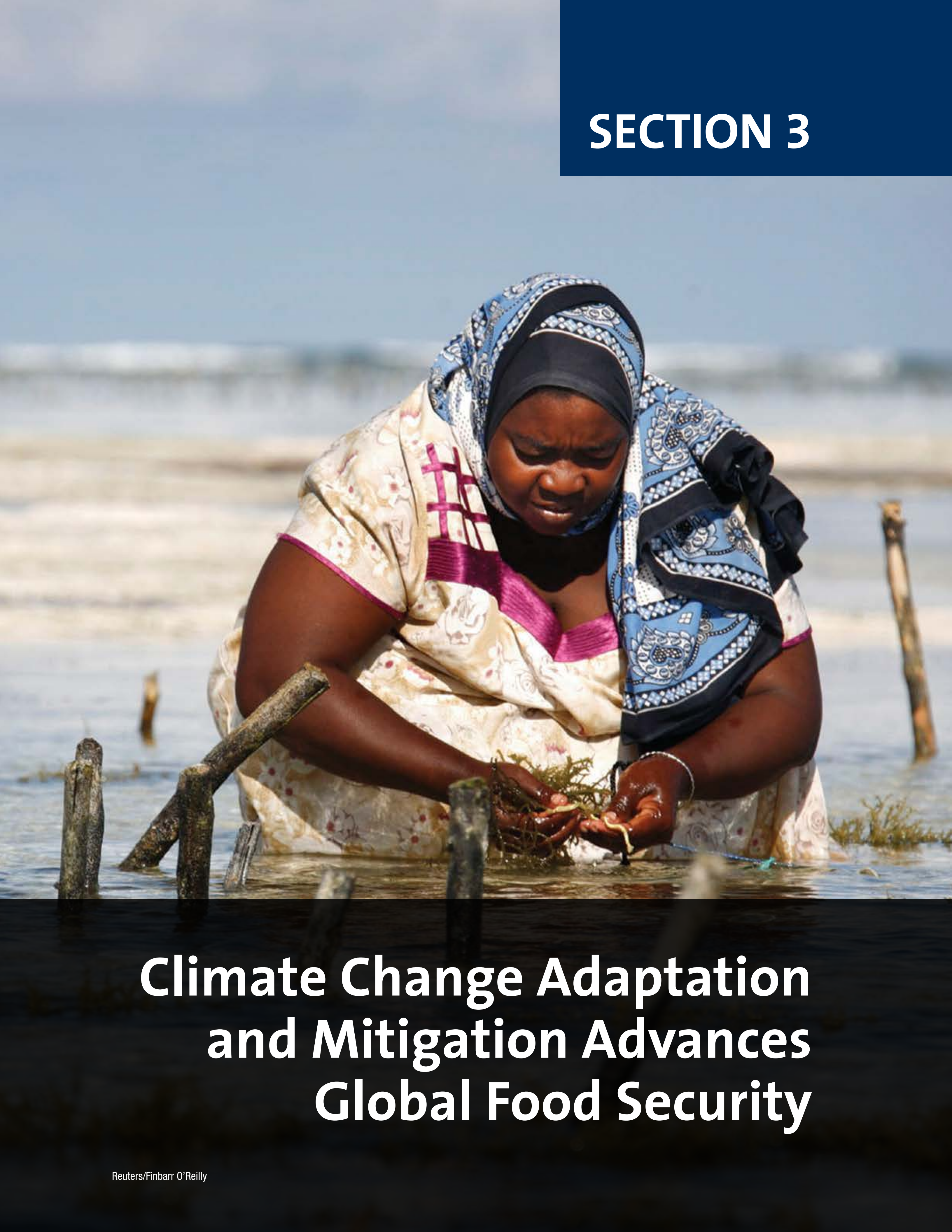
As the conflict in Syria has unfolded, experts increasingly point to the nation's drought as a significant underlying factor in the conflict. From 2006 to 2011 severe drought affected over 60 percent of the land and destroyed the livelihoods of many Syrian farmers. Crop failures of 75 to 100 percent were common. By 2010 some one million Syrian farmers were forced into cities already crowded with refugees from Iraq.

Observers caution that other nations could experience similar challenges. A study from NASA's Goddard Space Flight Center projected that the Middle East, North Africa, Pakistan, and other desert regions will likely see increased periods without rain as global temperatures increase. As devastating droughts destroy agricultural livelihoods and send farmers fleeing to cities, the world risks repeating crises like that in Syria.

Sources: *New York Times* 2013; *Washington Post* 2013; US Mission to the UN 2011.

Bioversity International/R.Khalil

SECTION 3



Climate Change Adaptation and Mitigation Advances Global Food Security

Reuters/Finbarr O'Reilly

Humans have been adapting how they produce, process, and consume food since agriculture was invented. But climate change raises the stakes in unique ways. Its effects are global and widely varying. In the next 35 years, many farmers will face conditions that are outside historical experience. At the same time, the food system must meet growing demand from a larger and wealthier global population, while dealing with growing scarcity of water, land, and other inputs, including higher and more volatile energy prices.[97]

The good news is that adaptation can also complement other food security, development, and economic goals. It can contribute to resilience, increase the incomes and sustainable food and nutrition security of rural farmers and workers in developing countries, provide ways for all countries to support livelihoods dependent on agriculture, and mitigate climate change by reducing greenhouse gas emissions from agriculture and capturing those from other sectors.

Governments, international organizations, and nongovernmental organizations can enhance the capacity to respond in a variety of ways. These include providing information on what works and doesn't work as the weather changes; supporting basic and applied research; providing a supportive policy environment for national and international adaptation and mitigation through international trade and investments; and funding improvements in human, institutional, and social capital at home and abroad.

This chapter addresses general strategies along the value chain to support adaptation to a changing climate and mitigation opportunities that also support resilience. It also presents options for enhancing food security that reduce agricultural greenhouse gas emissions and capturing emissions already in the atmosphere.

Breakthroughs in basic and applied science are needed

Dealing with climate change will require new advances in plant and animal biology and agricultural systems management. While research efforts to address food and nutrition security through agricultural production are beginning to expand after decades of declining funding,[98] the pace and scope of this research needs to be accelerated to deal with the additional effects of climate change. Innovations in basic and applied science are needed to address anticipated challenges. A refocusing of research to address a more complex set of objectives in addition to the traditional focus on increasing yields will be required. Plants and animal breeds will need to be developed to better withstand climate stresses such as higher temperatures and weather variability. Crops that can use water more efficiently, grow in marginal conditions such as on saline soils, have enhanced nutritional value, and have higher yields will need to be developed. Plant and animal germplasm preservation for domesticated and wild species needs to be a priority.

Innovations that increase resilience to climate change and address food and nutrition security challenges sustainably require expertise from a broad array of scientific disciplines. Their development is most effectively carried out in research partnerships—both public and private—in the United States and other developed countries, at international research centers, and at research institutes and universities in developing countries.

As the world's leading source of agricultural innovations historically, the United States has an immense opportunity and responsibility to develop and support the partnerships needed to address the challenge of climate change and global food and nutrition security. The United States possesses the most successful agricultural research enterprise globally through its universities, research institutes, and agrifood businesses. It has the capacity to rally the necessary resources and expertise at home and abroad to equip the global agriculture and food system to sustainably meet future demand. Through partnerships with other governments and organizations in both the developed and developing world, solutions that benefit populations around the world, from small-holder farmers living in Sub-Saharan Africa and South Asia to the US farm community, can be found.

Better data and assessment tools are needed

Throughout modern history, societies have been built around a climate that has been largely predictable. Crops were selected for the conditions in which they grew best, and whole industries such as the travel and ski industries developed around weather expectations. These circumstances are beginning to change as deviations from weather norms increase with rising global temperatures. While advanced computer models have been used for a few decades to predict climate changes, the farming industry, other businesses, and government will increasingly rely on these models to help them make long-term investment decisions and develop crucial policies.

The ability to assess the impacts of climate change on food and nutrition security is not yet well developed and this capability is needed to move forward. Current global models used to assess the future effects of climate change on food security are missing factors that could dramatically influence outcomes:[99]

- Increases in weather variability;
- Increases in ground-level ozone;
- Incidence of pest and disease damage to plants and animals (including humans);
- Increases in disease, pathogen, pest, and weed resistance to treatments;
- Increasing salinization of aquifers and soils and effects of all of these on nutrient composition;[100]
- Climate change effects beyond the farm gate such as storage and transportation challenges, which are likely to increase as higher temperatures, humidity, and extreme events interfere with domestic and international transportation systems;
- The political and economic consequences of food and nutrition security threats from climate change, including collapsing economies, mass migration, civil conflicts, outbreaks of violence, and war.

Improved models that take into account a fuller range of climate change impacts on food production, including the range of foods necessary for health, will be critical to developing agendas to address the coming challenges.

Solutions tailored to conditions on farms must be developed

Food production happens in millions of farmers' fields around the world, in conditions ranging from the drylands of the Sahel, where a timely arrival of the rainy season is key to a successful crop, to tropical Asia, where rice-based systems take advantage of

Box 8 – Existing technologies are a starting point for adaptation

Many technologies already exist that could facilitate adaptation by smallholder farmers when customized for local conditions and made available and affordable. Examples include:

- Change varieties or species of crops or rear different breeds or species of livestock (or fish in aquaculture), including neglected crops and breeds. Varieties or breeds with different environmental optima may need to be adopted, or those with broader environmental tolerances.
- Increase diversification of crops to hedge against risk of individual crop failure. Make use of integrated systems involving livestock and/or aquaculture to improve resilience.
- Change planting dates for food crops, feeds, and forage.
- Change irrigation practices to reduce water use. Make more use of rainwater harvesting. In some areas, increased precipitation may allow rain-fed agriculture in places where previously it was not possible.
- Use reduced tillage to lessen water loss.
- Incorporate manures and compost.
- Plant cover crops to increase soil organic matter and improve water retention.
- Alter animal diets and stocking rates.
- Prepare for increased frequency of extreme events, including putting in place water conservation measures in times of drought, increasing soil organic matter to help store water after storms, and improving drainage and farm design to avoid soil loss and gullying. Farms in coastal areas may need to adapt to increased frequency of saltwater intrusions and those in dryer areas to more frequent wildfires.
- Adopt integrated management strategies as pest, weed, and diseases respond to climate change. Recognize that the natural regulation of potential pests by their natural enemies may be disrupted by a changing climate.
- Engage with other food producers to share best practice and experience so as to enhance community-based adaptation.
- Recognize that where wild plants and animals supplement diets, climate change will alter their availability in ways difficult to predict.

Farmers with larger holdings tend to be more mechanized, use more tillage, and rely predominantly on cultivation of single crops. For climate resilience they should explore low- and no-till options; improve management of the resources applied, including nutrients and water, to support soil health; diversify crop production; and rotate crops.

Source: HLPE 2012.

ICRISAT/Swathi Sridharan

Box 9 – Women play a vital role in enhancing agricultural productivity and resilience

Women play a major role in agriculture and food security and thus need to be equal partners in dealing with the challenges of climate change. Women are involved in food production as farm managers and laborers, they earn income that helps their families purchase food, and they are largely responsible for preparing food within the household. In developing countries, on average women make up more than 40 percent of the agricultural workforce, ranging from 20 percent in Latin America to 50 percent in parts of Asia and Africa.[101]

Yet there is a substantial gender gap in access to agricultural inputs, with serious implications for agricultural productivity.[102] There are limited systematic gender-disaggregated data on land ownership, but the few studies that exist point to large gaps in land holdings, with women owning as little as 5 percent of agricultural land in West Asia and North Africa. In West Asia and North Africa less than 5 percent of agricultural land holders are women; in Sub-Saharan Africa women hold approximately 15 percent of agricultural land.[103] A recent study in the state of Karnataka in India found that women held 9 percent of the land.[104] For female-headed households that do own land, plots are usually smaller than those of male-headed households on average.

Women also own fewer livestock and have inferior access to productive inputs and services, including credit, technology, equipment, extension services, fertilizers, water, and agricultural labor. These constraints as well as others directly affect women's farm productivity. According to the FAO, by addressing the gender gap in agriculture, developing countries could experience gains in GDP of 2.5 to 4 percent with an associated decline of 12 to 17 percent in undernourished people.[105] These inequities must be taken into account, and efforts to adapt to climate change must address them to take full advantage of the contributions women can make.

Women have varying roles in food systems in different parts of the world. Effective planning for adaptation should anticipate the consequences on gender-specific workloads and effects on existing inequalities between men and women both within households and communities. Institutional and social changes are often essential elements of adaptation.

Luca Sage/Photonica World/Getty Images

the heavy rains that accompany the monsoons. Fields range in size from very small to extremely large.

Existing technologies and management systems will need to be tailored to the needs of individual farmers across this wide range of conditions. And new technologies and systems will need to be developed. Practices that are effective in one farmer's fields today may work only in fields a continent away in the future. Developing cooperative applied research programs that include agricultural industries and farmers and that share information globally is a productive complement to more traditional extension approaches.

Adaptation efforts must assess all available practices, including solutions developed using the latest techniques in biotechnology, precision agricultural engineering, enhanced livestock husbandry practices, and agroecological and agroforestry approaches. These include soil enhancement, water management, multiple cropping systems, use of local genetic diversity, and sustainable use and preservation of biodiversity.[106]

Both "low-tech" and "hi-tech" innovations can be important. Of course, for innovations to be of value to the poorest and most vulnerable communities and scalable, they must be affordable and applied to relevant crops, livestock, or agronomic practices. Initiatives such as the provision of "hi-tech," water-efficient corn to vulnerable communities in Africa[107] provide an example of how this might be done.[108]

The financial needs of smallholder farmers must be met

Adaptation is most effective if investments begin early. Farmers, especially smallholder farmers, will need resources to identify and to invest in new crop varieties and animal breeds, irrigation, food storage, and transport infrastructure. The private sector will be an important source of both information and financial resources, supplemented by local and national research and extension programs. Access to capital in developing countries can be provided in various ways. For example, national budgets can be reprioritized, as is being done under the Comprehensive Africa Agriculture Development Program (CAADP) compact in Africa.* Development projects and microfinance initiatives by private and nongovernmental organizations can be undertaken that specifically target smallholder food producers. Because of the important role that women play in agricultural production, programs should be clear about their consequences for women's activities and support their contributions to food security.

Policy distortions that hinder food security should be removed

Efficient climate change adaptation will put a greater premium on the modification of policies that distort market signals for efficient use of inputs and outputs. Two are of particular importance for maintaining food and nutrition security in the face of climate change.

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* In 2003 African heads of state met in Mozambique and pledged to allocate 10 percent of their national budget to agriculture. This pledge became known as the Comprehensive Africa Agriculture Development Programme (CAADP) Compact. As of 2014, 28 countries had begun the process of implementing the compact. Source: NEPAD 2014.

Government intervention in fertilizer markets varies significantly from country to country. In some countries fertilizer is heavily subsidized, which can lead to overuse. Other countries, particularly in Africa, tax it directly or indirectly, raising costs to farmers and resulting in very low rates of use.[109] Policy changes that price fertilizers more appropriately would encourage more efficient management practices and technological advances that increase efficiency. These changes would also reduce nitrous oxide emissions and improve water quality.

International trade rules play an important role in responding to the effects of climate change. As climate change alters regional comparative advantage and increases variability, open international trade transmits market signals that allow farmers to manage their changing production environment more efficiently. After many years of little action, the Doha Round of the World Trade Organization (WTO) negotiations made some progress in its December 2013 ministerial meeting. Recommendation 3 focuses on concrete steps that should be taken to improve trade rules to support climate change adaptation and mitigation.

Infrastructure projects must embed climate resilience

Although future weather patterns remain uncertain, some climate change adaptation can already be built into infrastructure design for agriculture. It is usually much cheaper to build with likely climate change in mind than to retrofit. Some examples follow:

- New rural roads should be built to withstand higher temperatures and more extreme events.
- Dams and irrigation systems should be designed for more extreme rainfall events.
- Construction of levies and coastal defenses for countries such as Bangladesh and Vietnam should be built for rising sea levels.
- “Soft” landscape engineering such as the planting of riverine forests should be considered in flood control projects.
- Passive policy measures such as the preservation of forests, natural grasslands, and mangroves should be put into place.

Though efforts have begun to incorporate climate resilience in infrastructure planning, the political and financial underpinnings of these mechanisms require considerably more development.

Special attention should be paid to the most vulnerable communities everywhere. Up-to-date systems should be put in place to assess ongoing and future risks as climate data accumulate and climate, water, crop, and economic modeling become more sophisticated.

Mitigation of greenhouse gases can support food and nutrition security and slow global warming

Agriculture can contribute to slowing climate change by reducing its own emissions and by converting carbon dioxide from other sectors into carbon in the soil. Many practices that increase soil carbon have been long used for their contributions to productivity and resilience by storing water and nutrients. Methane emissions can be reduced through alternate wetting and drying in irrigated rice fields and through improved pasture and animal management.[110] Nitrous oxide emissions can be reduced through encapsulated, slow-release nitrogen fertilizers that improve nitrogen use efficiency and through multiple, low-dose fertigation* applications where center pivot or drip irrigation is used.[111]

With the right economic incentives, the IPCC estimates that agricultural mitigation efforts could remove nearly all, if not more, than agriculture's total emissions. Mitigation efforts related to land use, including bioenergy, could reduce total greenhouse gas emissions by 20 to 60 percent in 2030 and by 15 to 40 percent through 2100. Especially in developing countries, cropland and grazing land management can be implemented more easily, while restoring organic materials to soils will require greater incentives. The IPCC also finds that policies that combine mitigation and adaptation will be most effective.†

> *Because of cutting trees came the drought; there were a lot of weeds; there was too much sun. So we started planting indigenous trees again.*
>
> Andrew Gitari, Kabaune village, Kenya
>
> Source: CGIAR CCAFS 2010

On-farm practices to reduce agricultural emissions while increasing productivity and resilience are described in more detail below. Many overlap with practices for adaptation. With good design, these practices can result in multiple wins, including the mitigation of greenhouse gas emissions, enhanced food and nutrition security, increased income for farmers small and large, enhanced environmental protection, and improved health and well-being.

Adopt sustainable intensification practices in existing fields

Last year's Chicago Council report promoted sustainable intensification practices to enhance food and nutrition security.‡ Sustainable intensification practices can increase productivity, reducing the pressure to convert nonagricultural lands to agriculture. While both intensification and extensification§ will increase greenhouse gas emissions,

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* Fertigation is the application of fertilizers, soil amendments, or other water-soluble products through an irrigation system. Source: Henry Wade et al. 2003.

† The IPCC reports the value of mitigation using an assumed price of carbon (in the form of a metric ton of carbon dioxide or the equivalent for other greenhouse gasses not emitted or removed from the atmosphere). For a carbon price of $110 per ton ($100 per metric ton), the use of profitable mitigation technologies in agriculture globally would remove 8 to 12 gigatons (7.2 to 11 metric gigatons) of carbon dioxide or its equivalent per year in 2030. Even for a price of only $20 in 2030, about one-third of this amount would be profitable to remove using agricultural technologies. By comparison, total agricultural emissions in 2009 were only 6.5 gigatons (5.9 metric gigatons). Land related mitigation, including bioenergy, could contribute 20 to 60 percent of total cumulative abatement to 2030, and 15 to 40 percent to 2100. The most profitable sources of agricultural mitigation vary with the carbon price, with the restoration of organic soils having the greatest potential at higher carbon prices ($100) and cropland and grazing land management at lower carbon prices ($20). Sources: Smith et al. 2014; Edenhofer et al. 2014.

‡ Sustainable intensification is an evolving concept, whose goal is to equip farmers with the innovations to increase production of nutritious foods while conserving land, water, and biodiversity resources. Source: Adapted from the Montpellier Panel 2013.

§ Extensification is the process of clearing additional land for crop production. Source: Tilman et al. 2011.

the net emissions from intensification are almost always less than from extensification. Researchers have estimated that the net effect of higher yields has avoided emissions of up to 177 million tons (161 million metric tons) of carbon (as carbon dioxide) since 1961, and each dollar invested currently in agricultural yields results in 150 pounds (68 kilograms) fewer carbon emissions relative to 1961 technology.[112] The focus of agricultural adaptation and mitigation policies and programs should be on improving productivity on existing fields rather than expansion of croplands.

> *Climate variability will hasten degradation of soil and water resources. Therefore our local community members should use trees to cushion their farms from degradation and benefit from the income generated.*
>
> William Dennis, Lushoto, Tanzania
>
> Source: Recha 2013

Restoration or improvement of degraded and partially degraded farmland should be a priority. Crop residues, for example, are sometimes thought of as waste material, but can provide a range of valuable services for food security, climate change adaptation, and greenhouse gas mitigation. In soils where organic material is depleted, soil organic carbon could be restored by 50 to 66 percent of the historic carbon loss with well-chosen agroecological practices, making land more productive.[113] Such practices include reduction of soil disturbance through low or no tillage and reduced grazing intensity and restoration of degraded croplands and grasslands through erosion control, cover crops, periodic fallowing, and well-managed livestock grazing. Since low productivity is often associated with high poverty, food insecurity, and poor health outcomes, efforts to increase productivity by improving degraded soils that are also targeted to the poor can lead to double wins.

Improve livestock productivity and manure management

Methane emissions from ruminants, both from digestive processes and from manure, are a substantial and growing share of anthropogenic methane emissions.[114] Reducing methane emissions from ruminants on a per-animal basis has proven challenging, but research into this area is continuing. The New Zealand Fund for Global Partnerships in Livestock Emission Research is one example.[115] However, improved feeding practices (including dietary additives), increased pasture productivity, and animal breeding could reduce methane emissions per unit of ruminant product (milk and meat).[116]

In addition, there is substantial potential for reducing methane and nitrous oxide emissions from animal manure through other approaches: prevention of volatilization of ammonia, aeration of animal manure during storage, and using animal manure to produce energy and fertilizers.[117]

As population and income growth increase demand for livestock products in developing countries, policies and programs that increase animal productivity and reduce emissions per unit of product are essential to slowing emissions growth and reducing poverty among livestock holders. In some parts of the world, meat consumption can be reduced to slow the growth of agricultural emissions. However, in developing countries where local diets include animal protein, increasing consumption by the poor will have positive nutritional effects. Small amounts of high-quality protein from livestock products (milk, meat, and eggs) have strong nutritional benefits. Furthermore, many smallholder farmers' livelihoods depend on ruminants,[118] which have the advantage that they can digest grasses and agricultural residues.

Improve water management

There is substantial potential for mitigating methane emissions through appropriate water management in irrigated rice. Methane emissions can be reduced by avoiding standing water when rice is not grown and shortening the duration of continuous flooding during the growing season.[119] Irrigation management regimes that decrease methane emissions tend to increase nitrous oxide emissions and vice versa. However, even though nitrous oxide has a higher global warming potential, the increase in nitrous oxide does not outweigh the benefits from methane reduction. Therefore, implementing irrigation management systems that reduce methane emissions is usually a net gain.[120] These practices have the added benefit of reducing water needs for irrigation. In many places, simply demonstrating these practices is sufficient to see widespread adoption. More generally, shifting from flooded fields to sprinkler systems or to drip irrigation reduces water use but requires greater investments in equipment and know-how.

Improve fertilizer management

Nitrogen fertilizer is the main factor in anthropogenic nitrous oxide emissions.[121] With better management practices, however, these emissions can be reduced. Much of the nitrogen applied to fields is currently not taken up by plants. According to one study, "On average, of every 100 units of nitrogen used in global agriculture, only 17 are consumed by humans as crop, dairy, or meat products. Global nitrogen-use efficiency is generally considered to be less than 50 percent under most on-farm conditions."[122] Efficiency can be increased (and emissions reduced) by adjusting timing, amount, and formulation of nitrogenous fertilizers. This reduces the amount of fertilizer that is converted to nitrous oxide and that is lost to the ecosystem, causing negative effects elsewhere. More efficient use also reduces the emissions associated with production of nitrogenous fertilizer.[123]

Increase efficiency throughout the food chain

Agriculture can mitigate greenhouse gas emissions in production by reducing the use of fossil fuels through improved energy and fertilizer use efficiency.[124] Lifecycle analysis should be used to avoid unexpected effects on emissions. Reductions can also be made through improved efficiency in food chains, including reduced food losses throughout the food system and changes in diet. The IPCC estimates these demand-side measures have a significant, but uncertain, potential to reduce greenhouse emissions from food production. Estimates vary from 0.84 to 9.5 billion tons (0.76 to 8.6 billion metric tons) of carbon dioxide equivalent per year by 2050.[125]

PART II

Recommendations

Oxfam/Alejandro Chaskielberg

The scientific evidence is strong that climate change will have significant negative effects on global food production, putting food security at risk. The United States, as a world agricultural leader, is well positioned to leverage its scientific enterprise, policy tools, business partnerships, land-grant universities, and global reach to be a driving force for the global food system's adaptation to climate change and to reduce greenhouse gas emissions.

The recommendations in this section lay out a plan for how the United States can recognize climate change in its global food and nutrition security policy that yield positive benefits at home and support resilience in other parts of the world. Addressing the need and methods for achieving both productivity growth and sustainability in the face of climate change challenges is a central theme.

These recommendations build on The Chicago Council's 2013 report *Advancing Global Food Security: The Power of Science, Trade, and Business.* The report highlighted the pressing challenge of food security in a world of growing populations, rising incomes, and scarce resources and called for making food and nutrition security a national and global priority. Climate change only adds to the urgency of this call. Waiting only increases the chances that the problems will escalate beyond our control.

While impacts of climate change will be greater in some regions than in others, no one will be immune to the consequences. Climate and food security challenges are happening at a time of ever-growing interconnectedness among the world's peoples, and their effects are felt globally. US agriculture has a strong interest in understanding the consequences on the domestic economy, human health and well-being, social and political stability, and international markets. If implemented, the recommendations will help build a sustainable food system here as well as abroad. The recommendations call upon US policymakers, research institutions, and the private sector to work in partnership to overcome this challenge. Some are meant to be actionable within a short time horizon (one to two years), while others will require more analysis, discussion, and a longer time frame to succeed. Although some recommendations are for increased expenditures, many actions can be achieved by using existing resources more efficiently.

RECOMMENDATION 1

Make global food security one of the highest priorities of US economic and foreign development policy

ICRISAT/Swathi Sridharan

Making global food security a high priority of US economic and development policy was a topline recommendation in last year's Chicago Council report. It bears repeating this year. The federal government needs to commit now more than ever to a long-term strategy for addressing food and nutrition security given the additional impacts of climate change on an already growing and difficult problem. The scientific breakthroughs needed to move forward require years, even decades of lead time. Breeding new varieties of plants can take five to 15 years even for well-understood crops.[1] That's the year 2030 for just one new variety. The time needed for basic research, which is critical to addressing climate change and food and nutrition security, takes even longer. Current model results on the impacts of a changing climate suggest there is no time to waste. And as discussed in previous sections, actual impacts may come even more rapidly due to the limitations of current climate and food security models. We ignore this at our peril.

Over the past year, several important US policy actions have been launched. The US Department of Agriculture (USDA) announced the formation of seven regional "climate hubs" in February 2014, although without new funding. The 2014 Farm Bill created a new nonprofit foundation, the Foundation for Food and Agriculture Research, to leverage private funding to support agricultural research, matched initially with $200 million in federal dollars. The president proposed $1 billion to support research on adaptation in his 2014 budget. The administration has set up a one-stop shop for federal climate data at www.data.gov/climate. These actions build on activities already under way as part of the Feed the Future and the Global Climate Change initiatives. In the global policy arena, the United States was the first country to submit its views on the scope of a post-2015 climate accord to the global climate negotiations under the auspices of the United Nations Framework Convention on Climate Change.

While these are positive steps, more remains to be done to ensure a successful, long-term US commitment to addressing food and nutrition security in the face of climate change.

Action 1a: Congress should commit the nation to a global food and nutrition security strategy.

Congress should pass authorizing legislation that commits the government to provide resources for a global food and nutrition security strategy. The president should actively support this effort. The bipartisan Lugar-Casey Global Food Security Act introduced in 2008 is an example of the type of proposed authorizing legislation that is needed to galvanize the US government. Sustaining food and nutrition security as a top government priority beyond the current administration depends on congressional endorsement. It requires the entire US government to work together in partnership with academic institutions, the private sector, and nongovernmental organizations.

Climate change is not going away. Efforts to address its impacts require collaboration among agencies and constituencies across the US government and require a long-term approach to yield results. The job ahead requires a level of commitment that can only be sustained by congressional leadership and action. Congressional leadership is needed to provide funding for the initiative and hold officials accountable. A recent signature foreign policy success—the President's Emergency Plan for AIDS Relief (PEPFAR)—sprang out of close collaboration between Congress and the administration

Box 10 – About the Lugar-Casey Global Food Security Act

The Lugar-Casey Global Food Security Act was introduced in the Senate on March 31, 2009, but did not pass. The Global Food Security Act was a five-year authorization to focus US development assistance on long-range agricultural productivity and rural development. It aimed to establish a Special Coordinator's Office for food security within the Executive Office of the President and charged the office with developing a whole-of-government food security strategy. The bill would have authorized nearly $10 billion over five years for programs focused on improving the rural environment for farming and would have created a new program, the Higher Education Collaboration for Technology, Agriculture, Research, and Extension (HECTARE), to improve research capacity at foreign universities and the dissemination of technology through extension services.

Source: The Chicago Council on Global Affairs 2009.

of George W. Bush and has enjoyed continuing support from Congress since its launch. This same type of leadership is needed now on food and nutrition security for all the world's people, including Americans.

A global food and nutrition security strategy is affordable, bipartisan, and enjoys public support. The Chicago Council's 2012 report on American public opinion and US foreign policy found that 91 percent of Americans considered "combating global hunger" an important foreign policy goal for the United States, with 42 percent considering it "very important." The percentage considering this important has been consistent in Chicago Council surveys since they began in 1974.[2] In the 2012 survey, 79 percent of Americans also considered "limiting climate change" an important foreign policy goal for the United States.

Legislators cannot allow ongoing US fiscal issues to deter them from preparing agriculture for the future. The consequences of inaction put America's economic and national security interests—and its ability to ensure a safe, affordable, and nutritious food supply for its citizens and others around the world—at such risk that making the investments suggested in this report is the most financially prudent course of action.

Nor should partisan politics stand in the way of this legislation. Virtually every senator and many representatives have farming constituencies. Everyone in Congress has constituencies concerned about the availability of affordable nutritious food at home and abroad. The future competitiveness of US farmers hinges on their ability to adapt to climate change and innovate in order to overcome the challenges detailed in this report.

Each chamber of Congress should hold at least one hearing per year to determine whether the government is making sufficient progress on global food and nutrition security and take corrective action if progress is lagging. Hearings should involve the House Agriculture Committee and the Senate Agriculture, Nutrition, and Forestry Committee; the House Foreign Affairs Committee and the Senate Foreign Relations Committee; the House Science, Space, and Technology Committee and the Senate Commerce, Science, and Transportation Committee. Such joint hearings in each chamber are opportunities to bring the expertise of several committees together around a challenge that cuts across jurisdictions and disciplines to build support among various interest groups.

Action 1b: Align whole-of-government efforts on sustainable food and nutrition security and climate change.

Feed the Future should develop a strategy to address climate change and identify the resources to support it. The United States Agency for International Development (USAID), the implementing agency for Feed the Future, should ensure that it has the internal capacity, including senior staff, to assess the consequences of climate change for global food security and be charged with ensuring that climate change is recognized and incorporated throughout Feed the Future.

As this report makes clear, climate change harms food security, and food security initiatives can also alter climate change. Any program to support food security should take explicit account of the potential effects of climate change and the potential for productivity- and resilience-enhancing mitigation. And any activity that is designed to support adaptation should be undertaken explicitly in concert with food security activities.

Currently, two whole-of-government initiatives address these issues: Feed the Future and the Global Climate Change Initiative. Feed the Future is administered by USAID's Bureau for Food Security. The Global Climate Change Initiative activities at USAID are managed by its Office of Global Climate Change in the Economic Growth, Education, and Environment Bureau. USAID's regional bureaus also fund programs related to climate change and biodiversity.

The Feed the Future strategy and the multiyear country strategies do recognize the importance of adapting to and mitigating climate change. Nearly half of its research and policy investments address technology and system improvements needed to increase resilience and help smallholder farmers adapt to the impacts of climate change. This includes support for the Consortium of International Agricultural Research Centers (CGIAR), US universities, and developing country partners. These investments benefit greatly from the research undertaken by USDA scientists and those it supports at US universities. New Feed the Future initiatives include the Food Security Innovation Center, launched in late 2012, which now includes 23 Feed the Future Innovation Labs. The labs focus on efforts to develop climate-resilient corn, wheat, beans, cowpeas, sorghum, chickpeas, soybeans, small-scale irrigation, livestock, a food security policy lab, and several more.

The Global Climate Change Initiative is organized around three pillars: clean energy, adaptation, and sustainable landscapes. The implementation of the initiative at USAID is guided by USAID's climate change strategy, which prioritizes the development of low-emission development activities. Sample low-emission activities include clean energy investments and payments for forest-based carbon storage (REDD+ activities). Newer work on developing sustainable landscapes, which include agriculture, is also under way.

Clearly, these two initiatives overlap substantially in the area of agriculture. The independence of Feed the Future's and the Global Climate Change Initiative's work on agriculture increases the potential for inefficiencies in resource use across these two initiatives. For example, having adaptation activities in agriculture, as is done under the Global Climate Change Initiative, undertaken outside of Feed the Future creates the

Box 11 – About the Global Climate Change Initiative

In 2010 the Obama administration announced the Global Climate Change Initiative. The initiative is a US commitment to collaborate with its international partners to build resilience; integrate climate change knowledge and practice into the full range of bilateral, multilateral, and private mechanisms; and promote clean and sustainable economic development through adaptation and mitigation activities. The initiative, which stems from the 2010 Presidential Policy Directive on Global Development, is led by USAID, the US State Department, and the US Treasury Department. It relies on a variety of bilateral, multilateral, and private-sector mechanisms to achieve these goals.

In June 2013 President Obama announced the President's Climate Action Plan, addressing three primary objectives: cutting carbon pollution in America; preparing the United States for climate change impacts; and leading international efforts to combat global climate change and prepare for its impacts. The plan lays out a broad array of actions, from $8 billion in loan guarantees for advanced fossil energy and efficiency projects that support investments in innovative technologies, to calling for an end to US government support for public financing of new coal-fired powers plants overseas.

Sources: The White House 2013; USAID 2014.

potential for inefficiency. Similarly, because water issues are managed out of a separate office within the agency, there is potential for inefficiency and a lack of coordination on understanding climate-related water issues.

Because of the cross-cutting nature of climate change issues and because so many government agencies touch climate change activities related to global food security, there are several steps that could improve coordination and effectiveness.

First, Feed the Future should develop a stand-alone strategy on climate change. Feed the Future has issued independent strategies on cross-cutting issues such as gender and nutrition, and the US government would benefit from a similar approach to the climate change and food security issues. The strategy would more fully develop the initial plans on climate change adaptation and mitigation laid out in the overall Feed the Future strategy, highlight the good work currently being done, and set out goals for future work. It would also integrate relevant portions of the President's Action Plan on Climate into Feed the Future efforts and empower USAID, the agency responsible for Feed the Future implementation, with implementing climate change activities related to global food security. An important part of this approach is integrating information about climate change into country-level plans, including working with other government agencies, researchers, international organizations, and the private sector to strengthen its capacity to support adaptation and productivity-enhancing mitigation. It would lay out metrics for measuring progress, which the government should track annually through the Feed the Future progress report.

Second, USAID should ensure that it has the internal capacity to understand the range of effects of climate change on food and nutrition security and implement climate-smart agricultural activities. It should also ensure that there are senior staff able to offer policy and program guidance on a wide range of topics, from sources and uses of the most up-to-date climate data to recommendations on climate-smart approaches. Although important, internal capacity alone will never address all the technical and policy issues that could arise. USAID's Innovation Labs could play an important role in providing that expertise and more generally be a source of guidance on strategic decision making.

Finally, because the effects of climate change will be both global and local, this report recommends that Feed the Future continue to strengthen its support for advanced education of national scientists and their interaction with the global research community, building on promising programs such as the Borlaug Higher Education Agricultural Research and Development Program. The US government can be proud of its role in supporting the training of many of the world's agricultural leaders and its support for development of several of the world's top institutions of higher learning in agriculture. In the past five years, the US government has ramped up training the next generation of agricultural researchers. These efforts should be expanded to develop the local institutions abroad that can train scientists to deal with the local and global consequences of climate change.

Action 1c: Lead efforts to place climate change and food and nutrition security at the center of international agreements.

The United States should formally request that the IPCC undertake a report on climate change and food security drawn from relevant material in the three major reports from the IPCC's Fifth Assessment Report.

Major international decisions related to food security and climate change will be made in 2014 and 2015 under the rubric of the post-2015 Development Agenda. The list of events begins with the UN Climate Summit in September 2014 and ends with the UNFCCC Conference of Parties in December 2015. During this time, the UN seeks to establish an agreement on a set of Sustainable Development Goals augmenting the Millennium Development Goals approved by the UN in 2000 and an agreement on climate change adaptation and mitigation. The US government should work to ensure that food and nutrition security takes center stage in these discussions.

The UNFCCC negotiations on agriculture have been challenging, with no agreement even to commission a study under the auspices of its scientific review body (the Subsidiary Body for Scientific and Technological Advice) on adapting to climate change and reducing greenhouse gas emissions while enhancing agricultural productivity.

The IPCC is widely recognized as an impartial source of reviews of the scientific literature on all aspects of climate change. The just-released IPCC Fifth Assessment Report has scientific material that is relevant to the deliberations about agriculture, but also many other topics; each of the three component reports is about 1,500 pages.

The IPCC can undertake technical reports that draw on recent assessments, essentially collating that information for special purposes, without the extensive review process that accompanies reports from its working groups. The United States, in collaboration with other countries if possible, should formally request a technical report on food security and climate change that collects all of the information related to food security from the three working group reports, to be completed no later than June 2015. This would be of enormous service to UNFCCC negotiators and others preparing for the Paris Conference of the Parties in December 2015.

Box 12 – About Feed the Future

Feed the Future is the administration's global hunger and food security initiative. It is administered by USAID in partnership with other US government agencies, including but not limited to the State Department, the Treasury Department, the USDA, and the Peace Corps. In 2009 President Obama laid the foundation for Feed the Future when he called on global leaders to reverse declines in agricultural development investment and announced renewed US investment in global food security at the G8 Summit in L'Aquila, Italy. He set a powerful example by promising and then fulfilling $3.5 billion in US government spending from 2009 to 2012 to help smallholder farmers in low-income nations around the world.

Feed the Future partners with 19 developing countries in Africa, Asia, and Latin America and the Caribbean to reduce hunger and poverty. The initiative has a strong focus on research, technology, and policy reform, using a value chain approach. It focuses on boosting agricultural productivity and generating opportunities for economic growth and trade. The initiative seeks long-term solutions through a variety of approaches, including supporting partner countries' food security priorities; promoting international collaboration; empowering women farmers; supporting partnerships between research, civil society, and the private sector; and integrating agriculture and nutrition.

Source: Feed the Future 2014.

Beyond this immediate technical report, regular national and global assessments of climate change and food security should be undertaken. Middle- and high-income countries are increasingly carrying out regular assessments, but nations without this capacity need external assistance. The United States should also support the IPCC undertaking a special report on food security and climate change that assesses the growing literature in this area and provides detailed country-level data where appropriate.

Action 1d: Urge international action to use water resources for agriculture more efficiently.

Globally, agriculture accounts for approximately 70 percent of the world's fresh water withdrawals from rivers and groundwater.[3] In some regions, these sources are abundant, and fresh-water withdrawals are not problematic. In other areas, these sources are already stressed, as demand from human use, agriculture, industry, and energy generation continues to grow and supply does not. Furthermore, the infrastructure of water supply, from irrigation systems to residential delivery, is absent or deteriorating, and investment in new infrastructure is not keeping up.

Climate change makes this bad situation worse. It has already altered the annual availability of rainfall and its distribution throughout the year. Higher temperatures mean more precipitation on average, but its distribution across the planet could change substantially, with some regions receiving much more precipitation and others receiving less. The timing of the rains could change, shifting growing seasons, increasing the number of downpours in some places, and lengthening dry periods in others. The World Economic Forum's 2014 Risk Report ranks water crises as the third greatest concern globally after fiscal crises in key economies and structurally high unemployment/underemployment.

Climate change effects and the uncertainties associated with them make it even more important that this scarce resource is managed carefully—to the greatest benefit of human well-being. In too many places those who control access to water are not able to assess and leverage its value whether through price-based or other mechanisms. In some places ownership of access to water is not clearly codified, or the rules developed for its management are no longer appropriate. Management of water is made more challenging by its mobile nature, flowing across political boundaries, both domestic and international.

The international community must develop integrated land-use and water policies that promote efficient use of water resources, optimizing water management of river basins and aquifers. Where river basins include several countries, transboundary treaties will be increasingly important for efficient use of water. But even within countries, water management will be more challenging, as box 13 on the Colorado River illustrates. The US government should urge national and international communities to examine opportunities and implement strategies to increase the efficient use of water in the agriculture sector and reduce the potential for competition with growing municipal, industrial, and energy demands.

Land and water scarcity has already led some governments and corporations to purchase large land areas in Africa and Latin America. In at least some cases the

Box 13 – The Colorado River Basin: What happens when human laws contradict the laws of nature?

The Rocky Mountains act as a giant rain catcher in the middle of the North American continent. On the east side they channel moisture moving north from the Gulf of Mexico to the heartland. On the west side they grab moisture from storm systems that move northeast from the Gulf of California, north from the Gulf of Mexico in late summer, or east from the Pacific Northwest. Most of this western rain eventually flows into the Colorado River or evaporates.

The Colorado River is managed and operated under numerous compacts, federal laws, court decisions, contracts, and regulatory guidelines collectively known as the "Law of the River." The Colorado River Compact, signed in 1922 among seven US states, is the heart of this "law." It governs the allocation of rights to the river's water. The compact and subsequent agreements allocated specific quantities of water to each of seven states. Later research revealed that at the time of the agreement, the region was experiencing a relatively wet period. As demand grew in the lower basin states of Arizona, Nevada, and California and the region reverted to more historically typical precipitation patterns, the surplus available in 1922 turned into a deficit. Water from the river has not reached the sea since 1998.

Climate change is expected to raise temperatures in the US southwest. In Colorado, for example, the statewide average annual temperatures are projected to warm by 2.5°F to 5.5°F by midcentury and much more by its end. Summers are projected to warm slightly more than winters. Typical summer temperatures in the 2050s are projected to be warmer than all but the very hottest summers that have ever been observed in Colorado.

As is true everywhere, the future of rainfall in the region is much less certain. Small changes in weather patterns can shift large Pacific storms down the coast to California or east to the Rockies. The average across many of the climate models is for little change in rainfall in the region.

The higher temperatures mean greater evapotranspiration; one estimate is for an increase from 30 to 31 million acre feet of annual rainfall in western Colorado returning to the skies each year by 2050. With no increase in precipitation, the volume of water leaving Colorado via the river will decline by about 10 percent annually. More losses will occur as evaporation draws water from the river and the major reservoirs downstream.

The water allocations in the Law of the River are already in conflict with what is available from today's climate. As climate change progresses, the legal environment will have to adjust to what Mother Nature, as influenced by human activities, can provide.

Source: Richard 2014.

long-standing informal use rights of local farmers were ignored. Climate change could increase the demand for these acquisitions. Efforts to address climate change and food security should be sensitive to the rights of farmers in places where these rights are not already well enforced. Better developed property rights and transparency in all land purchases are important for food and nutrition security generally and adaptation to climate change.

Agriculture's use of water can also be improved through compiling better data on water scarcity and investing in innovations and infrastructure that promote water efficiency. Suggested actions on these points are explored in Recommendations 2 and 4.

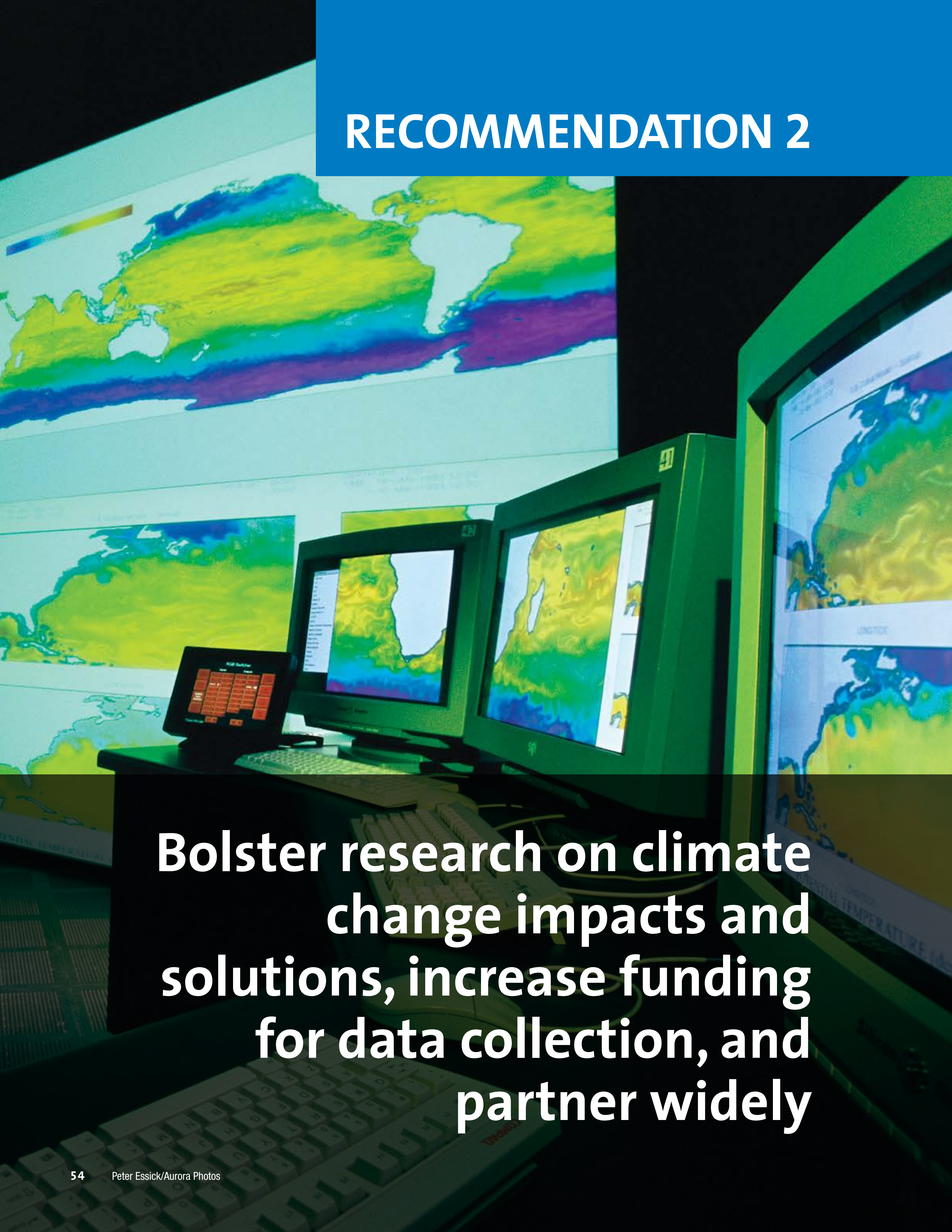
Box 14 – The Securing Water for Food challenge aims to improve water sustainability

Water scarcity is one of the most pressing development challenges of the early 21st century, with climate change compounding the problems arising from growing human, agricultural, and energy demand. To accelerate solutions, USAID, the Swedish International Development Cooperation Agency, and the Ministry of Foreign Affairs of the Kingdom of The Netherlands announced the launch of Securing Water for Food: A Grand Challenge for Development at the 2013 World Water Week in Stockholm, Sweden. The three agencies have committed a total of $32 million to the challenge to identify and accelerate innovations and market-based approaches to improve water sustainability, with the goal of improving food security and alleviating poverty.

The Securing Water for Food challenge will fund and provide acceleration support to science and technology innovators, entrepreneurs, businesses, students, and other organizations for projects taking place in developing countries. The challenge focuses on the following areas: water efficiency and reusing wastewater (especially along the food value chain); water capture and storage; and salinity and salt water intrusion. These focus areas aim to enable food production with less water, or make more water available for food production, processing, and distribution.

The selection process for the first challenge is currently under way, and winners will participate in an acceleration event during World Water Week 2014. The first call for innovations received applications from 520 organizations from over 90 countries, proposing work in over 60 countries in nearly every region of the world. The second challenge, called the Desal Prize, will start in June 2014 with the goal of accelerating the creation of small-scale brackish water desalination technologies that bridge gaps in the current technology market and can be used by smallholder farmers.

Source: Securing Water for Food 2014.



RECOMMENDATION 2

Bolster research on climate change impacts and solutions, increase funding for data collection, and partner widely

Peter Essick/Aurora Photos

The US government must increase funding for basic and applied research to address threats to the food system from climate change and opportunities for greenhouse gas mitigation that also enhance food and nutrition security. These funds should be used in partnerships with the private sector, US academic institutions, other national research organizations, and the international research community, in particular the CGIAR Consortium.

The US government should also launch a major effort to reclaim its leadership in the provision of global data as a public good. The effort should improve global data collection and dissemination to understand the global resources needed to support sustainable food and nutrition security. It should draw on recent advances in sensing technology, including remote sensing from satellites and aircraft and improved ground-based sensors of various kinds. Partnerships with the other governments and the private sector should be a key part of this effort.

In last year's report, the Council recommended that the world should "forge a new science of agriculture based on sustainable intensification" and recommended a doubling of US investment in agriculture and food research. Since that time several announcements underline the fact that important elements of this recommendation are widely endorsed. These include the establishment of the Foundation for Food and Agricultural Research and the USDA climate hubs (box 15), the announcement that funding from all sources for the CGIAR Consortium reached $1 billion in 2013,[4] the recent creation of food security centers at leading academic institutions, and major initiatives by private foundations.

Yet despite recent global growth in funding, agricultural research efforts remain underfunded, especially in the United States (see box 16 for information on spending trends).[5] This year's report repeats the call for increased funding as suggested in 2013 and calls for additional resources to be focused on climate change impacts and solutions.

Some high-level priorities for research based on what is known already about the effects of climate change are suggested in Action 2a. Moving forward, since productive investment decisions need better assessments about future threats, Action 2b calls for improvements in modeling and data collection to provide those assessments. Action 2c proposes funding for new partnerships that take advantage of the research talent in US universities, other public research institutions at home and abroad, and the private sector.

Action 2a: Fund more and varied research on adaptation and mitigation.

Dealing with climate change will require resources to be devoted to new research areas for both adaptation and mitigation in agriculture. While much can be done to adapt the food system to climate change using existing knowledge and technology if it is made available to farmers in appropriate ways, breakthroughs in basic and applied science are crucial to address anticipated challenges.

A refocusing of research to address a more complex set of objectives beyond the traditional focus on increasing yields is required. Consideration of water and soil conditions and of the resilience of yields to varying weather should be better integrated into current research. Climate change effects on the nutritional characteristics of food should be an explicit research focus. Crops and other plants with new temperature

Box 15 – About the USDA Regional Climate Hubs

USDA has launched a program to help farmers make informed decisions based on climate change effects in their locales. The Regional Hubs for Risk Adaptation and Mitigation to Climate Change will help farmers, ranchers, and forest landowners make decisions about how to respond to climate change by providing science-based knowledge on management options and program support.

Climate hubs will address specific growing risks from climate change such as fires, pests, flooding, and droughts by translating science and research into practical information that farmers, ranchers, and forest landowners can use to adapt to climate change and manage resources. The seven climate hubs are in the following locations:

- **Midwest:** National Laboratory for Agriculture and the Environment, Agricultural Research Service, Ames, Iowa
- **Northeast:** Northern Research Station, Forest Service, Durham, New Hampshire
- **Southeast:** Southern Research Station, Forest Service, Raleigh, North Carolina
- **Northern Plains:** National Resources Center, Agricultural Research Service, Fort Collins, Colorado
- **Southern Plains:** Grazinglands Research Lab, Agricultural Research Service, El Reno, Oklahoma
- **Pacific Northwest:** Pacific Northwest Research Station, Forest Service, Corvallis, Oregon
- **Southwest:** Rangeland Management Unit/ Jornada Experimental Range, Agricultural Research Service, Las Cruces, New Mexico

Source: USDA 2014.

Peter Essick/Aurora Photos

optima, that have a more plastic response to variable weather, and that can use water more efficiently or grow on saline soils are examples of innovations that may help climate change adaptation. Similarly, animal breeds that are more resilient to climate stress would be advantageous.

In some circumstances neglected and underutilized species of plants and animals will be required to maintain productivity on land that climate change has rendered marginal for agriculture. These “orphan” species have not received nearly as much research attention, public or private, as staple varieties.* The founding of the African Orphan Crops Consortium with partners that include private companies, national and international research centers, the African Union, and nongovernmental organizations[6] is a promising start to redressing that neglect. Recent advances in genetics allow modern plant and animal breeding to be applied to many more species than until recently was possible. Species such as sorghum, millet, beans, and a range of roots and tubers are candidates, as are indigenous varieties of fruits and vegetables. Involvement from the start of the farmers who currently grow or might grow these crops in the design of any breeding program is essential. The food industry should also expand the range of crops it uses.

Priority setting for agricultural scientific research must explicitly incorporate a range of plausible climate change effects, recognize the importance of “systems” thinking such as landscape approaches, and include new and innovative data collection efforts to provide the empirical underpinnings for new activities. Food companies must address their contributions to the dual problems of undernutrition and obesity and identify cost-effective improvements in food technology that reduce waste.

Finally, it is essential to monitor and evaluate different adaptation and mitigation strategies on the ground. Resources for assessing progress against agronomic and social targets should be included in program design, and improving monitoring and evaluation should itself be a research target.

The following list identifies five categories of research priorities for investments based on the current understanding of the challenges to food security from climate change.

Increased tolerance to higher temperatures

Rising temperatures will eventually cause yields to decline everywhere.[7] Basic research is needed into the options for reducing these losses while increasing productivity and enhancing nutritional characteristics. One example is the C_4 rice project lead by the International Rice Research Institute that attempts to make a fundamental change in rice biology to improve its efficiency in converting carbon dioxide into plant material while also increasing heat tolerance.[8] These efforts can delay the worst outcomes, but unless greenhouse gas emissions are reduced, temperature increases eventually will be too great for any effective intervention.

Increased resilience to variable weather and extreme events

Many plants have narrow windows of temperature and water needs for optimal performance. For example, high temperatures and dry conditions during flowering or grain

* “Orphan crops” are food crops and tree species that have been neglected by researchers and industry because they are not economically important on the global market.

Box 16 – Recent global research spending trends reverse historical decrease, but US domestic spending is stagnant

Researchers in both the public and private sectors at home and abroad have played changing roles in the successes of the global food system. In 2008, the latest year for which globally comparable numbers are available, annual spending on agricultural research globally was just over $40 billion. Of this amount, $32 billion was spent by the public sector (79 percent), split roughly evenly between high-income countries (US spending was $4.8 billion) and low- and middle-income countries.[9]

Following a decade of slowing growth at the end of the 20th century, global public spending increased by 22 percent from 2000 to 2008. Spending by China and India accounted for close to half of the global increase. Little spending growth occurred in developed countries, including the United States. Although CGIAR plays an important role in agricultural R&D in developing countries, it accounts for only a small share of global public agricultural R&D spending (1.8 percent in 2008). The CGIAR has seen a major increase in spending recently, from $531 million in 2008 to $860 million in 2012, an increase of almost 62 percent in that four-year period.[10]

Private-sector investment in agriculture and food processing R&D increased from $12.9 billion in 1994 to $18.2 billion in 2008, an increase of 41 percent. About 45 percent of this amount was directed to R&D related to improving inputs used in agricultural production, with the remainder directed to areas related to food processing and product development.[11]

Over the past several decades, the real rate of growth of US funding for public agricultural R&D has gradually slowed, and in more recent years spending has actually decreased. US funding for productivity-enhancing research has also fallen from 65 percent of total public spending in 1976 to 56 percent in 2009. Private spending has increased to 58 percent of total public plus private spending, up from a roughly equal share through the end of the 1980s. Federal versus university research spending has shifted from roughly equal shares around the middle of the 20th century to nearly three-quarters conducted by universities in recent years.[12]

There are no global statistics on the share of research expenditures devoted to adaptation and mitigation. A partial measure of this is funding for CGIAR's Climate Change, Agriculture, and Food Security Research Program (CCAFS), which was just under 9 percent of the 2012 CGIAR budget.[13]

filling can substantially reduce corn yields. Potato yields are substantially reduced if nighttime minimums are much above 68°F (20°C). Many temperate fruits require an extended cold period for fruit production. Successful research will produce crops that yield more under a wider range of weather conditions during the growing season.

An example of potentially successful research to deal with flooding in rice cultivation has been recently announced. Deepwater rice, cultivated in Bangladesh and elsewhere, can grow up to a foot a day to keep leafy material above seasonal floods. Japanese researchers recently discovered two "snorkel" genes that trigger this response.[14] Successful incorporation of these genes in other plants might increase their odds of survival when heavy rainfall floods fields. Other opportunities for research in this area include plants that have evolved in areas with frequent drought or saline intrusion.

More varied farming practices that leverage system dynamics

In much of the developing world, fields are planted with multiple crops at the same time and with two to four harvests throughout the year. In today's developed countries, agricultural production takes place largely in fields sown to a single crop. This simplification has come about in part because it facilitates the use of high-yielding technologies. Mixed systems remain where policies discourage use of the newer technologies or because their managers value traits such as acceptable performance in a risky environment. To benefit from mixed farming systems, farmers must experiment continuously to find desirable practices. On individual farms, farmers experiment over generations to find combinations that take advantage of local conditions and meet local needs. The question is whether these local optimizations can be scaled up. If recent breakthroughs in analysis of big data, application of information technology to farm management (including automated devices), and computational biology are combined with farm-level data of sufficient quality and diversity, the scaling up may indeed be possible.

Management strategies for combating pests and diseases

Climate change will generally increase pressures from existing pests and diseases and create conditions that may exacerbate the pressures from and the establishment of invasive species. The range of research needs begins with new rapid diagnostic tools and models of pests and disease pressures integrated with crop, environmental, and economic models. For both developed and developing countries, it includes the investment in and maintenance of phytosanitary systems that exclude new pests and anticipate the introduction of new invasive species. It requires novel methods of control and eradication that explore the use of beneficial insects and microbial strategies for defense, effective eradication tools, and research for improvement or replacement of fumigation protocols.

Reduced waste from farm to fork

By some estimates approximately one-third of food is wasted. In high-income countries it is wasted largely by consumers. In low-income countries a third of the food does not reach the market due to insufficient storage facilities, pests, and rot. Technologies that can reduce these losses cost effectively would be highly beneficial. Less waste would help ease production pressures, thereby reducing agricultural greenhouse gas emissions as less expansion of land area is required and fewer inputs that produce greenhouse gases are needed.[15] Innovation from the private sector can help address this challenge. This topic is addressed in more detail in Recommendation 4.

Action 2b: Develop more sophisticated models and collect better data.

US government research funding (in particular USDA and the National Science Foundation, in partnership with USAID and the Department of Energy, as appropriate) should support a systematic public- and private-sector effort to develop modeling tools and collect the data needed to accelerate advances in plant and animal technologies and water management. Such advances will help increase productivity, enhance nutrition, increase resilience to the effects of climate change, and contribute to reduced greenhouse gas concentrations.

Box 17 – Blue skies research holds promise for food security, climate change adaptation, and mitigation

Blue skies refers to scientific research where "real-world" applications are not immediately apparent but could potentially have great value. Some examples follow that could eventually contribute to global food security and climate change adaptation and greenhouse mitigation. These have the advantage of having a model technology to follow, "invented" by mother nature sometime in the distant past.

Transfer nature's improved photosynthesis to more plants

About 97 percent of all plants use a method of carbon fixation in photosynthesis called C_3. The remaining 3 percent have evolved more recently to use a method called C_4. Most crops are C_3, but a few, like corn and sugarcane, use the C_4 method. C_4 plants have an advantage in environments with drought, higher temperatures, and low nitrogen availability and use carbon dioxide more efficiently. The C_4 rice project led by the International Rice Research Institute is attempting to convert rice from the C_3 to C_4 method. If this is successful, it could also be applied to other C_3 food crops, potentially improving productivity and resilience in the face of climate change.

Convert annual crops to perennial

Annual crops that grow and die within one year provide most of our plant-based food supply. Perennial crops such as trees and forage grasses are alive year-round and are harvested multiple times before dying.

Fields with perennial crops offer many benefits for food security and climate change adaptation. The benefits include reduced soil erosion because perennial crops have greater root mass and protect the soil year-round; reduced chemical runoff and more effective fertilizer uptake because their extensive root systems are more efficient at absorbing chemicals; and lower fossil fuel emissions than annual agriculture because annual tillage is not needed.

Many of our food crops are related to grasses and have wild ancestors that are perennial. If the traits that lead to perennial behavior could be transferred to annual food crops, it might result in substantial improvements in productivity and resilience to climate change.

Adapt more crops to exploit the nitrogen-fixing advantages of legumes

The ability of crops such as legumes to convert atmospheric nitrogen to ammonium, which is usable by some plants, has the potential to replace the need for nitrogenous fertilizer. Legumes attract the symbiotic bacteria Rhizobia to root nodules where the conversion takes place. If this symbiotic relationship could be transferred to nonleguminous crops, it could greatly reduce the need for added inorganic fertilizer.

Incorporate the biology of salt tolerance in more crops

There are large areas of the world where salt build-up in the soil and brackish groundwater make agriculture difficult or impossible. Higher sea levels from climate change will make this problem worse for low-lying coastal regions. Salt-tolerant plants, called halophytes, can tolerate much higher levels of salt concentrations in water than most agricultural plants. To exist in such conditions, halophytes have evolved to extract pure water and store salt in special parts of the plant. If this mechanism could be transferred to food crops, it would make production possible in some marginal areas and keep coastal agriculture viable in the face of rising sea levels.

Low-energy desalination

Most of the world's water is in its oceans and is too saline for agricultural use or human consumption. Desalination technology is available and used where fresh water is scarce, but it is expensive and requires large amounts of energy. Recent advances have improved the efficiency of salt extraction and lowered energy requirements, but it remains expensive. Research that exploits the process halophytes use might result in substantial reduction in the costs and energy use of desalination.

Low-energy production of nitrogenous fertilizer

The success of the Green Revolution in agriculture was driven in part by the widespread availability of nitrogenous fertilizer produced by the energy-intensive Haber-Bosch process invented about 1915 that uses methane for the hydrogen and nitrogen from the air to produce ammonia. Since that time relatively few advances have been made in this technology. Understanding the processes used by nitrogen-fixing bacteria might reduce the cost and energy use of current fertilizer manufacturing technologies.

S. Kilunga/CCAFS

Box 18 – Projects seek to improve global modeling

There is a growing recognition that judicious use of software models that incorporate interactions between biophysical and socioeconomic factors can improve strategic planning and investment decisions. Many efforts are under way to improve these models. Two are highlighted here.

The Agricultural Model Intercomparison and Improvement Project (AgMIP)

The Agricultural Model Intercomparison and Improvement Project (AgMIP) is an international effort linking the climate, crop, and economic modeling communities with cutting-edge information technology to produce improved crop and economic models and the next generation of climate-impact projections for the agricultural sector. It aims to identify world food security risks in the face of climate change and improve developed and developing countries' adaptation capacity.

AgMIP supports teams of experts in crop and economic modeling and holds topic-specific and regional conferences as well as an annual Global Workshop that bring together the agricultural modeling community to share interdisciplinary progress and advance ongoing initiatives.[16]

AgMIP global gridded crop model results show steadily decreasing yields for wheat, corn, and soybean in mid- and high-latitude regions even for small temperature increases and greater vulnerability in lower latitudes. This initial crop model assessment characterized global crop model uncertainty for the first time, highlighting the need for continuing rigorous model evaluation and improvement.[17]

FOODSECURE

FOODSECURE is an interdisciplinary project supported by the European Commission that brings 19 partner organizations from 13 countries together to address the future of global food and nutrition security through rigorous analyses and stakeholder participation. FOODSECURE uses modeling to better understand the determinants of global food and nutrition security, help decision makers predict and prepare for future food and nutrition crises, and guide the pathways for technological and institutional changes and policies.

Like AgMIP, FOODSECURE also brings leaders in the modeling community together through conferences and other events to collaborate and share information on pressing issues related to modeling and food security.

Sources: AgMIP 2014, FOODSECURE 2014.

Neil Palmer/CIAT

The effects of climate change on food and nutrition security are just beginning to be felt, and the consequences are expected to become increasingly severe. Substantial uncertainty remains, however, about the effects all along the value chain, from farmers' fields to consumers.

More sophisticated assessments of current and future climate change impacts are needed to validate existing research priorities or propose changes. Such assessments require improved modeling of plant, animal, and food system performance and related greenhouse gas emissions combined with supporting data collection efforts. Public-private partnerships will be essential to this task. Model development as a public good is likely best undertaken with the public sector in the lead, but with substantial private-sector input. The private sector can then expand the models to facilitate their internal priority processes. Both the public and private sectors collect large quantities of potentially relevant data, but neither make them readily available. Some efforts to gather data and make them publicly available are under way—such as the Open Agriculture Data Alliance and the Global Open Data for Agriculture and Nutrition initiative—but more needs to be done.[18]

More sophisticated models improve priority setting and research

As described in section 3, current models of how climate change impact food production and food security are inadequate to drive decision making and priorities for adaptation and mitigation. Individual models and how they work together must be improved. To do this, four related efforts are needed: (1) systematic improvements to existing model types (hydrology, crop, economic, integrated assessment, climate), (2) improved comparison of model results and understanding of the sources of differences in their outputs, (3) improved data collection to support modeling, and (4) development of data and code-sharing protocols to facilitate model integration.

Partnerships to improve these models should include national and international public-sector research institutions, academic institutions with existing or planned programs on food security (see Action 2c), and companies involved in the development of agricultural technologies, both biological and informational.

Recent information technology and biology breakthroughs offer an opportunity to dramatically improve modeling of plant, animal, and pest behavior under differing climatic conditions to speed up the process of developing new varieties and management practices to deal with those conditions. For example, translational breeding—the adaptation of information derived from genome technologies for crop and livestock improvement—is an important new area of research that is targeted in the president's 2014 budget for an increase in funding by USDA. Better coordination of national and international initiatives and resources on data collection and modeling that can accelerate an assessment of the problems and identify resource allocation issues is critical. This should be one of the key activities of the newly created Foundation for Food and Agricultural Research.

You can't manage well what you don't measure: Better data are essential

Better data are essential to understanding what the problems really are and identifying priorities for research. The costs of collecting the needed data have been declining. But the expenditures have been declining more rapidly. Institutional innovations can make

Box 19 – FEWS NET and AMIS help prepare for unpredictable weather

Agricultural stakeholders at all levels are increasingly turning to big data to inform decision making and long-term strategies. Innovative methods for gathering, sharing, and utilizing data are crucial to heading off humanitarian crises that may arise as climate change affects food security and to helping farmers adapt to more unpredictable weather and climate conditions. Two examples are described here.

FEWS NET

The Famine Early Warning Systems Network, or FEWS NET, is an innovative approach to tackling short-term food security threats before a crisis strikes. In 1985 USAID created FEWS NET after famines devastated East and West African nations. With 20 field offices, FEWS NET provides objective, evidence-based analysis to help governments and relief agencies prepare for and respond to crises.

FEWS NET monitors over 35 of the world's most food-insecure countries in conjunction with US government science agencies such as NASA and the US Geological Survey as well as local government ministries, international agencies, and nongovernmental organizations. Their products include monthly reports and maps outlining current and projected food insecurity; alerts on emerging or likely crises; and specialized reports on such topics as weather and climate, agricultural production, and markets and trade.

AMIS

The Agricultural Market Information System (AMIS) was established in 2011 at the request of the G20 ministers of agriculture to improve transparency in the food market and encourage coordinated policy action in response to market uncertainties. As an interagency platform, AMIS aims to improve collaboration between countries that produce, import, and export food, with a particular focus on wheat, corn, rice, and soybeans. AMIS achieves its mission through market monitoring and analysis; production, trade, utilization, and stocks statistics for wheat, corn, rice, and soybeans; capacity development; and policy dialogue and outreach.

AMIS also operates the Global Food Market Information Group, which assembles countries' technical representatives to gather and share food market data, and the Rapid Response Forum, where senior officials develop and coordinate policies and common strategies.

Sources: FEWS NET 2014; USAID 2014; USGS 2011.

existing expenditures more productive, but increasing resources used to collect data while protecting privacy will also be essential.

The US federal statistical system is ill-equipped to collect and manage the data needed to assess climate change effects. Relevant data sets are found at the National Oceanic and Atmospheric Administration, the Departments of the Interior and Agriculture as well as other agencies. The announcement in early 2014 by the administration of a central place for climate change–related data is a welcome first step in organizing existing data, but new data are also needed. Although regular, repeated observations from space are essential to understand processes on the earth, the National Aeronautics and Space Administration does not see operational activities in its mandate. There is a great need for a systematic assessment of data needs and possibly a congressional directive on which agency should receive funding to support rationalization of existing data collection efforts and new data collection.

New data collection efforts and improvements to existing efforts are essential and relatively low cost. Data collection should include partnerships with governments, universities, international research organizations, farmers, and the private sector. Agriculture around the world today is already subject to a wide range of weather conditions. Farmers are intimately familiar with what works and what does not in their fields today. Collecting data on their practices now will provide some information on what might work in different locations as the climate changes. Agricultural researchers frequently collect data, but seldom do so with an eye to their broader usefulness. The private sector collects data to support its own activities, but seldom assesses whether they could contribute to a public good without harm to its own competitive position.

Six data sets are crucial to understanding climate change challenges and identifying priorities for research investments and policy innovations: (1) data on weather, (2) data on water availability, water quality, and future water requirements, (3) agronomic data for parameter estimates in crop models, (4) data on land cover and land use, (5) data on consumer preferences, and (6) data for parameter estimates in economic models (see box 20).

Action 2c: Upgrade and strengthen university and private-sector partnerships.

US funding agencies should encourage leading US academic institutions with food security programs to harmonize efforts, reduce duplication, and increase efficiency and productivity of public- and private-sector resources.

US academic institutions are home to the world's leading scientists with the skills to address the research challenges identified above. But this expertise is too often scattered across multiple departments in separate colleges, making partnerships difficult. Partnerships of a variety of kinds will become increasingly important to efficient use of research resources. Several leading US academic institutions have developed centers that currently undertake or plan to devote significant human and financial resources to research and education activities relevant to food security and climate change, with multidisciplinary work a central part of their activities. It seems desirable to explore what is under way or planned, especially as it relates to the need for improved modeling of food and nutrition security and climate change identified in Action 2b.

There are likely opportunities for synergies across these institutions, taking advantage of their different strengths. Cooperation between the public and private sectors on basic and applied precompetitive research should be encouraged. The Foundation for Food and Agriculture Research, with its mandate of matching public-private funding, can play a catalytic role in encouraging cooperation among these academic institutions and with the private sector.

Partnerships internationally are also necessary. The private-public partnership between Monsanto and the CGIAR Consortium's agricultural trials repository to make some of its corn trial data available is one example. Public-public partnerships will also be increasingly important. The agricultural research programs of China, India, and Brazil are comparable in size and productivity with those of most developed countries and are growing rapidly. Public-sector research programs in many middle and low-income countries were allowed to wither at the end of the last century. They are being rebuilt, but more is needed.

Box 20 – Priorities for data collection

Improved data collection efforts are among the most pressing needs in addressing climate change impacts on food security. The following are key areas where more data are desperately needed.

Weather

It goes without saying that farming worldwide depends on the weather. With good seasonal weather forecasts and up-to-date weather information, farmers can plan both short- and long-term activities to reduce the risk of damage. With the instances of severe weather on the rise, the agricultural community worldwide needs to stay ahead of the game in the area of weather forecasting. And longer-term investment strategies require regular repeated observations of weather data over many years. This means effective use and continued modernization of weather satellites and related tools. Too much of the world's weather data are behind pay walls with high costs and restricted access. Governments and the private sector should continue to invest in the most modern methods for collecting weather data and predicting weather and improve ways of communicating this information broadly.

Weather data are the foundation on which adaptation strategies are built. Adaptation necessitates the most accurate weather data possible, both for short-term planning and for longer-term priority setting and analysis. The United States and other governments must increase funding to collect this information, in partnership with the private sector where appropriate. For example, cell phone towers could also support automated weather data stations—especially in developing countries, where towers are often located and weather data are sparse—an approach the G20 endorsed in its 2012 Los Cabos meeting.

Water availability, water quality, and future water requirements

The stresses on water resources are already mounting, and climate change will only exacerbate this problem.[19] Climate change will increase the number of extreme rainfall events with potential for rapid rises in stream levels and flooding.[20] A clear understanding of current availability of water, coupled with scenarios of future needs, can provide managers with information about the problems they face now and how they might change.

Water data collection has been reduced everywhere. For example, at home and abroad the number of stream gages, crucial in understanding seasonal river flows, has been declining. The US Geological Survey reports that 656 stream gauges have either been lost or are at risk of shutdown because of lack of funds.[21] This trend needs to be reversed.

Crop models

Crop models are critical for understanding crop performance under varying soil, weather, and water conditions as well as with varying inputs such as seed varieties and fertilizers. Yet today's crop models cannot simulate the effects of important climate phenomena of food systems or greenhouse gas emissions resulting from agricultural activities. Perhaps most importantly, the most widely used crop models were developed using data collected primarily for crops grown in temperate regions.

There has been too little communication and data sharing between plant breeders and crop modelers. For relatively little additional expenditure, plant breeders could collect data that would greatly improve the performance of today's crop models. Another area of potential for improving crop modeling is to incorporate the advances that have been achieved in computational biology, where scientists are combining innovative computational tools with extremely detailed understanding of the underlying processes of plant growth and development.

Land cover and land use

Addressing the effects of climate change requires an understanding of how land is used today and what drives land use change. Global data sets of current land cover are highly inadequate and there are no reliable global data on changes in land cover and land use. Part of the problem is inconsistent approaches to converting raw data, typically sensed from satellites, into useful land cover classifications, e.g., what percentage of crown cover constitutes a forest. But lack of comparable raw data with global coverage is also an issue.

Satellite-based remote sensing data, in particular from the Landsat satellites, have been the workhorse of land cover data, but their temporal and spatial resolutions are not adequate for understanding agricultural changes. Much agriculture in the developing world takes place in fields that are 16 to 33 feet (5 to 10 meters) on a side, but Landsat satellites only collect information at 98-foot (30-meter) resolution. A growing season for many crops is three or four months with continuous change in plant characteristics. But Landsat images are available only three times per growing season in ideal conditions and often less frequently.

The United States no longer leads in this area. Other countries are launching remote sensing sites with more appropriate characteristics. Examples include the European Union's Sentinel system and the Chinese Brazilian Earth Resources satellites. The private sector is working on small, inexpensive satellites with the potential to address these constraints. Planet Labs, for example, recently launched 28 microsatellites. These approaches should be encouraged, with the caveat that a critical need for assessing food security is for regular, repeated observations at appropriate spatial and temporal resolutions with free access to the data.

Consumer preferences

To understand what food demands farmers will need to meet in the future, a clear understanding of today's demands and what determines them, e.g., income, government subsidies, distribution networks and infrastructure, culture, family structure, and food prices, is needed. Twenty to 30 years ago the agricultural economics profession undertook path-breaking work in collecting data and estimating the determinants of food demand. But that research has languished and much of the economic modeling relies on consumer preference estimates that are very old. Consistent estimates need to be developed to better understand global preferences using innovative public- and private-sector methods and new consumer behavior surveys. This research will also be helpful in understanding what might be driving people toward or away from a diverse diet that promotes health.

Economic modeling

Data for the economic modeling of agriculture must be improved to help understand potential global impacts of climate change. A recent study comparing the results from nine of the world's leading global economic models found large differences in their simulations of the effects of climate change due to differing parameters and functions describing today's economic activities and tomorrow's responses to climate change.[22] Adopting consistent parameter estimates for today, as described above for demand preferences, would reduce some of the differences. Clarifying assumptions about tomorrow's values—such as the ease of converting tropic rainforests to cropland—is needed.

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RECOMMENDATION 3

Include climate change adaptation in trade negotiations

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Beyond its importance to food and nutrition security and development generally, the global food trade has a specific role to play in climate change adaptation.[23] With the effects of increasing weather variability and more extreme events felt over a greater geographical range, an efficiently functioning international trade system can allow one region to substitute for production shocks in another. Policies to support these trade flows should be a priority in international trade negotiations.

In addition, agricultural price volatility is likely to grow with increasing weather variability. Policymakers need to consider how best to structure trade and market access policies to deal with food supply emergencies and price spikes, what level of information transparency is optimal in the public and private sector, and whether or not there is merit in proposals for real or virtual intervention stocks. Domestic policy decisions need to take into account the global nature of climate change and the importance of international risk sharing that relatively open and transparent international trade can provide.

Because climate change presents global challenges, global solutions are preferable. However, regional agreements can provide important intermediate results that allow for some experimentation with a range of approaches.

After many years of exceedingly slow progress on the Doha Round of the WTO negotiations, the WTO ministerial in Bali in December 2013 revived the prospects for further progress in global trade negotiations. A key decision was to undertake a work program on food security and trade over the next five years.

In addition, two regional trade negotiations provide shorter-term opportunities for US actions that support sustainable, resilient food security and address the challenges of climate change. These are the Trans-Pacific Partnership (TPP) among 12 Pacific Rim nations that includes some 40 percent of the world's total production and the Transatlantic Trade and Investment Partnership (TTIP) between the European Union and the United States. Both have desired completion dates in the near future, contingent on Congress approving legislation to provide Trade Promotion Authority. These negotiations offer a unique near-term opportunity to facilitate adaptation to climate change through international trade flows.

Action 3a: Include controls on export restrictions in the TPP and TTIP negotiations.

As a result of the food crisis of 2008, food and nutrition security concerns have become more visible in agricultural trade negotiations. And with growing use of export restrictions, access to supplies is increasingly recognized as being as important as the traditional goal of access to markets. Current WTO rules are unclear or inadequate on food security matters, and the Doha negotiating mandate does not allow much room to make progress in addressing these concerns. Climate change will make the challenge of achieving food security domestically much harder in some countries. Global food trade will play an increasingly important role in a world facing climate change.

The TPP and TTIP negotiations should include rules that clearly identify and limit the situations in which export restrictions are allowed. More meaningful control on quantitative export restrictions would need to be accompanied by closer monitoring to assure that existing and any new rules are being followed. The TPP and TTIP agreements currently being negotiated could be the starting points for implementing these changes. At the same time, any new measures should not lead to perverse incentives that increase environmental damage or distort markets.

Action 3b: Incorporate climate change adaptation and resilience in the WTO work program on food security.

Stockholding* is undertaken by a wide range of market participants to reach a wide range of needs. The private sector views stockholding as an essential part of supply chain management, hedging against unforeseen outcomes in the market and ensuring adequate supplies for operations. Similarly, public-sector stockholding can provide a food security hedge on unforeseen production shortfalls or disturbances in the marketplace that cannot be easily dealt with by the private sector. With increasing variability due to climate change, it is likely that optimal levels of stockholding by both public and private sectors will increase.

The WTO currently allows quantitative restrictions on exports to support domestic availability under a food security justification. But this rule can actually worsen food and nutrition security as climate change effects become more severe, especially when information on stockholding is not readily available.†

The Work Program for food security agreed to in Bali in December 2013 provides a forum where issues of stockholding for food security should be explored. In these discussions, building resilience and adapting to climate change should be taken into account in developing good food and nutrition security policies. The distortionary effects of excessive public stockholding as well as export restrictions should be recognized and alternatives explored. Innovative solutions to stockholding such as prepositioning stocks for regional shortfalls or public-private partnerships should be considered. This report recommends that the information provision elements of General Agreement on Tariffs and Trade (GATT) Article XI be significantly strengthened and that an information dissemination mechanism, perhaps through the newly developed AMIS, be part of any new trade agreements.[24]

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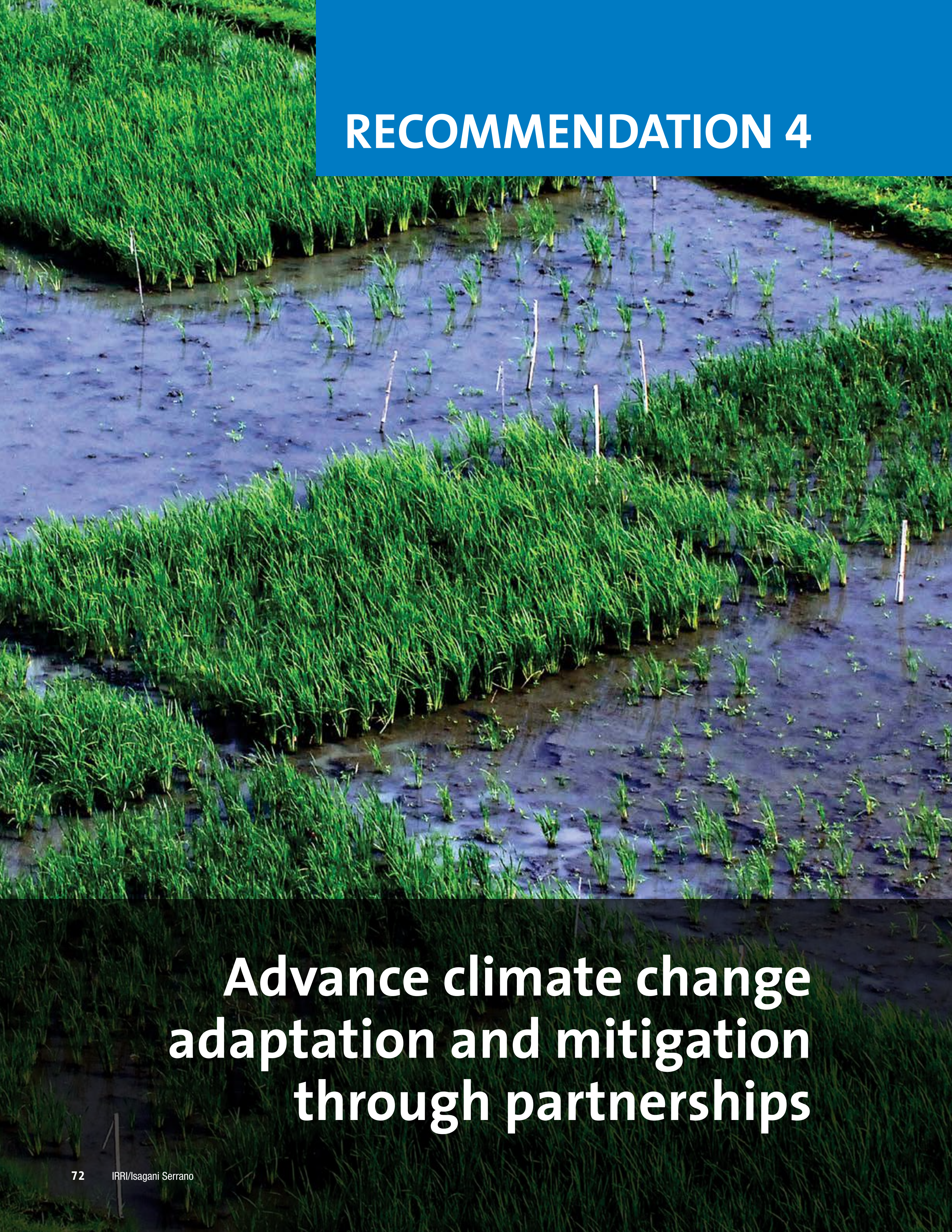
* Stock holding is a term used in agriculture for the storing of produce for use at some future time.

† "Under WTO rules, countries can restrict exports of agricultural products, but only temporarily, and they have to comply with GATT Article XI (ie, 11), in this case paragraph 2(a), and with Article 12 of the Agriculture Agreement. These require the restricting country to take into account the impact on importing countries' food security, to notify the WTO as soon as possible, and as far in advance as possible, to be prepared to discuss the restriction with importing countries and to supply them with detailed information when asked for it." Source: WTO 2014.

RECOMMENDATION 4



Advance climate change adaptation and mitigation through partnerships

IRRI/Isagani Serrano

While scientific research and innovation are critical to adapting to and mitigating climate change impacts on food and nutrition security, these efforts are of no use unless they can be implemented in the field and across the value chain. Here, as in the other recommendations in this report, partnerships between the public and private sectors are of critical importance. The new Foundation for Food and Agricultural Research explicitly recognizes the benefits of such partnerships. This recommendation focuses on three specific opportunities for partnerships—in information sharing (extension), insurance (risk sharing), and infrastructure (deferred maintenance and creation). The government should actively partner with other governments, regional organizations, and businesses in carrying out this recommendation. The Millennium Challenge Corporation, the Overseas Private Investment Corporation, and the USDA could help catalyze these investments.

Action 4a: Upgrade extension services to farmers to provide critical information and training on adaptation.

Improving the information and training available to farmers to help them acquire needed skills and resources to adapt to climate change is essential. One size doesn't fit all. Modern extension services based on different funding models that can involve public, private, and nongovernmental organizations are needed. These extension services themselves must be equipped to provide appropriate climate change adaptation advice, taking into account the unique needs of women and disadvantaged groups. Though national planning for adaptation is essential, emphasis should be placed on involving and engaging with the communities where changes actually have to occur.

In addition to formal public-sector extension services that provide information, programs such as farmer-field schools that allow best practices and knowledge to be shared among farming and other food-producing communities can help facilitate autonomous adaptation. The private sector has become increasingly important in disseminating information and this should continue. The Advanced Maize Seed Adoption Program is one example of such collaboration. This partnership between DuPont, the government of Ethiopia, and USAID will provide sample seed for demonstration plots and field training sessions and help build a network of farmer dealers and cooperatives to facilitate the use of high-quality inputs and management practices.

Modern communication technologies should be leveraged to help provide on-going access to information needed by farmers when they need it. Timely access to location-specific weather forecasts can improve farmers' ability to cope with increased weather variability and extreme events. For example, in places in Africa where the true onset of the rains is crucial for adequate soil moisture, predictions of the date(s) would help farmers better time their planting. The near ubiquitous reach of mobile phones and related technologies in even the poorest countries offers a means of providing information and advice to food producers and in particular smallholder farmers.

Action 4b: Develop insurance strategies to manage weather risk.

The nature of food production means that cash flows vary over time and are at risk when adverse weather events occur. Climate change will increase the likelihood of such extreme events and the risk of crop and livestock loss, making it more important for producers to have risk-coping instruments. The role of public-sector intervention

Box 21 – International efforts to address climate change's effects on food secuity are under way

A wide range of national and international organizations have programs under way to address food security and climate change challenges. Four are highlighted here.

Brazil's Agropensa System

Brazil's Agropensa System was established in 2013 by the Brazilian government's Agricultural Research Corporation (EMBRAPA). It provides a platform to produce and disseminate technological knowledge and innovations for agriculture, both within Brazil and internationally. Agropensa monitors trends, undertakes research, and develops strategic and actionable plans for EMBRAPA and its partners.

Climate Change, Agriculture, and Food Security Research Program (CCAFS)

CCAFS is a collaboration among all 15 research centers of the CGIAR to ensure that climate change effects are fully addressed by CGIAR and other researchers and by national and international research and policy centers. CCAFS brings together leading researchers worldwide in agricultural science, climate science, and environmental and social sciences to address climate change and agriculture. Areas of research focus include climate risk management, agricultural adaptation, low emissions agriculture, and national and global policy arenas.

Food, Agriculture, and Natural Resources Policy Analysis Network (FANRPAN)

FANRPAN traces its origins back to 1994, when the ministers of agriculture from eastern and southern Africa saw the need for independent policy input to address chronic food insecurity and the challenges of managing natural resources. Among its many activities related to climate change and food security are its programs "Learning, Communicating, and Advocating for Climate Smart Agriculture" and "Strategies for Adapting to Climate Change in Rural Sub-Saharan Africa: Targeting the Most Vulnerable."

Climate-Smart Agriculture Alliance

The Climate-Smart Agriculture Alliance is a nascent effort to bring together farmers, scientists, government officials, and representatives from the private sector and civil society to identify and address common goals. The alliance strives to create partnerships that can implement the "triple-wins" of enhancing agricultural productivity, climate change adaptation and mitigation, and food and nutrition security that are the essence of climate-smart agriculture. Using the results from a series of conferences begun in 2010, the Climate-Smart Agriculture Alliance is developing a plan of action to be presented at the UN Climate Summit in September 2014.

Sources: CCAFS 2014; FANRPAN 2014, EMBRAPA 2014, Climate Smart Agriculture Alliance 2014.

Neil Palmer/CIAT

remains unclear. In wealthier countries the insurance industry is in a position to enable food producers (and their customers) to hedge against uncertainty, but it often relies on expensive government-subsidized schemes. Experiments are under way in developing countries with weather-index-based insurance programs.[25] Research is needed into how best to provide poor food producers with access to appropriate risk management resources such as programs that pay out automatically when certain weather criteria are met rather than using complex loss adjustment. Care must be taken, however, that these programs do not reduce incentives to adopt resilient practices that have greater long-term average benefits and smaller peak benefits. They must also avoid creating market-distorting incentives to overproduce a certain commodity.

Given that climate change is expected to bring more frequent weather shocks with greater geographic impact affecting whole regions and countries, the costs of weather index insurance schemes could rise significantly. Innovative solutions designed specifically for these challenges such as sovereign insurance should be investigated.* The increased likelihood and type of extreme events should be an area of emphasis in disaster management planning and in designing the provision of emergency relief.

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* Sovereign insurance is insurance purchased by a country to cover unanticipated events such as natural disasters instead of using standard budgetary measures.

Box 22 – Kilimo Salama leverages technology to provide weather insurance to African smallholders

Kilimo Salama means "safe farming" in Swahili. The Kilimo Salama project is an agricultural insurance program for smallholder Kenyan and Rwandan farmers, which takes advantage of innovative technologies to help farmers manage risks related to agricultural production. The program is a partnership between the Syngenta Foundation for Sustainable Agriculture, UAP Insurance, and Safaricom, Kenya's leading mobile network provider.

Kilimo Salama develops and distributes low-cost agricultural insurance to smallholder farmers, who can insure as little as one acre of farmland against risks such as drought or excessive rainfall. Kilimo Salama calculates payouts automatically based on data from weather stations and satellites, rather than farm visits. When Kilimo Salama calculates that a payout is due, farmers receive a text message and Kenya's M-PESA mobile banking technology delivers the payment. In 2013 Kilimo Salama insured nearly 200,000 farmers and plans to expand its operation into other Sub-Saharan countries in the near future.

Sources: Kilimo Salama 2014; Syngenta Foundation for Sustainable Agriculture 2014.

Box 23 – Reducing postharvest losses can help combat food and nutrition insecurity in the face of climate change

In the developing world, on-farm, postharvest food loss is substantial. Sources of loss include harvesting methods, handling techniques, type or availability of storage, and contamination from pests and pathogens. Climate change could increase the losses. Many new programs to reduce postharvest losses are under way. Two are highlighted here.

Burkina Faso

In Burkina Faso, USAID and Catholic Relief Services supported the development and distribution of triple-lined storage bags that are air tight, killing off pests and eliminating the need for chemicals to protect the contents. These bags increase storage time, improve food quality and safety, and allow farmers to sell goods when prices are higher.

Nigeria

Postharvest loss is also being combatted in Nigeria, where smallholder cassava farmers struggle to process cassava roots quickly before they deteriorate. USAID, the International Institute of Tropical Agriculture, and the Shell Petroleum Development Company created the Cassava Enterprise Development Project, which provides smallholder farmers with tools such as industrial washers, peelers, and graters to facilitate postharvest processing.

Sources: The World Bank 2011; USAID 2013; Integrated Cassava Project 2014.

The Chicago Council/Riccardo Gangale

Action 4c: Implement climate change adaptation strategies beyond the farm gate.

The most direct effects of climate change are on food production, but the effects will be felt all along the food chain.

Improve the transportation and marketing infrastructure with climate resilience in mind

Climate change poses particular civil engineering challenges. In many places higher temperatures will require more resistant road surfaces. The risks of increasing floods and storm surges need to be considered when designing bridges, ports, and related facilities.[26] River transportation systems will need to deal with more frequent periods of low and high flows. Port infrastructure will need to deal with increasing sea levels. The logistics of transporting and storing food may be affected by climate change, for example increasing the need for refrigeration or postharvest drying.

Climate change will reduce the potential of some areas to produce food, while favoring others. Similarly, the location of marine fisheries may change so that catches are landed in different ports. Though these changes are likely to occur slowly, they will require adaptation in food supply networks, water storage and delivery systems, phytosanitary systems, and possibly in the routes that food is traded internationally.

Promote efficiencies throughout the food value chain that reduce waste, protect quality, and help ensure continuity of supply

The likely greater frequency of extreme events will increase the disruption of supply networks and place an increased premium on diversified sourcing. Food chain intermediaries and retailers may need access to greater reserve stocks. There is a particular challenge to ensuring continuity of supply to large cities and conurbations in less-developed countries.

Addressing food loss along the marketing chain has received attention recently for its potential to lower agricultural emissions by reducing the amount of food production needed and because of the likely challenges from climate change. These challenges include more postharvest losses due to higher temperatures and humidity as well as more expensive cold storage management on the way to consumers.

A 2011 FAO study estimated that roughly one-third of food produced for human consumption is lost or wasted globally. In low-income countries, much of the loss is postharvest and early in the supply chain. The losses are mainly connected to inadequacies in harvesting techniques, storage and cooling facilities, infrastructure, and packaging and marketing systems. In high-income countries, substantial losses occur at or near final consumption.[27] Losses arise from a range of sources—consumer behavior, lack of coordination between different actors in the supply chain, restrictions built into farmer-buyer sales, arbitrary quality standards, foodborne illness outbreaks, and unclear “best before” dates. A 2014 USDA study estimated that 31 percent (by weight) of the food available at retail and consumer levels in the United States in 2010 went uneaten.[28] Livestock products (meat, poultry, fish, and dairy) and vegetables accounted for 66 percent of the loss.[29] Cost-effective reduction of food losses and waste could contribute significantly to mitigation of greenhouse gas emissions.

Adaptation in the food chain should strive to incorporate mitigation measures wherever possible. Governments should promote responsible consumption, reduction of food waste, and efficiencies throughout the food chain. The private sector should be encouraged to develop products and distribution systems that cause fewer greenhouse gas emissions.

Action must be taken now

Climate change presents significant challenges to agriculture and the global food system. In a world already facing unprecedented increases in food demand over the next several decades, the impact of rising average temperatures, more varied rains, more frequent weather extremes, and rising sea levels will make feeding the world's people increasingly difficult unless action is taken now to adapt the global food system to a more volatile future.

While the poor and those living in tropical and coastal areas will initially be hardest hit, the effects of a warming climate will be felt everywhere. Crises in one area of the world can reverberate throughout the global food system and create a domino effect of consequences for everyone, including higher prices, food shortages, increasing hunger, and growing economic and political instability. Evidence shows that climate changes are already under way, and recent weather disasters around the world, from floods in Pakistan to drought in Russia and the United States, demonstrate the economic, political, and human impact of adverse weather events, which are expected to increase with a changing climate.

Yet with strong leadership and enough time, resources, and talent dedicated to this effort, the world has the ability to prepare the food system for the coming challenges and help farmers adapt to new and changing conditions. By making climate challenges to food security a national priority, by focusing scientific attention on data collection and modeling tools to better predict impacts and on innovations to address them, by making the global trading system more flexible and efficient in delivering food when and where it's needed, and by working with the private sector, the international community, and nongovernmental organizations to bring innovations to farmers fields and increase efficiencies throughout the food chain, food and nutrition security for the world's people can be enhanced.

With unparalleled expertise, historical experience, and leadership potential at its disposal, the United States must act to attack this challenge head on. Time for solutions is limited as the effects of climate change continue to mount in the coming decades. America's own interests are at stake as well as the future for billions of people worldwide. The United States can and must muster the will to rise to this challenge. America has risen to great challenges throughout its history and met them with resounding success. This may be one of the most critical challenges yet, not just for the United States, but for humanity. Now is the time to stay true to our national interests and ideals and prove once again that we can achieve what we set our minds to.

About the Principal Author

Gerald Nelson is professor emeritus, University of Illinois, Urbana-Champaign. Most recently he served as a senior research fellow at the International Food Policy Research Institute (IFPRI) in Washington, DC, where he coordinated its climate change research, led the policy analysis activities of the CGIAR Research Program on Climate Change, Agriculture, and Food Security, and was the principal investigator on major projects on food security and climate change issues funded by The Bill & Melinda Gates Foundation and the German and British aid agencies. His research includes global modeling of the interactions among agriculture, land use, and climate change; consequences of macroeconomic, sector and trade policies, and climate change on land use and the environment using remotely sensed, geographic and socioeconomic data; and the assessment of the effects of genetically modified crops on the environment.

About The Chicago Council on Global Affairs

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The Global Agricultural Development Initiative, launched in 2008 and expanded in 2010, purposes to build support and provide policy innovation and accountability for a long-term US commitment to agricultural development as a means to alleviate global poverty. It aims to maintain the policy impetus towards a renewed US focus on agricultural development, provide technical assistance to agricultural development policies' formulation and implementation, and offer external evaluation and accountability for US progress on food security. The initiative is led by Douglas Bereuter, president emeritus of the Asia Foundation, and Dan Glickman, former US secretary of Agriculture, and is overseen by an advisory group comprised of leaders from the government, business, civic, academic, and NGO sectors. For further information, please visit thechicagocouncil.org/globalagdevelopment.

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President Emeritus, The Asia Foundation
Former Member, US House of Representatives (Nebraska)

Douglas Bereuter is the president emeritus of the Asia Foundation, a nongovernmental development organization he led for more than six years following his 26-year service as a member of the US House of Representatives. During his congressional career, he was a leading member of the House International Relations Committee, where he served as vice chairman for six years, chaired the Asia-Pacific Subcommittee and later the Europe Subcommittee, had long tenures on its subcommittees on Economic Policy & Trade and Human Rights, and was president of the NATO Parliamentary Assembly. He also served on the House Financial Services Committee for 23 years and on the House Permanent Select Committee on Intelligence, retiring as its vice chairman. Bereuter graduated Phi Beta Kappa from the University of Nebraska and has master's degrees from Harvard University in both city planning and public administration. He served as an infantry and intelligence officer in the US Army, practiced and taught graduate courses in urban and regional planning, led various agencies and programs in the Nebraska state government, and served one four-year term as a Nebraska state senator. He is a member of the Council on Foreign Relations, the World Affairs Council of Northern California, and the State Department's International Security Advisory Board. He is also board chairman of the Arbor Day Foundation and the treasurer of the Nebraska Community Foundation.

Dan Glickman
Former US Secretary of Agriculture
Former Member, US House of Representatives (Kansas)
Senior Fellow, The Bipartisan Policy Center
Vice President, The Aspen Institute

Dan Glickman is a cochair of The Chicago Council's Global Agricultural Development Initiative. He is vice president of the Aspen Institute and executive director of the Aspen Institute Congressional Program, which was established in 1983. Glickman also serves as a senior fellow at the Bipartisan Policy Center, where he is cochair of its Democracy Project. Prior to joining the Aspen Institute, Glickman served as US secretary of agriculture in the Clinton administration. He also represented the 4th congressional district of Kansas for 18 years in the US House of Representatives, where he was very involved in federal farm policy on the House Agriculture Committee. He also served on the House Judiciary Committee as chairman of the House Permanent Select Committee on Intelligence. In addition, he is the former chairman of the Motion Picture Association of America, Inc., and former director of the Institute of Politics at Harvard University's John F. Kennedy School of Government. Glickman has served as president of the Wichita, Kansas, school board; was a partner in the law firm of Sargent, Klenda, and Glickman; and worked as a trial attorney at the US Securities and Exchange Commission. He received his BA in history from the University of Michigan and his JD from the George Washington University. He is a member of the Kansas and District of Columbia bars.

MEMBERS

Catherine Bertini

Senior Fellow, The Chicago Council on Global Affairs
Professor of Public Administration and International Affairs, Maxwell School, Syracuse University

Catherine Bertini is a senior fellow at The Chicago Council on Global Affairs. For five years she cochaired the Council's Global Agricultural Development Initiative. She also chaired the Council's Girls in Rural Economies project as well as the Council's work on domestic agriculture. Bertini is also a professor of public administration and international affairs at the Maxwell School of Citizenship and Public Affairs at Syracuse University. She previously served as UN undersecretary-general for management (2003 to 2005) and as executive director of the UN World Food Program (WFP), the world's largest international humanitarian agency (1992 to 2002). For two years she was senior fellow, agricultural development, at the Bill and Melinda Gates Foundation. Before serving in the UN, Bertini was USDA assistant secretary for food and consumer services, where she ran the nation's then $33 billion domestic food assistance programs. She was a fellow at the John F. Kennedy School of Government at Harvard University and policymaker in residence at the Gerald R. Ford School of Public Policy at the University of Michigan. Bertini is the 2003 World Food Prize Laureate. She is a presidential appointee to the Board of International Food and Agricultural Development. In 2012 she served as a member of the Department of State's Accountability Review Board on Benghazi.

Howard W. Buffett

President, Buffett Farms Nebraska LLC

Howard W. Buffett is a lecturer at Columbia University's School of International and Public Affairs, where he teaches management techniques for improving the effectiveness of foreign aid and global philanthropy. Before joining Columbia's faculty, he was the executive director of the Howard G. Buffett Foundation, which strengthens food security for vulnerable populations throughout the world. He now serves as a trustee of the foundation.

Buffett previously served in the US Department of Defense, overseeing agriculture-based economic stabilization and redevelopment programs in Iraq and Afghanistan. He received the Joint Civilian Service Commendation Award, the highest-ranking civilian honor presented by the Joint Chiefs of Staff at the request and approval of the Combatant Commanders. Prior to that, Buffett was a policy advisor for the White House Domestic Policy Council, where he coauthored the president's cross-sector partnership strategy. Prior to serving in the White House, he was a special assistant in the Office of the Secretary at the US Department of Agriculture, where he authored the expansion strategy for the nation's Cooperative Extension System.

Buffett earned his BA from Northwestern University and his MPA in Advanced Management and Finance from Columbia University. He coauthored the *New York Times* bestselling book *40 Chances: Finding Hope in a Hungry World*, which examines global hunger and food systems challenges, drawing from his experiences while traveling in more than 70 countries across six continents. He is from Omaha, Nebraska, where he operates a 400-acre, conservation-based farm.

John Carlin

Visiting Professor and Executive-in-Residence, Kansas State University
Former Governor, Kansas

John Carlin is currently a visiting professor/executive in residence at Kansas State University in the School of Leadership Studies. He teaches a masters-level class in executive leadership and an undergraduate class in practical politics. He also currently chairs the board for the Kansas Bioscience Authority. This authority was created in 2004 for the purpose of advancing the biosciences in Kansas. For three years Carlin chaired the Pew Trust Commission on Industrial Farm Animal Production. Their final report was issued in 2008 and it has helped inform policymakers in Washington on key issues facing agriculture and our food supply. Carlin had returned to his home state of Kansas after serving 10 years as archivist of the United States, being appointed by President Clinton in 1995. He served two four-year terms as governor of Kansas, leaving office in January of 1987. He was chairman of the National Governors Association from 1984 to 1985. After leaving public office he taught at Wichita State University, was involved in two small business ventures, and traveled internationally on behalf of Kansas businesses. Prior to being governor, he served four terms in the Kansas House of Representatives, the last term as speaker of the house. Carlin has a BS degree in dairy husbandry from Kansas State University, graduating in 1962. He then returned to the family farm to manage the Registered Holstein herd and diverse farming operation.

Jason Clay

Senior Vice President, Markets and Food, World Wildlife Fund (WWF)

Jason Clay leads the market transformation work of WWF-US for agriculture, aquaculture, business and industry, finance, fisheries, and forests. Over the course of his career he has worked on a family farm and in the US Department of Agriculture. He has taught at Harvard and Yale and spent more than 30 years with human rights and environmental organizations. In 1989 Clay invented Rainforest Marketing, one of the first fair-trade ecolabels in the United States, and was responsible for cocreating Rainforest Crunch and more than 200 other products with combined retail sales of $100 million. From 1999 to 2003 he codirected a consortium with the WWF, World Bank, UN Food and Agriculture Organization, and National Aquaculture Centres of Asia/Pacific to identify the most significant environmental and social impacts of shrimp aquaculture and analyze better management practices that measurably reduce them. Since then he has co-convened (with the World Bank's International Finance Corporation and others) multistakeholder roundtables of producers, investors, buyers, researchers, and nongovernmental organizations to identify and reduce the social and environmental impacts of such products as salmon, soy, sugarcane, cotton, and tilapia. Clay leads WWF's efforts to work with private-sector companies to improve their supply chain management, particularly with regard to ingredient sourcing as well as carbon and water impacts. He also leads WWF's efforts to transform entire sectors by improving their overall performance. Clay is the author of more than 15 books, 400 articles, and 700 invited presentations. His most recent books are *World Aquaculture and the Environment*, *Exploring the Links between International Business and Poverty Reduction: A Case Study of Unilever in Indonesia*, and *World Agriculture and the Environment*. In addition to his role at WWF, Clay is National Geographic's first ever Food and Agriculture Fellow. He also won the 2012 James Beard Award for his work on global food sustainability. Clay studied at Harvard University and the London School of Economics before receiving a PhD in anthropology and international agriculture from Cornell University.

Gordon Conway

Professor of International Development, Imperial College London

Gordon Conway is a professor of international development at Imperial College, London, and director of Agriculture for Impact, a grant funded by The Bill & Melinda Gates Foundation, which focuses on European support of agricultural development in Africa. From 2005 to 2009 he was chief scientific adviser to the Department for International Development. Previously he was president of the Rockefeller Foundation and vice-chancellor of the University of Sussex. He was educated at the Universities of Wales (Bangor), Cambridge, West Indies (Trinidad), and California (Davis). His discipline is agricultural ecology. In the early 1960s, working in Sabah, North Borneo, he became one of the pioneers of sustainable agriculture. He was elected a fellow of the Royal Society in 2004 and an honorary fellow of the Royal Academy of Engineering in 2007. He was made a Knight Commander of the Order of Saint Michael and Saint George in 2005. He is a deputy lieutenant for East Sussex. He was recently president of the Royal Geographical Society. He has authored *The Doubly Green Revolution: Food for all in the 21st century* (Penguin and University Press, Cornell) and coauthored *Science and Innovation for Development* (UK Collaborative on Development Sciences (UKCDS)). His most recent book *One Billion Hungry: Can We Feed the World?* was published in October 2012.

Gebisa Ejeta

Distinguished Professor of Plant Breeding and Genetics, Purdue University

Gebisa Ejeta is Distinguished Professor of Plant Breeding & Genetics and International Agriculture and serves as executive director of the Center for Global Food Security at Purdue University. Ejeta has been a member of the faculty of Purdue University since 1984. His career has been devoted to education, research, and international development with contributions in human and institutional capacity building, in technology development and transfer, and in advocacy for science in support of the cause of the poor. Ejeta has served in advisory roles to several international development agencies. He currently serves on the boards of The Chicago Council for Global Affairs Global Agricultural Development Initiative (GADI), the National Academy of Sciences Board on Agriculture and Natural Resources (BANR), and the Global Crop Diversity Trust (GCDT). Ejeta is the 2009 World Food Prize Laureate and a recipient of a national medal of honor from the president of Ethiopia. He is a fellow of the American Association for the Advancement of Sciences, the American Society of Agronomy, and the Crop Science Society of America. Ejeta has served the US government in several capacities, including as special advisor to USAID administrator Rajiv Shah and as science envoy of the US State Department. He was appointed by President Obama as member of the

Board for International Food and Agricultural Development (BIFAD) in 2010. He was more recently appointed by Secretary General Ban Ki Moon to the first UN Scientific Advisory Board.

Cutberto Garza

University Professor, Boston College
Visiting Professor, Johns Hopkins Bloomberg School of Public Health
Visiting Professor, George Washington University's School of Public Health

Cutberto Garza previously held appointments as professor of pediatrics at Baylor College of Medicine and of nutrition at Cornell University (where he served as director of the Division of Nutritional Sciences and as vice provost). His major research interests are in pediatric and maternal nutrition. He has worked with the United Nations University (as director of the UNU Food and Nutrition Program), World Health Organizations, and other international and national organizations. He served as chair of the WHO Steering Committee that developed the new WHO Child Growth Standards, IOM's Food and Nutrition Board, and the NRC's Board on International Scientific Organizations. He currently serves as chair of the World Food Program's Technical Advisory Group. He is a member of the Institute of Medicine. He is the recipient of the Alan Shawn Feinstein World Hunger Prize for Education and Research, awarded by Brown University in 1996. He delivered the first Founders' Lecture sponsored by the American Academy of Breastfeeding Medicine in 2006 and received the Conrad Elvehjem Award for Public Service in Nutrition, awarded by the American Society for Nutrition in 2008. He also received the Samuel J. Fomon Nutrition Award in 2011 from the American Academy of Pediatrics.

Carl Hausmann

Former CEO, Bunge North America

Carl Hausmann has more than 35 years of experience in the agribusiness and food industries and has successfully led a publicly held company in Europe as well as businesses in North America, South America, and Africa. Hausmann previously served as managing director of global government and corporate affairs of Bunge Limited ("Bunge"), a leading global agribusiness and food company, from 2010 until his retirement in 2012. Prior to that he was CEO of Bunge Europe and Bunge North America. He began his career at Continental Grain, serving in increasingly senior positions, and served as CEO at Central Soya, Cerestar USA, and Cereol SA. Hausmann served as the vice chair of the Consortium of International Agricultural Research Centers (CGIAR), a global partnership that unites organizations engaged in research for a food secure future. He currently is the vice chair of Bioversity International, one of the 15 member centers that form the CGIAR. He also serves on the board of directors of the International Food and Agricultural Trade Policy Council (IPC) and is a past president of Fediol, the European association of oilseed crushers. Hausmann received a bachelor's degree from Boston College and an MBA from the Institut Européen d'Administration des Affaires (INSEAD) in France.

A.G. Kawamura

Cochair, Solutions from the Land Dialogue

A.G. Kawamura is a third generation grower and shipper from Orange County, California. From 2003 to 2010 he was the secretary of the California Department of Food and Agriculture. He is cochair of Solutions From the Land (SFL), a nationally acclaimed project that is developing an innovative and sustainable roadmap for 21st century agriculture. He serves on several boards and committees including the Ag Advisory Committee for the AGree Initiative; the Board on Agriculture and Natural Resources (BANR), a policy arm of the National Academy of Sciences' Natural Resource Council; trustee for the Council on Agriculture, Science, and Technology (CAST); American Farmland Trust board member; Farm Foundation Round Table member; Western Growers Association board member and former chair; and 25x'25 steering committee member. Kawamura serves on the boards of the California State University Foundation, the Delta Vision Foundation, and the California Ag Leadership Foundation. For over 30 years Kawamura has pursued a lifelong goal to work towards an end to hunger and malnutrition. He has worked closely with Second Harvest and Orange County Food Banks to create exciting projects that address nutrition and hunger. As a progressive urban farmer, Kawamura has a lifetime of experience working within the shrinking rural and urban boundaries of southern California. Through their company, Orange County Produce, LLC, he and his brother Matt are engaged in building an interactive, 21st-century, 100-acre agricultural showcase at the Orange County Great Park in Irvine, California.

Mark E. Keenum

President, Mississippi State University (MSU)

Mark Everett Keenum became Mississippi State's 19th president on January 5, 2009, following a distinguished public service career. After completing his bachelor's and master's degrees in agricultural economics at Mississippi State, Keenum joined the university faculty in 1984 as a marketing specialist with the Mississippi Cooperative Extension Service. Two years later he accepted a position as a research associate with the Mississippi Agricultural and Forestry Experiment Station at MSU. He continued his education at the university, in 1988 receiving a doctorate in agricultural economics, and he joined the faculty of that department as assistant professor/economist. In 1989 Keenum joined the Washington, DC, staff of US Senator Thad Cochran as legislative assistant for agriculture and natural resources. As Senator Cochran's adviser on agricultural affairs, he worked on numerous issues important to US agriculture, including the 1990, 1996, and 2002 farm bills. From 1996 to 2006 he served as chief of staff for Senator Cochran. In this role Keenum was the chief adviser to the senator on political, legislative, and appropriations issues. He also was responsible for managing all administrative and legislative functions of Senator Cochran's Washington, DC, office and three Mississippi offices, including direct oversight of the US Senate Committee on Agriculture, Nutrition, and Forestry and the US Senate Committee on Appropriations. Prior to being named president of Mississippi State in November 2008, Keenum served as undersecretary of the US Department of Agriculture for two years, where he provided leadership and oversight for the Farm Service Agency, the Risk Management Agency, and the Foreign Agricultural Service.

Thomas R. Pickering

Vice Chairman, Hills and Company

Thomas R. Pickering, currently vice chairman at Hills and Company, retired as senior vice president international relations and a member of the executive council of the Boeing Company in July 2006. He served in that position for five-and-half years. Pickering joined Boeing in January 2001 upon his retirement as US undersecretary of state for political affairs, where he had served since May 1997. Pickering holds the personal rank of career ambassador, the highest in the US Foreign Service. In a diplomatic career spanning five decades, he was US ambassador to the Russian Federation, India, Israel, El Salvador, Nigeria, and the Hashemite Kingdom of Jordan. From 1989 to 1992 he was ambassador and representative to the United Nations in New York. Pickering entered on active duty in the US Navy from 1956 to 1959 and later served in the Naval Reserve to the grade of lieutenant commander. Between 1959 and 1961 he was assigned to the Bureau of Intelligence and Research of the State Department and later to the Arms Control and Disarmament Agency. Pickering received a bachelor's degree (cum laude) from Bowdoin College in Brunswick, Maine, in 1953. In 1954 he received a master's degree from the Fletcher School of Law and Diplomacy at Tufts University. In 2012 he chaired the Benghazi Accountability Review Board at the request of secretary of state Hillary R. Clinton, which made recommendations on improving security stemming from the attack on the US Mission at Benghazi, Libya, on September 11, 2012. In 1983 and in 1986 Pickering won the Distinguished Presidential Award and in 1996 the Department of State's highest award—the Distinguished Service Award.

Jose Luis Prado

President, Quaker Foods North America, a division of PepsiCo

Since January 2011 Jose Luis Prado has been president of Quaker Foods North America, a division of PepsiCo, Inc. As a $3.2 billion business, Quaker is an important better-for-you brand within PepsiCo's global growth strategy. The first Mexican to lead a PepsiCo business unit and 29-year veteran of the company, Prado began his career in PepsiCo Mexico Foods and has served in a variety of positions, including president, Frito-Lay Snacks Caribbean; president, PepsiCo Snacks Argentina/Uruguay; Frito Lay area vice president for Andean and South Cone Frito-Lay International (FLI); and most recently as president, Gamesa-Quaker Mexico. Prado is a transformational and empowering leader known for his passion for developing talent within his organization and refers to himself as the "Quaker Coach." He often uses the city of Chicago as his inspiration to focus and manage his business via the powerful words and architecture of Daniel Burnham. He is also committed to the community by nourishing healthy families via programs such as the NFL's Fuel Up to Play 60, Common Threads, and the Chicago Fire soccer team, which Quaker sponsors so it can have a direct impact on getting thousands of kids active by playing soccer.

Prado also serves on the boards of Northern Trust, The Chicago Council on Global Affairs; Northwestern University Kellogg School of Business; Chicago Symphony Orchestra; GENYOUth, a national nonprofit organization; and the Hispanic Association on Corporate Responsibility. He is also a member of the Commercial Club, Economic Club, and Executive Club of Chicago. He has a BS in mechanical engineering (cum laude) from the National Polytechnical Institute, an MS in systems from the Iberoamericana University, and an MBA from the Monterrey Institute of Technology.

Steven Radelet

Distinguished Professor in the Practice of Development, Edmund A. Walsh School of Foreign Service, Georgetown University

Steven Radelet is a development economist whose work focuses on economic growth, poverty reduction, foreign aid, and debt, primarily in Africa and Asia. Radelet has extensive experience as a policymaker in the US government—as an adviser to developing country leaders and as a researcher, teacher, and writer. He previously served as chief economist for USAID, senior adviser for development to secretary of state Hillary Clinton, and deputy assistant secretary of the Treasury for Africa, the Middle East, and Asia. He currently serves as an economic adviser to President Ellen Johnson Sirleaf of Liberia. He spent four years as an adviser to the Ministry of Finance in Jakarta, Indonesia, and two years as adviser in the Ministry of Finance in The Gambia. He was a Peace Corps volunteer in Western Samoa. From 2002 to 2009 Radelet was senior fellow at the Center for Global Development. From 1990 to 2000 he was on the faculty of Harvard University, where he was a fellow at the Harvard Institute for International Development (HIID) and a lecturer on economics and public policy. He is author of *Emerging Africa: How 17 Countries Are Leading the Way,* the textbook *Economics of Development,* and dozens of other publications.

Cynthia E. Rosenzweig

Senior Research Scientist, NASA Goddard Institute for Space Studies

Cynthia Rosenzweig is a senior research scientist at the NASA Goddard Institute for Space Studies, where she heads the Climate Impacts Group. She is cochair of the New York City Panel on Climate Change, a body of experts convened by the mayor to advise the city on adaptation for its critical infrastructure. She co-led the Metropolitan East Coast Regional Assessment of the US National Assessment of the Potential Consequences of Climate Variability and Change, sponsored by the US Global Change Research Program. She was a coordinating lead author of the IPCC Working Group II Fourth Assessment Report. She is codirector of the Urban Climate Change Research Network (UCCRN) and coeditor of the First UCCRN Assessment Report on Climate Change and Cities (ARC3), the first-ever global, interdisciplinary, cross-regional, science-based assessment to address climate risks, adaptation, mitigation, and policy mechanisms relevant to cities. She is the founder of AgMIP, a major international collaborative effort to assess the state of global agricultural modeling, understand climate impacts on the agricultural sector, and enhance adaptation capacity as it pertains to food security in developing and developed countries. She was named as one of “Nature’s 10: Ten People Who Mattered in 2012” by the science journal *Nature.* A recipient of a Guggenheim Fellowship, she joins impact models with climate models to project future outcomes of both land-based and urban systems under altered climate conditions. She is a professor at Barnard College and a senior research scientist at the Earth Institute at Columbia University.

Navyn Salem

Founder and Executive Director, Edesia / Global Nutrition Solutions

In 2007 Navyn Salem set out to help end the crisis of malnutrition for over 250 million children around the world. Her approach was simple: increase access to innovative, ready-to-use foods like Plumpy'Nut and Nutributter in developing countries, while building on the success of these fortified, peanut-based solutions to reach greater numbers of vulnerable, malnourished populations. In 2009, after first establishing a factory in her father's home country of Tanzania, Salem founded Edesia, a nonprofit food aid manufacturer in Providence, Rhode Island. This factory now produces over 6,600 tons (6,000 metric tons) each year of ready-to-use foods (RUFs) for humanitarian agencies such as UNICEF, WFP, and USAID, working on behalf of children in emergency situations and conflict zones. Since production began in March 2010, Edesia has reached over two million children in 40 countries, including Chad, Guatemala, Haiti, Pakistan, and Syria. In 2012 Salem was named New England Business Woman of the Year by Bryant University, received the Roger E. Joseph Prize from Hebrew Union College for being an outstanding humanitarian, and was awarded an honorary doctorate in social sciences from Boston College, her alma mater. In 2013 she received an honorary degree in business administration from Bryant University. In 2014 she was named a Henry Crown Fellow at the Aspen Institute.

Paul E. Schickler

President, DuPont Pioneer

Paul E. Schickler is president of DuPont Pioneer, the advanced seed genetics business of DuPont. In this role, which he has held since 2007, he has continued to expand Pioneer's global business by remaining focused on innovation that improves local productivity and profitability of farmers in more than 90 countries. Since joining Pioneer in 1974, Schickler has served in a variety of finance and administrative leadership roles throughout the business, including vice president of international operations from 1999 to 2007. He currently serves on the DuPont Committee on Agricultural Innovation and Productivity in the 21st Century and the DuPont Agriculture Decision Board, and he is a member of the DuPont Operating Team. Schickler is a graduate of Drake University, where he received bachelor of science and master of arts degrees in business administration. He currently serves on The Chicago Council on Global Affairs board of directors; The Chicago Council's Global Agricultural Development Initiative advisory group; the Greater Des Moines Partnership board of directors; the Grand View University board of directors; the STEM Food and Ag Council; and the Iowa Business Council. A strong contributor to the community, Schickler is an active supporter of United Way, the World Food Prize Foundation, Meals from the Heartland, and the Farm Journal Legacy Project.

Lindiwe Majele Sibanda

CEO and Head of Mission, Food, Agriculture, and Natural Resources Policy Analysis Network

Lindiwe Majele Sibanda is the CEO and head of mission of the Food, Agriculture, and Natural Resources Policy Analysis Network (FANRPAN). She works with governments, farmers, the private sector, and researchers and is currently coordinating food security policy research and advocacy initiatives aimed at making Africa a food-secure continent. She is an animal scientist by training and a practicing commercial beef cattle farmer. She has been at the forefront of the global agriculture, food security, and climate change policy agenda. She received her BSc degree at the University of Alexandria in Egypt and her MSc and PhD at the University of Reading in the UK. Sibanda serves on numerous international boards and is currently the board chair of the International Livestock Research Institute (ILRI), which is one of the 15 members of the Consultative Group on International Agricultural Research (CGIAR).

Robert L. Thompson
Visiting Scholar, John Hopkins University's School of Advanced International Studies
Professor Emeritus, University of Illinois

Robert L. Thompson is a visiting scholar at Johns Hopkins University's School of Advanced International Studies and professor emeritus at the University of Illinois, where he held the Gardner Endowed Chair in Agricultural Policy from 2004 to 2010. He is a senior fellow with The Chicago Council on Global Affairs and serves on the International Food and Agricultural Trade Policy Council. Previously, Thompson served as director of rural development at the World Bank (1998 to 2002); president of Winrock International Institute for Agricultural Development (1993 to 1998); dean of agriculture (1987 to 1993) and professor of agricultural economics (1974 to 1993) at Purdue University; assistant secretary for economics at the US Department of Agriculture (1985 to 1987) and senior staff economist for food and agriculture at the President's Council of Economic Advisers (1983 to 1985).

Thompson received his BS degree from Cornell University and MS and PhD degrees from Purdue University and holds honorary doctorates from Pennsylvania State University and Dalhousie University (Canada). He is a fellow of the American Agricultural Economics Association and the American Association for the Advancement of Science and a foreign member of the Royal Swedish Academy of Agriculture and Forestry and the Ukrainian Academy of Agricultural Sciences. He is a former president of the International Association of Agricultural Economists.

Ann M. Veneman
Former Executive Director, UN Children's Fund
Former Secretary, US Department of Agriculture

Ann M. Veneman has a distinguished career in public service, serving as the executive director of the United Nations Children's Fund (UNICEF) from 2005 to 2010 and as the US secretary of agriculture from 2001 to 2005. Veneman's leadership and vision has been recognized both nationally and internationally. In 2009 she was named to the Forbes 100 Most Powerful Women list, and she has been the recipient of numerous awards and honors. At UNICEF Veneman directed a staff of over 11,000 in more than 150 countries around the world. She worked to support child health and nutrition, quality basic education for all, access to clean water and sanitation, and the protection of children and women from violence, exploitation, and HIV/AIDS. She traveled to more than 70 countries to review the plight of children; to witness the devastation caused by natural disaster, conflict, disease, and exploitation; and to advance programs aimed at improving and saving lives.

As secretary of the US Department of Agriculture (USDA), Veneman directed one of most diverse federal agencies, with a budget of $113 billion and 110,000 employees. She also served as secretary of the California Department of Food and Agriculture from 1995 to 1999, overseeing the state agency responsible for the nation's largest agricultural producing region. From 1986 to 1993 she served in various positions in the USDA, including deputy secretary, deputy undersecretary for international affairs, and associate administrator of the Foreign Agricultural Service. At USDA Veneman advanced an expanded the trade agenda, food protection, progressive farm policy, responsible forest policy, and stronger nutrition programs.

Veneman currently serves on the boards of directors for Alexion, Nestlé S.A., and S&W Seed Company. Alexion is a global biopharmaceutical company that combines groundbreaking science with a steadfast commitment to meeting the needs of patients living with severe, life-threatening and often ultra-rare diseases. Nestlé is the world's leading nutrition, health, and wellness company, providing consumers a wide range of food and beverage products. S&W produces innovative seed products. Veneman is also a member of the Council on Foreign Relations and the Trilateral Commission. She is a frequent speaker on a range of topics, including poverty alleviation, empowering women and girls, food security and nutrition, and global health. Throughout her career Veneman has served on a number of advisory councils, committees, and nonprofit boards, particularly those involving higher education. Currently she is cochair of Mothers Day Every Day and on the boards of the Close Up Foundation, the National 4-H Council, Malaria No More, the Global Innovative Health Technology Fund, and Landesa. She is also a cochair of the Bipartisan Policy Center initiative on Obesity and Physical Activity and on the Bipartisan Policy Center Commission on Political Reform. She serves on the advisory boards of BRAC, the FEED Project, Pencils of Promise, The Chicago Council's Global Agricultural Development Initiative, the Omega Women's Leadership Center, Living Goods, Runa Tea, Aloha, and Driptech. In 2012 she served as a fellow at the Harvard School of Public Health and the U.C. Berkeley Goldman School of Public Policy.

A lawyer by training, Veneman has practiced law in both California and in Washington, DC. Early in her career she was a deputy public defender. Veneman holds a bachelor's degree in political science from the University of California, Davis; a master's degree in public policy from the University of California, Berkeley; and a juris doctor degree from the University of California, Hastings College of the Law. She has been awarded honorary doctorate degrees from several universities and colleges.

Derek Yach

Senior Vice President, The Vitality Group

Derek Yach has focused his career on advancing global health. He is senior vice president of the Vitality Group, part of Discovery Holdings Ltd, where he leads the Vitality Institute for Health Promotion. Prior to that he was senior vice president of global health and agriculture policy at PepsiCo, where he supported portfolio transformation and led engagement with major international groups and new African initiatives at the nexus of agriculture and nutrition. He has headed global health at the Rockefeller Foundation, has been a professor of global health at Yale University, and is a former executive director for Noncommunicable Diseases and Mental Health of the World

Health Organization (WHO). At WHO he served as cabinet director under Director-General Gro Harlem Brundtland, where he led the development of WHO's Framework Convention on Tobacco Control and the Global Strategy on Diet and Physical Activity. Yach established the Centre for Epidemiological Research at the South African Medical Research Council. He has authored or coauthored over 200 articles covering the breadth of global health. Yach serves on several advisory boards, including those of the Clinton Global Initiative, the World Economic Forum, the NIH's Fogarty International Centre, and PepsiCo's Scientific Advisory Board. His degrees include an MBChB from the University of Cape Town, BSc (Hons Epi) from the University of Stellenbosch, and an MPH from the Johns Hopkins Bloomberg School of Public Health.

Acronym List

AgMIP—The Agricultural Model Intercomparison and Improvement Project

AMIS—Agricultural Market Information System

CAADP—Comprehensive Africa Agriculture Development Program

CCAFS—CGIAR's Climate Change, Agriculture, and Food Security Research Program

CGIAR—Consortium of International Agricultural Research Centers

EMBRAPA—The Brazilian Enterprise for Agricultural Research

FANRPAN—The Food, Agriculture, and Natural Resources Policy Analysis Network

FAO—Food and Agriculture Organization of the United Nations

FEWS NET—The Famine Early Warning Systems Network

GATT—General Agreement on Tariffs and Trade

HECTARE—Higher Education Collaboration for Technology, Agriculture, Research, and Extension

IPCC—The Intergovernmental Panel on Climate Change

PEPFAR—President's Emergency Plan for AIDS Relief

RCP— Representative Concentration Pathways

TPP—Trans-Pacific Partnership

TTIP—The Transatlantic Trade and Investment Partnership

UNFCCC—United Nations Framework Convention on Climate change

USAID—United States Agency for International Development

USDA—United States Department of Agriculture

WTO—World Trade Organization

Endnotes

Part I

1. Christopher B. Field et al., "Summary for Policymakers," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva: IPCC Secretariat, 2014), http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf.
2. Food and Agriculture Organization of the United Nations (FAO), *The State of Food Insecurity in the World 2012: Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition* (Rome: FAO, 2012), 8, http://www.fao.org/docrep/016/i3027e/i3027e.pdf.
3. Organisation for Economic Co-operation and Development (OECD) and Food and Agriculture Organization of the United Nations (FAO), *OECD-FAO Agricultural Outlook 2012-2021* (Rome: FAO, 2012), 17, http://dx.doi.org/10.1787/agr_outlook-2012-en.
4. OECD and FAO, *OECD-FAO Agricultural Outlook 2012-2021*.
5. United States Department of Defense, *Quadrennial Defense Review 2014* (Washington, DC: US Department of Defense, March 4, 2014), http://www.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf.
6. Marco Lagi, Karla Z. Bertand, and Yaneer Bar-Yam, *The Food Crisis and Political Instability in North Africa and the Middle East* (Cambridge, MA: New England Complex Systems Institute, 2011), 4, http://necsi.edu/research/social/food_crises.pdf.
7. Philip G. Pardey and Jason Beddow, *Agricultural Innovation: The United States in a Changing Global Reality* (Chicago: The Chicago Council on Global Affairs, April 2013), http://www.thechicagocouncil.org/UserFiles/File/GlobalAgDevelopment/Report/Agricultural_Innovation_Final.pdf.
8. Dina Smeltz, *Foreign Policy in the New Millennium: Results of the 2012 Chicago Council Survey of American Public Opinion and US Foreign Policy* (Chicago: The Chicago Council on Global Affairs, 2012), 14, http://www.thechicagocouncil.org/UserFiles/File/Task%20Force%20Reports/2012_CCS_Report.pdf.
9. Food and Agriculture Organization of the United Nations (FAO), *The State of Food Insecurity in the World 2011: How does international price volatility affect domestic economies and food security?* (Rome: FAO, 2011), http://www.fao.org/docrep/014/i2330e/i2330e.pdf.
10. James C. Riley, "Estimates of Regional and Global Life Expectancy, 1800-2001," *Population and Development Review* 31, no. 3 (September 2005): 537-543, http://www.jstor.org/stable/pdfplus/3401478.pdf?acceptTC=true&acceptTC=true&jpdConfirm=true; United Nations Population Division (UNPD), Department of Economic and Social Affairs, *World Population Prospects: The 2000 Revision* (New York: UNPD, 2001), https://www.un.org/esa/population/publications/wpp2000/highlights.
11. H. Charles J. Godfray et al., "Food security: The challenge of feeding 9 billion people," *Science* 327, no. 5967 (2010): 812-818, http://www.sciencemag.org/content/327/5967/812.full.pdf.
12. United Nations Population Division (UNPD), Department of Economic and Social Affairs, *World Urbanization Prospects: The 2011 Revision* (New York: UNPD, 2012), http://esa.un.org/unpd/wpp/ppt/CSIS/WUP_2011_CSIS_4.pdf.
13. Godfray et al., "Food security: The challenge of feeding 9 billion people"; Colin K. Khoury et al., "Increasing homogeneity in global food supplies and the implications for food security," *Proceedings of the National Academy of Sciences* 111, no. 11 (2014): 4001-4006, http://www.pnas.org/cgi/content/long/1313490111v1.
14. Pardey and Beddow, *Agricultural Innovation.*

15. Gerald C. Nelson et al., *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options* (Washington, DC: International Food Policy Research Institute, 2010), http://www.ifpri.org/sites/default/files/publications/rr172.pdf.

16. Department for Environment Food and Rural Affairs (DEFRA), HM Government, *The 2007/2008 Agricultural Price Spikes: Causes and Policy Implications* (London: DEFRA, 2010), http://archive.defra.gov.uk/foodfarm/food/pdf/ag-price100105.pdf.

17. Nelson et al., *Food Security, Farming, and Climate Change to 2050.*

18. Ibid. The US National Intelligence Council recognized this latter threat in its 2008 National Intelligence Assessment "National Security Implications of Global Climate Change to 2030" and in a series of unclassified reports released in 2013. Sources: National Intelligence Council, *Natural Resources in 2020, 2030, and 2040: Implications for the United States* (Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, July 25, 2013), http://www.dni.gov/files/documents/NICR%202013-05%20US%20Nat%20Resources%202020,%202030%202040.pdf; National Intelligence Council, *Global Food Security: Key Drivers – A Conference Report* (Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, February 1, 2013); National Intelligence Council, *The Future of Indian Ocean and South China Sea Fisheries: Implications for the United States* (Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, July 30, 2013); National Intelligence Council, *Global Food Security: Emerging Technologies to 2040* (Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, July 30, 2013); National Intelligence Council, *Global Food Security: Market Forces and Selected Case Studies* (Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, May 10, 2012).

19. David Lobell and Sharon Gourdji, "The influence of climate change on global crop productivity," *Plant Physiology* 160, no. 4 (December 2012): 1686-1697, http://www.ncbi.nlm.nih.gov/pubmed/23054565.

20. Jerry M. Melillo, Terese T. C. Richmond, Gary W. Yohe, eds., *Climate Change Impacts in the United States: The Third National Climate Assessment* (Washington, DC: US Global Change Research Program, 2014).

21. Viatcheslav V. Kharin et al., "Changes in Temperature and Precipitation Extremes in the IPCC Ensemble of Global Coupled Model Simulations," *Journal of Climate* 20 (2007): 1419-1444, http://journals.ametsoc.org/doi/abs/10.1175/JCLI4066.1.

22. Tim Dyson, "On the Demography of South Asian Famines: Part I," *Population Studies* 45, no. 1 (March 1991): 5–25, http://www.jstor.org/discover/10.2307/2174991?uid=2&uid=4&sid=21103963148073.

23. David Fieldhouse, "For Richer, for Poorer?" in *The Cambridge Illustrated History of the British Empire*, ed. P.J. Marshall (Cambridge: Cambridge University Press, 1996), 132.

24. Daniel Worster, *Dust Bowl: The Southern Plains in the 1930s* (New York: Oxford University Press, 1979), 49.

25. Adam B. Ellick, "Floods Could Have Lasting Impact for Pakistan," *The New York Times,* August 17, 2010, http://www.nytimes.com/2010/08/17/world/asia/17pstan.html?pagewanted=all.

26. United States Global Change Research Program (USGCRP), *Global Climate Change Impacts in the United States*, eds. Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson (New York: Cambridge University Press, 2009).

27. National Aeronautics and Space Administration (NASA), "Climate change: How do we know?" accessed April 14, 2014, http://climate.nasa.gov/evidence.

28. World Meteorological Organization (WMO), *WMO statement on the status of the global climate in 2013,* WMO-No. 1130 (Geneva: WMO, 2014), https://docs.google.com/file/d/0BwdvoC9AeWjUeEV1cnZ6QURVaEE/edit.

29. Intergovernmental Panel on Climate Change (IPCC), "2013: Summary for Policymakers," in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. T.F. Stocker

et al. (Cambridge: Cambridge University Press, 2013), 20, http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf.

30. Ibid.

31. NASA has provided a video that displays annual temperature changes across the globe from 1950 at http://www.youtube.com/watch?v=gaJJtS_WDmI. National Aeronautics and Space Administration (NASA), "Six Decades of a Warming Earth," published January 21, 2014, accessed April 11, 2014.

32. IPCC, "2013: Summary for Policymakers," in *Climate Change 2013: The Physical Science Basis.*

33. M.L. Parry et al., "Effects of climate change on global food production under SRES emissions and socio-economic scenarios," *Global Environmental Change* 14, no. 1 (2004): 53-67, http://www.sciencedirect.com/science/article/pii/S0959378003000827.

34. Peter G. Jones and Philip K. Thornton, "Croppers to livestock keepers: Livelihood transitions to 2050 in Africa due to climate change," *Environmental Science & Policy* 12, no. 4 (June 2009): 427–437, http://dx.doi.org/10.1016/j.envsci.2008.08.006.

35. Jason B. Fellman et al., "Global estimates of soil carbon sequestration via livestock waste: a STELLA simulation," *Environment, Development and Sustainability* 11, no. 4 (August 2009): 871-885.

36. Sonja J. Vermeulen, Bruce M. Campbell, and John S.I. Ingram, "Climate Change and Food Systems," *Annual Review of Environmental Resources* 37 (November 2012): 195–222; World Resources Institute, "Climate Analysis Indicators Tool (CAIT) 2.0," accessed April 23, 2014, http://cait2.wri.org.

37. R. Lal, "Soil Carbon Sequestration Impacts on Global Climate Change and Food Security," *Science* 304, no. 5677 (June 11, 2004): 1623–1627, http://www.sciencemag.org/content/304/5677/1623.abstract.

38. Keith A. Smith, "The impact of agriculture and other land uses on emissions of methane and nitrous and nitric oxides," *Environmental Sciences* 2, no. 2-3 (2005): 101-108, http://www.tandfonline.com/doi/abs/10.1080/15693430500370423#.U1WhllVdWuu.

39. Ronald L. Sass and Frank M. Fisher, "Methane emissions from rice paddies: a process study summary," *Nutrient Cycling in Agroecosystems* 49, no. 1 (1997): 119-127, http://link.springer.com/article/10.1023%2FA%3A1009702223478.

40. Mario Herrero et al., "Livestock and Greenhouse Gas Emissions: Mitigation Options and Trade-Offs," in *Climate Change Mitigation and Agriculture,* eds. Eva Wollenberg et al. (New York: Routledge, 2012): 316-332.

41. A.F. Bouwman, "Direct emission of nitrous oxide from agricultural soils," *Nutrient Cycling in Agroecosystems* 46, no. 1 (1996): 53-70, http://link.springer.com/article/10.1007%2FBF00210224.

42. The IPCC defines global warming potential as "an index, based on radiative properties of greenhouse gases, measuring the radiative forcing following a pulse emission of a unit mass of a given greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The global warming potential represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in causing radiative forcing." It provides a measure for policymakers to compare the relative climate impacts of two different emissions. Source of the definition: Intergovernmental Panel on Climate Change (IPCC), "Annex III: Glossary," ed. Serge Planton, in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. T.F. Stocker et al. (Cambridge and New York: Cambridge University Press, 2013), http://www.climatechange2013.org/images/report/WG1AR5_AnnexIII_FINAL.pdf. Source of the percentage: World Resources Institute, "Climate Analysis Indicators Tool (CAIT) 2.0."

43. Mario Herrero and Philip K. Thornton, "Livestock and global change: Emerging issues for sustainable food systems," *Proceedings of the National Academy of Sciences of the United States of America* 110, no. 52 (2013): 20878–20881, http://www.pnas.org/content/early/2013/12/13/1321844111.full.pdf+html.

44. Lenny Bernstein et al., *Climate Change 2007: Synthesis Report. An Assessment of the Intergovernmental Panel on Climate Change,* eds. Abdelkader Allali et al. (Geneva: IPCC, 2007), https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

45. High Level Panel of Experts on Food Security and Nutrition (HLPE), *Food Security and Climate Change: A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security* (Rome: HLPE, 2012), http://www.ifpri.org/sites/default/files/HLPE-Report-3-Food_security_and_climate_change-June_2012.pdf.

46. Lal, "Soil Carbon Sequestration Impacts on Global Climate Change and Food Security."

47. Lobell and Gourdji, "The influence of climate change on global crop productivity."

48. David B. Lobell, Wolfram Schlenker, and Justin Costa-Roberts, "Climate Trends and Global Crop Production since 1980," *Science* 333, no. 6042 (July 29, 2011): 616–620, http://www.ncbi.nlm.nih.gov/pubmed/21551030.

49. Field et al., "Summary for Policymakers," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability,* 18.

50. Philip K. Thornton and Laura Cramer, eds., *Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate,* Working Paper No. 23 (Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security, 2012), https://cgspace.cgiar.org/bitstream/handle/10568/21226/ccafs-wp-23-cc_impacts_CGIAR.pdf?sequence=7.

51. United States Geological Survey (USGS) and United States Agency for International Development (USAID), *Famine Early Warning Systems Network—Informing Climate Change Adaptation Series: Using Observed Warming to Identify Hazards to Mozambique Maize Production,* Fact Sheet 2011–3110 (US Department of the Interior and USGS, September 2011), http://pubs.usgs.gov/fs/2011/3110/pdf/fs2011-3110.pdf; David B. Lobell et al., "Nonlinear heat effects on African maize as evidenced by historical yield trials," *Nature Climate Change* 1, no. 1 (2011): 42-45.

52. Suzanna K. Redfern, Nadina Azzu, and Jesie S. Binamira, "Rice in Southeast Asia: Facing risks and vulnerabilities to respond to climate change," in *Building Resilience for Adaptation to Climate Change in the Agriculture Sector: Proceedings of a Joint FAO/OECD Workshop,* eds. Alexandre Meybeck et al. (Rome: FAO and OECD, 2012), 296, http://www.fao.org/docrep/017/i3084e/i3084e18.pdf; Shaobing Peng et al., "Rice yields decline with higher night temperature from global warming," *Proceedings of the National Academy of Sciences of the United States of America* 101, no. 27 (2004): 9971-9975, http://www.pnas.org/content/101/27/9971.full.

53. Thornton and Cramer, eds., *Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate*.

54. M. M. Mekonnen and A. Y. Hoekstra, *The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products. Volume 1: Main Report,* Value of Water Research Report Series No. 47 (Delft, the Netherlands: UNESCO-IHE, December 2010), http://www.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf.

55. Food and Agricultural Organization of the United Nations (FAO), "Opportunity Untapped: Water in Agriculture Factsheet" (Rome: FAO, n.d.), accessed April 14, 2014, http://www.unwater.org/downloads/media/scarcity/factsheet_wwf_eng.pdf.

56. HLPE, *Food Security and Climate Change.*

57. Thornton and Cramer, eds., *Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate*.

58. Ibid.

59. Ibid.

60. J.L. Hatfield et al., "Climate Impacts on Agriculture: Implications for Crop Production," *Agronomy Journal* 103 (2011): 351–370; Robert Hijmans,"Relocating Rice Production in China," *Rice Today* 6, no. 4 (2007): 25; A.L. Ivanov, *Global Manifestations of Climate Change in the Agricultural Sector* (Moscow: Russian Agricultural Academy, 2004); A.L. Ivanov and

V.I. Kiryushin, *Global Climate Change and Forecast of Weather Risks in Agriculture* (Moscow: Russian Agricultural Academy, 2009).

61. Maria Baca et al., "An Integrated Framework for Assessing Vulnerability to Climate Change and Developing Adaptation Strategies for Coffee Growing Families in Mesoamerica," *PloS One* 9, no. 2, e88463 (2014), http://www.plosone.org/article/fetchObject.action?uri=info%3Adoi%2F10.1371%2Fjournal.pone.0088463&representation=PDF; Elisabeth Malkin, "A Coffee Crop Withers," *The New York Times,* May 5, 2014, http://nyti.ms/1htlueM.

62. John R. Porter et al., "Chapter 7: Food Security and Food Production Systems," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. Pramod Aggarwal and Kaija Hakala (Geneva: IPCC Secretariat, 2014), http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap7_FGDall.pdf.

63. Josef Schmidhuber and Francesco N. Tubiello, "Global food security under climate change," *Proceedings of the National Academy of Sciences of the United States of America* (2007), http://www.pnas.org/cgi/reprint/104/50/19703\nhttp://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed8&NEWS=N&AN=2008023853.

64. Ibid.

65. K.A. Garrett et al., "Climate Change Effects on Plant Disease: Genomes to Ecosystems," *Annual Review of Phytopathology* 44 (January 2006): 489–509, http://www.ncbi.nlm.nih.gov/pubmed/16722808.

66. Ibid.

67. Andy Jarvis et al., "Is Cassava the Answer to African Climate Change Adaptation?" *Tropical Plant Biology* 5, no. 1 (February 15, 2012): 9–29, http://www.springerlink.com/content/n36675226277455j/.

68. Ibid.

69. Thornton and Cramer, eds., *Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate*.

70. Mike Livingston et al., *Economic and Policy Implications of Wind-Borne Entry of Asian Soybean Rust into the United States,* Outlook Report No. OCS-04D-02 (Washington, DC: USDA Economic Research Service, April 2004), http://www.utcrops.com/soybean/diseases/disease_images/ERSreportOnSBR.pdf.

71. See http://climate.engineering.iastate.edu/Document/Grain%20Quality.pdf for more details on climate change effects on grain quality. Source: Eugene S. Takle, "Impact of Climate Change on Grain Quality," Iowa State University Climate Science Program, accessed April 9, 2014.

72. J.L. Hatfield et al., "Climate Impacts on Agriculture: Implications for Crop Production," *Agronomy Journal* 103 (2011): 351–370.

73. Elizabeth A. Ainsworth and Justin M. McGrath, "Direct Effects of Rising Atmospheric Carbon Dioxide and Ozone of Crop Yields," *Global Change Research* 37 (2010): 109–130; Lin Erda et al., "Climate Change Impacts on Crop Yield and Quality with CO2 Fertilization in China," *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 360, no. 1463 (2005): 2149–2154.

74. C. Wrigley, "Global Warming and Wheat Quality," *Cereal Foods World* 51 (2006): 34–36.

75. International Rice Research Institute, "Coping with Climate Change," *Rice Today* 6, No. 3 (July-September 2007): 10-15, http://www.scribd.com/doc/34620921/Rice-Today-Vol-6-No-3.

76. Smith, "The impact of agriculture and other land uses on emissions of methane and nitrous and nitric oxides."

77. Nikos Alexandratos, "World Food and Agriculture to 2030/50, Highlights and Views from Mid-2009" (paper presented at the Expert Meeting on "How to Feed the World in 2050," FAO, Rome, June 24-26, 2009, revised July 25, 2009), ftp://ftp.fao.org/docrep/fao/012/ak969e/ak969e00.pdf.

78. Herrero and Thornton, “Livestock and global change.”

79. HLPE, *Food Security and Climate Change*.

80. Thornton and Cramer, eds., *Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate.*

81. T.F. Stocker et al., “2013: Technical Summary,” in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. T.F. Stocker et al. (Cambridge and New York: Cambridge University Press, 2013), 84, http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf.

82. Ibid.

83. HLPE, *Food Security and Climate Change.*

84. “Mississippi River Facts,” National Park Service, accessed April 9, 2014, http://www.nps.gov/miss/riverfacts.htm.

85. Eugene S. Takle et al., “US Food Security and Climate Change: Agricultural Futures,” *Economics* 7 (February 13, 2013): 2013-2034, http://www.economics-ejournal.org/economics/journalarticles/2013-34.

86. Ibid.

87. Field et al., “Summary for Policymakers,” in *Climate Change 2014: Impacts, Adaptation, and Vulnerability,* 18.

88. Porter et al., “Chapter 7: Food Security and Food Production Systems,” in *Climate Change 2014: Impacts, Adaptation, and Vulnerability,* 3.

89. Field et al., “Summary for Policymakers,” in *Climate Change 2014: Impacts, Adaptation, and Vulnerability.*

90. Nelson et al., *Food Security, Farming, and Climate Change to 2050.*

91. Takle, et al, “US Food Security and Climate Change: Agricultural Futures.” Changes in temperature between 2000 and 2050 as projected by four global climate models (CNRM-CM3 France, CSIRO-MK3 Australia, DCHM5 Germany, and MIROC3.2 Japan), each using the A1B emissions scenario from the IPCC's Fourth Assessment.

92. Food and Agriculture Organization of the United Nations (FAO), *The State of Food Insecurity in the World 2013: The multiple dimensions of food security* (Rome: FAO, 2013), 8, http://www.fao.org/docrep/018/i3434e/i3434e.pdf.

93. Marco Lagi, Karla Z. Bertand, and Yaneer Bar-Yam, *The Food Crisis and Political Instability in North Africa and the Middle East* (Cambridge, MA: New England Complex Systems Institute, 2011), 4, http://necsi.edu/research/social/food_crises.pdf.

94. The World Bank, *World Development Report 2008: Agriculture for Development* (Washington, DC: World Bank, 2008), 81.

95. United States Department of Defense, *Quadrennial Defense Review 2014* (Washington, DC: US Department of Defense, March 4, 2014), http://www.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf.

96. National Intelligence Council, *Global Food Security: Key Drivers – A Conference Report* (Washington, DC: National Intelligence Council, 2012).

97. Lobell and Gourdji, “The influence of climate change on global crop productivity.”

98. Pardey and Beddow, *Agricultural Innovation.*

99. Gerald C. Nelson et al., “Climate change effects on agriculture: Economic responses to biophysical shocks,” *Proceedings of the National Academy of Sciences of the United States of America* (March 4, 2014), http://www.ncbi.nlm.nih.gov/pubmed/24344285; Gerald C. Nelson et al., “Agriculture and Climate Change in Global Scenarios: Why Don't the Models Agree,” *Agricultural Economics* 45, no. 1 (2014): 85–101, http://onlinelibrary.wiley.com/doi/10.1111/agec.12091/pdf; Porter et al., “Chapter 7: Food Security and Food Production Systems” in *Climate Change 2014: Impacts, Adaptation, and Vulnerability.*

100. President's Council of Advisors on Science and Technology (PCAST), *Report to the President on Agricultural Preparedness and the Agriculture Research Enterprise* (Washington, DC: Executive Office of the President, December 2012), http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_agriculture_20121207.pdf.

101. Food and Agriculture Organization of the United Nations (FAO), *The State of Food and Agriculture, Women in Agriculture: Closing the Gender Gap for Development* (Rome: FAO, 2011).

102. Ibid.

103. Ibid.

104. Hema Swaminathan, J. Y. Suchitra, and Rahul Lahoti, *Karnataka Household Asset Survey: Measuring the Gender Asset Gap* (Bangalore: Indian Institute of Management Bangalore, 2011).

105. FAO, *The State of Food and Agriculture.*

106. See for example: United Nations Food and Agriculture Organization (FAO), *Save and grow: A policymaker's guide to the sustainable intensification of smallholder crop production* (Rome: FAO, 2011); Miguel A. Altieri, Fernando R. Funes-Monzote, and Paulo Petersen, "Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty," *Agronomy for Sustainable Development* 32, no. 1 (January 2012): 1-13; International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), *Agriculture at a Crossroads: The Synthesis Report*, eds. Beverly D. McIntyre et al. (Washington, DC: IAASTD, 2009); Olivier De Schutter, "Report of the Special Rapporteur on the right to food," *United Nations General Assembly*, A/65/281 (New York: UN, 2010), http://www.srfood.org/images/stories/pdf/officialreports/20101021_access-to-land-report_en.pdf; Rebecca Clements et al., *Technologies for Climate Change Adaptation–Agriculture Sector*, ed. Xianli Zhu (Roskilde, Denmark: United Nations Environment Programme, 2011).

107. "Water Efficient Maize for Africa," The African Agricultural Technology Foundation, accessed April 11, 2014, http://wema.aatf-africa.org/.

108. DEFRA, *The 2007/2008 Agricultural Price Spikes*; Gordon Conway, Jeff Waage, and Sarah Delaney, *Science and Innovation for Development* (London: UK Collaborative on Development Sciences, 2010), http://www.ukcds.org.uk/sites/default/files/content/resources/science_innovation_development_v2.pdf.

109. P. M. Vitousek et al., "Nutrient imbalances in agricultural development," *Science* 324, no. 5934 (June 19, 2009): 1519-1520.

110. Xiaoyuan Yan et al., "Global Estimations of the Inventory and Mitigation Potential of Methane Emissions from Rice Cultivation Conducted Using the 2006 Intergovernmental Panel on Climate Change Guidelines," *Global Biogeochemical Cycles* 23, no. 2 (2009); Henning Steinfeld and Tom Wassenaar, "The role of livestock production in carbon and nitrogen cycles," *Annual Review of Environment and Resources* 32, no. 1 (2007): 271-294.

111. J.R. Freney, *Management Practices to Increase Efficiency of Fertilizer and Animal Nitrogen and Minimize Nitrogen Loss to the Atmosphere and Groundwater* (Canberra, Australia: Food & Fertilizer Technology Center for the Asian and Pacific Region, February 19, 2013), http://www.fftc.agnet.org/files/lib_articles/20130422100045/tb186.pdf.

112. Jennifer A. Burney, Steven J. Davis, and David B. Lobell, "Greenhouse Gas Mitigation by Agricultural Intensification," *Proceedings of the National Academy of Sciences of the United States of America* 107, no. 26 (June 29, 2010): 12052–12057, http://www.pnas.org/cgi/content/abstract/0914216107v1.

113. Lal, "Soil Carbon Sequestration Impacts on Global Climate Change and Food Security."

114. Stocker et al., "2013: Technical Summary," in *Climate Change 2013: The Physical Science Basis.*

115. "The New Zealand Fund for Global Partnerships in Livestock Emissions Research," Ministry for Private Industries, accessed April 14, 2014, http://www.mpi.govt.nz/nzlivestockemissionsfund.

116. Herrero and Thornton, "Livestock and global change."

117. Herrero et al., "Livestock and Greenhouse Gas Emissions: Mitigation Options and Trade-Offs."

118. Ibid.

119. Yan et al., "Global Estimations of the Inventory and Mitigation Potential of Methane Emissions from Rice Cultivation."

120. Romeo J. Cabangon et al., "Effect of Irrigation Method and N-Fertilizer Management on Rice Yield, Water Productivity, and Nutrient-Use Efficiencies in Typical Lowland Rice Conditions in China," *Paddy and Water Environment* 2, no. 4 (December 2004): 195–206, http://link.springer.com/article/10.1007%2Fs10333-004-0062-3#; H. Pathak, C. Li, and R. Wassmann, "Greenhouse gas emissions from Indian rice fields: Calibration and upscaling using the DNDC model," *Biogeosciences* 2, no. 2 (2005): 113–123, http://www.biogeosciences.net/2/113/2005/bg-2-113-2005.pdf.

121. S. Park et al., "Trends and seasonal cycles in the isotopic composition of nitrous oxide since 1940," *Nature Geoscience* 5, no. 4 (April 2012): 261–265, www.nature.com/ngeo/journal/v5/n4/full/ngeo1421.html.

122. Global nitrogen-use efficiency is measured by recovery efficiency in the first year, that is, fertilized crop nitrogen - unfertilized crop N update/N applied. Source: Dave S. Reay et al., "Global Agriculture and Nitrous Oxide Emissions," *Nature Climate Change* 2, no. 6 (May 13, 2012): 413, http://www.nature.com/nclimate/journal/v2/n6/full/nclimate1458.html.

123. Cabangon et al., "Effect of Irrigation Method and N-Fertilizer Management on Rice Yield"; Pathak, Li, and Wassmann, "Greenhouse gas emissions from Indian rice fields."

124. Pete Smith et al., "Greenhouse gas mitigation in agriculture," *Philosophical transactions of the Royal Society of London. Series B, Biological Sciences* 363, no. 1492 (2008): 789-813.

125. Edenhofer et al., "Summary for Policymakers," in *Climate Change 2014: Mitigation of climate change.*

Part II

1. Julian M. Alston, Philip G. Pardey, and Vernon W. Ruttan, "Research Lags Revisited: Concepts and Evidence from US Agriculture," Staff Paper, Department of Applied Economics, No. P08-14 (St. Paul: University of Minnesota, 2008).

2. Smeltz, *Foreign Policy in the New Millennium.*

3. AQUASTAT, "Water Uses" (Rome: FAO, 2014), accessed April 30, 2014, http://www.fao.org/nr/water/aquastat/water_use/index.stm.

4. Frank Rijsberman, "CGIAR Consortium 2013 Reflections and 2014 Outlook: A Mid-Term Review for the New Billion $ CGIAR," CGIAR, accessed April 9, 2014, http://library.cgiar.org/bitstream/handle/10947/2918/CGIAR%20Consortium%202013%20Reflections%20and%202014%20Outlook%20-%20A%20Mid-Term%20Review%20for%20the%20New%20Billion%20Dollar%20CGIAR.pdf?sequence=1.

5. Pardey and Beddow, *Agricultural Innovation.*

6. The African Orphan Crops Consortium includes the Beijing Genomics Institute; Biosciences eastern and central Africa; iPlant Collaborative; Life Technologies; Mars, Incorporated; New Partnership for Africa's Development (NEPAD); University of California, Davis; World Wildlife Federation; and World Agroforestry Centre. Source: "Improving nutrition through African Orphan Crops," Mars Inc., accessed April 14, 2014, http://www.mars.com/global/african-orphan-crops.aspx.

7. Stephen P. Long et al., "Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO_2 Concentrations" *Science* 312, no. 5782 (June 30, 2006): 1918-1921.

8. "The C4 Rice Project," International Rice Research Institute, accessed April 11, 2014, http://c4rice.irri.org/.

9. Nienke Beintema et al., *ASTI Global Assessment of Agricultural R&D Spending: Developing Countries Accelerate Investment* (Washington, DC: IFRI and GFAR, 2012), http://www.ifpri.org/sites/default/files/publications/astiglobalassessment.pdf.

10. Ibid.

11. Ibid.

12. Pardey and Beddow, *Agricultural Innovation.*

13. CGIAR, *Financial Report 2012* (Montpellier, France: CGIAR, 2012): 14, http://library.cgiar.org/bitstream/handle/10947/2869/2012_CGIAR_Financial_Report.pdf?sequence=1.

14. Yoko Hattori et al., "The Ethylene Response Factors SNORKEL1 and SNORKEL2 Allow Rice to Adapt to Deep Water," *Nature* 460, no. 7258 (August 20, 2009): 1026–1030, http://www.ncbi.nlm.nih.gov/pubmed/19693083.

15. Food and Agriculture Organization of the United Nations (FAO), *Global food losses and food waste – Extent, causes, and prevention* (Rome: FAO, 2011).

16. Cynthia Rosenzweig, J. W. Jones, J. L. Hatfield, A. C. Ruane, K. J. Boote, P. Thorburn, J. M. Antle, et al. "The agricultural model intercomparison and improvement project (AgMIP): protocols and pilot studies." *Agricultural and Forest Meteorology* 170 (March 2013): 166-182.

17. Cynthia Rosenzweig, Joshua Elliott, Delphine Deryng, Alex C. Ruane, Christoph Müller, Almut Arneth, Kenneth J. Boote, et al. "Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison." *Proceedings of the National Academy of Sciences* 111, no. 9 (2014): 3268-3273.

18. For more information on these initiatives, go to http://openag.io/ and http://godan.info. Source: "Open Ag Data Alliance," accessed April 24, 2014; "Global Open Data for Agriculture and Nutrition," accessed April 24, 2014.

19. Lobell and Gourdji, "The influence of climate change on global crop productivity."

20. Bryson Bates et al., eds., *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change* (Geneva: IPCC Secretariat, 2008), https://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf.

21. "USGS Threatened and Endangered Stations," United States Geological Survey, last modified April 14, 2014, http://streamstatsags.cr.usgs.gov/ThreatenedGages/ThreatenedGages.html.

22. Gerald C. Nelson et al., "Climate change effects on agriculture."

23. Hsin Huang, Martin von Lampe, and Frank van Tongeren, "Climate change and trade in agriculture," *Food Policy* 36 (2011): S9–S13, http://www.sciencedirect.com/science/article/pii/S0306919210001119.

24. "About AMIS," Agricultural Market Information System, accessed April 11, 2014, http://www.amis-outlook.org/.

25. Xavier Giné et al., "Statistical Analysis of Rainfall Insurance Payouts in Southern India," *American Journal of Agricultural Economics* 89, no. 5 (2007): 1248–1254.; Xavier Giné and Dean Yang, "Insurance, Credit, and Technology Adoption: Field Experimental Evidence from Malawi," *Journal of Development Economics* 89, no. 1 (2009): 1–11.

26. World Bank, *Economics of Adaptation to Climate Change: Synthesis Report* (Washington, DC: World Bank, 2010), https://openknowledge.worldbank.org/handle/10986/12750.

27. FAO, *Global food losses and food waste*.

28. Jean C. Buzby et al., *The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States*, USDA Economic Research Service, EIB-121 (Washington, DC: USDA, February 2014), http://ageconsearch.umn.edu/bitstream/164262/2/EIB121.pdf.

29. Ibid.

References

The 25x'25 Alliance. *Agriculture and Forestry in a Changing Climate: Adaptation Recommendations*. Lutherville, Maryland: 25x'25, April 2013. http://www.25x25.org/storage/25x25/documents/Adaptation/agriculture_and_forestry_in_a_changing_climate_-_adaptation_recommendations.pdf.

The African Agricultural Technology Foundation. "Water Efficient Maize for Africa." Accessed April 11, 2014. http://wema.aatf-africa.org/.

Agricultural Market Information System. "About AMIS." Accessed April 11, 2014. http://www.amis-outlook.org/.

The Agricultural Model Intercomparison and Improvement Project (AgMIP). "About Us." Accessed April 27, 2014. https://www.agmip.org/about-us/.

Ainsworth, Elizabeth A., and Justin M. McGrath. "Direct Effects of Rising Atmospheric Carbon Dioxide and Ozone of Crop Yields." *Global Change Research* 37 (2010): 109–130.

Alexandratos, Nikos. "World Food and Agriculture to 2030/50, Highlights and Views from Mid-2009." Paper presented at the Expert Meeting on "How to Feed the World in 2050," FAO, Rome, June 24-26, 2009. Revised July 25, 2009. ftp://ftp.fao.org/docrep/fao/012/ak542e/ak542e04.pdf.

Alston, Julian M., Philip G. Pardey, and Vernon W. Ruttan. "Research Lags Revisited: Concepts and Evidence from US Agriculture." Staff Paper, Department of Applied Economics, No. P08-14. St. Paul: University of Minnesota, 2008.

Altieri, Miguel A., Fernando R. Funes-Monzote, and Paulo Petersen. "Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty." *Agronomy for Sustainable Development* 32, no. 1 (January 2012): 1-13.

AQUASTAT. "Water Uses." Rome: FAO, 2014. Accessed April 30, 2014. http://www.fao.org/nr/water/aquastat/water_use/index.stm.

Baca, Maria, Peter Läderach, Jeremy Haggar, Götz Schroth, and Oriana Ovalle. "An Integrated Framework for Assessing Vulnerability to Climate Change and Developing Adaptation Strategies for Coffee Growing Families in Mesoamerica." *PloS One* 9, no. 2, e88463 (2014). http://www.plosone.org/article/fetchObject.action?uri=info%3Adoi%2F10.1371%2Fjournal.pone.0088463&representation=PDF.

Baker, Peter, and Rachel Donadio. "Obama Wins More Food Aid But Presses African Nations on Corruption." *The New York Times*, July 10, 2009. http://www.nytimes.com/2009/07/11/world/europe/11prexy.html.

Barrow, C.J. "Biochar: Potential for Countering Land Degradation and for Improving Agriculture." *Applied Geography* 34 (May 2012): 21–28. http://linkinghub.elsevier.com/retrieve/pii/S0143622811001780.

Barucha, Zareen, and Jules Pretty. "The Roles and Values of Wild Foods in Agricultural Systems." *Philosophical Transactions of the Royal Society. Series B, Biological Sciences* 365, no. 1554 (September 2010): 2913–2926. http://rstb.royalsocietypublishing.org/content/365/1554/2913.short.

Bates, Bryson C., Zbigniew W. Kundzewicz, Shaohong Wu, and Jean Palutikof, eds. *Climate Change and Water. Technical paper of the Intergovernmental Panel on Climate Change*. Geneva: IPCC Secretariat, 2008. https://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf.

Beintema, Nienke, Gert-Jan Stads, Keith Fuglie, and Paul Heisey. *ASTI Global Assessment of Agricultural R&D Spending: Developing Countries Accelerate Investment.* Washington, DC: IFRI and GFAR, 2012. http://www.ifpri.org/sites/default/files/publications/astiglobalassessment.pdf.

Bernstein, Lenny, Peter Bosch, Osvaldo Canziani, Zhenlin Chen, Renate Christ, Ogunlade Davidson, William Hare, et al. *Climate Change 2007: Synthesis Report*. Edited by Abdelkader Allali, Roxana Bojariu, Sandra Diaz, Ismail Elgizouli, Dave Griggs, David Hawkins, Olav Hohmeyer, et al. Geneva: IPCC Secretariat, 2007. https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

Borras, Saturnino M. Jr., Ruth Hall, Ian Scoones, Ben White, and Wendy Wolford. "Towards a Better Understanding of Global Land Grabbing: An Editorial Introduction." *The Journal of Peasant Studies* 38, no. 2 (2011): 209-216.

Bouwman, A. F. "Direct Emission of Nitrous Oxide From Agricultural Soils." *Nutrient Cycling in Agroecosystems* 46, no. 1 (1996): 53-70. http://link.springer.com/article/10.1007 %2FBF00210224.

Butler, James H., and Stephen A. Montzka. *The NOAA Annual Greenhouse Gas Index*. Boulder: National Oceanic & Atmospheric Administration Earth System Research Laboratory, updated 2014. http://www.esrl.noaa.gov/gmd/aggi/aggi.html.

Burney, Jennifer A., Steven J. Davis, and David B. Lobell. "Greenhouse Gas Mitigation by Agricultural Intensification." *Proceedings of the National Academy of Sciences of the United States of America* 107, no. 26 (June 2010): 12052–12057. http://www.pnas.org /cgi/content/abstract/0914216107v1.

Buzby, Jean C., Hodan Farah Wells, and Jeffrey Hyman. *The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States.* USDA Economic Research Service, EIB-121. Washington, DC: US Department of Agriculture, February 2014. http://ageconsearch.umn.edu/bitstream/164262/2/EIB121.pdf.

Cabangon, Romeo J., To Phuc Tuong, Ernesto G. Castillo, Lang Xing Bao, Guoan Lu, Guangho Wang, Yanlai Cui, et al. "Effect of Irrigation Method and N-Fertilizer Management on Rice Yield, Water Productivity, and Nutrient-Use Efficiencies in Typical Lowland Rice Conditions in China," *Paddy and Water Environment* 2, no. 4 (December 2004):195–206.

CGIAR. *Financial Report 2012.* Montpellier, France: CGIAR, 2012. http://library.cgiar.org/bitstream/handle/10947/2869/2012_CGIAR_Financial_Report.pdf?sequence=1.

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). "About us." Accessed April 27, 2014. http://ccafs.cgiar.org/about-us#.U1rWC1VdWus.

———. "Andrew Gitari – Kabaune village, Giaki – Kenya." YouTube video, 5:58. Posted November 9, 2010. https://www.youtube.com/watch?v=7J1do3WP98A.

———. "Ruth Marigu Njue – Karurumo village – Kenya." YouTube video, 3:58. Posted November 9, 2010. https://www.youtube.com/watch?v=BQnNNmVyh9o.

The Chicago Council on Global Affairs (CCGA). *Renewing American Leadership in the Fight Against Global Hunger and Poverty.* Chicago: The Chicago Council on Global Affairs, 2009.

Childress, Malcolm D., Paul Siegel, and Mika-Petteri Törhönen. "A New Conceptual Framework for Linking Land Policy with Climate Change Adaptation and Mitigation in the ECA Region: Toward a Multi-dimensional Landscape Approach to Natural Resource Governance and Tenure." Paper prepared for Annual World Bank Conference on Land and Poverty 2012, Washington, DC, April 24-25, 2012. http://www.landandpoverty.com/agenda/pdfs/paper/childress_full_paper.pdf.

Clements, Rebecca, Jeremy Haggar, Alicia Quezada, and Juan Torres. *Technologies for Climate Change Adaptation–Agriculture Sector*. Edited by Xianli Zhu. Roskilde, Denmark: United Nations Environment Programme, 2011.

Conway, Gordon, Jeff Waage, and Sarah Delaney. *Science and Innovation for Development.* London: UK Collaborative on Development Sciences, 2010. http://www.ukcds.org.uk/sites/default/files/content/resources/science_innovation_development_v2.pdf.

Department for Environment Food and Rural Affairs (DEFRA), HM Government. *The 2007/2008 Agricultural Price Spikes: Causes and Policy Implications*. London: DEFRA, 2010. http://archive.defra.gov.uk/foodfarm/food/pdf/ag-price100105.pdf.

Dyson, Tim. "On the Demography of South Asian Famines: Part I." *Population Studies* 45, no. 1 (March 1991): 5–25. http://www.jstor.org/discover/10.2307/2174991?uid=2&uid=4&sid=21104187888533.

Edenhofer, Ottmar, Ramón Pichs Madruga, Youba Sokona, Shardul Agrawala, Igor Alexeyevich Bashmakov, Gabriel Blanco, John Broome, et al. "Summary for Policymakers." In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC Secretariat, 2014. http://report.mitigation2014.org/spm/ipcc_wg3_ar5_summary-for-policymakers_approved.pdf.

Ellick, Adam B. "Floods Could Have Lasting Impact for Pakistan." *The New York Times*, August 17, 2010. http://www.nytimes.com/2010/08/17/world/asia/17pstan.html?pagewanted=all.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). "Quem somos." Accessed April 27, 2014. https://www.embrapa.br/quem-somos.

Erda, Lin, Xiong Wei, Ju Hui, Xu Yinlong, Li Yue, Bai Liping, Xie Liyong. "Climate Change Impacts on Crop Yield and Quality with CO2 Fertilization in China." *Philosophical Transactions of the Royal Society. Series B, Biological Sciences* 360 (2005): 2149–2154.

The Famine Early Warning Systems Network (FEWS NET). "About Us." Accessed April 27, 2014. http://www.fews.net/about-us.

Feed the Future. "About Feed the Future." Accessed April 25, 2014. http://www.Feedthefuture.gov/about.

———. “Overview.” Accessed April 25, 2014. http://feedthefuture.gov/sites/default/files/resource/files/ftf_overview_factsheet_oct2012.pdf.

Field, Christopher B., Vicente R. Barros, Michael D. Mastrandrea, Katharine J. Mach, Mohamed A. K. Abdrabo, W. Neil Adger, Yury A. Anokhin, et al. “Summary for Policymakers.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC Secretariat, 2014. http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf.

Fieldhouse, David. “For Richer, for Poorer?” In *The Cambridge Illustrated History of the British Empire*, edited by P.J. Marshall. Cambridge: Cambridge University Press, 1996.

Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN). “About FANRPAN.” Accessed April 27, 2014. http://www.fanrpan.org/about/.

Food and Agricultural Organization of the United Nations (FAO). *Adaptation to Climate Change in Agriculture, Forestry and Fisheries: Perspective, Framework and Priorities*. Rome: FAO, 2007.

———. *Global food losses and food waste – Extent, causes and prevention*. Rome: FAO, 2011.

———. *Opportunity Untapped: Water in Agriculture Factsheet*. Rome: FAO, n.d. Accessed April 14, 2014. http://www.unwater.org/downloads/media/scarcity/factsheet_wwf_eng.pdf.

———. *Save and grow: A policymaker’s guide to the sustainable intensification of smallholder crop production*. Rome: FAO, 2011.

———. *The State of Food and Agriculture. Women in Agriculture: Closing the Gender Gap for Development*. Rome: FAO, 2011.

———. *The State of Food Insecurity in the World 2011: How does international price volatility affect domestic economies and food security?* Rome: FAO, 2011. http://www.fao.org/docrep/014/i2330e/i2330e.pdf.

———. *The State of Food Insecurity in the World 2012: Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition*. Rome: FAO, 2012. http://www.fao.org/docrep/016/i3027e/i3027e.pdf.

———. *The State of Food Insecurity in the World 2013: The multiple dimensions of food security*. Rome: FAO, 2013. http://www.fao.org/docrep/018/i3434e/i3434e.pdf.

FOODSECURE. “What is FOODSECURE.” Accessed April 27, 2014. http://www.foodsecure.eu/WhatIsFoodSecure.aspx.

Fellman, Jason B., Eldon H. Franz, Chelsea L. Crenshaw, and Denise Elston. “Global estimates of soil carbon sequestration via livestock waste: A STELLA simulation.” *Environment, Development and Sustainability* 11, no. 4 (August 2009): 871-885.

Fox, Porter. “The End of Snow.” *The New York Times*, February 7, 2014. http://www.nytimes.com/2014/02/08/opinion/sunday/the-end-of-snow.html?_r=0.

Freney, J.R. *Management Practices to Increase Efficiency of Fertilizer and Animal Nitrogen and Minimize Nitrogen Loss to the Atmosphere and Groundwater*. Canberra, Australia: Food & Fertilizer Technology Center for the Asian and Pacific Region, February 19, 2013. http://www.fftc.agnet.org/files/lib_articles/20130422100045/tb186.pdf.

Friedman, Thomas L. "WikiLeaks, Drought and Syria." *The New York Times,* January 21, 2014. http://www.nytimes.com/2014/01/22/opinion/friedman-wikileaks-drought-and-syria.html.

———. "Without Water, Revolution." *New York Times*, May 18, 2013. http://www.nytimes.com/2013/05/19/opinion/sunday/friedman-without-water-revolution.html?_r=2&.

Garnett, T., M.C. Appleby, A. Balmford, I.J. Bateman, T.G. Benton, P. Bloomer, B. Burlingame, et al. "Sustainable Intensification in Agriculture: Premises and Policies." *Science* 341, no. 6141 (July 5, 2013): 33-34. http://www.sciencemag.org/content/341/6141/33.

Garrett, K.A., S.P. Dendy, E.E. Frank, M.N. Rouse, and S.E. Travers. "Climate Change Effects on Plant Disease: Genomes to Ecosystems." *Annual Review of Phytopathology* 44 (January 2006): 489–509. http://www.ncbi.nlm.nih.gov/pubmed/16722808.

Giné, Xavier, Robert M. Townsend, and James Vickery. "Statistical Analysis of Rainfall Insurance Payouts in Southern India." *American Journal of Agricultural Economics* 89, no. 5 (2007): 1248–1254.

Giné, Xavier, and Dean Yang. "Insurance, Credit, and Technology Adoption: Field Experimental Evidence from Malawi." *Journal of Development Economics* 89, no. 1 (2009): 1–11.

Global Open Data for Agriculture and Nutrition. Accessed April 24, 2014. http://godan.info.

Godfray, H. Charles J., John R. Beddington, Ian R. Crute, Lawrence Haddad, David Lawrence, James F. Muir, Jules Pretty, Sherman Robinson, Sandy M. Thomas, and Camilla Toulmin. "Food security: The challenge of feeding 9 billion people." *Science* 327, no. 5967 (2010): 812-818. http://www.sciencemag.org/content/327/5967/812.full.pdf.

Hammes, K., M. S. Torn, A. G. Lapenas, and M. W. I. Schmidt. "Centennial Black Carbon Turnover Observed in a Russian Steppe Soil." *Biogeosciences* 5 (2008): 1339-1350. www.biogeosciences.net/5/1339/2008/.

Hansen, J., R. Ruedy, M. Sato, and K. Lo. "Global surface temperature change." *Reviews of Geophysics* RG4004, 48, no. 4 (December 2010). http://onlinelibrary.wiley.com/doi/10.1029/2010RG000345/pdf.

Hatfield, J.L., K. J. Boote, B. A. Kimball, L. H. Ziska, R. C. Izaurralde, D. Ort, Allison Thomson, and D. Wolfe. "Climate Impacts on Agriculture: Implications for Crop Production." *Agronomy Journal* 103 (2011): 351–370.

Hattori, Yoko, Keisuke Nagai, Shizuka Furukawa, Xian-Jun Song, Ritsuko Kawano, Hitoshi Sakakibara, Jianzhong Wu, et al. "The Ethylene Response Factors SNORKEL1 and SNORKEL2 Allow Rice to Adapt to Deep Water." *Nature*

460, no. 7258 (August 20, 2009): 1026–1030. http://www.ncbi.nlm.nih.gov/pubmed/19693083.

Herrero, Mario, and Philip K. Thornton. "Livestock and global change: Emerging issues for sustainable food systems." *Proceedings of the National Academy of Sciences of the United States of America* 110, no. 52 (2013): 20878–20881. http://www.pnas.org/content/early/2013/12/13/1321844111.full.pdf+html.

Herrero, Mario, Philip K. Thornton, Petr Havlík, and M. Rufino. "Livestock and Greenhouse Gas Emissions: Mitigation Options and Trade-Offs." In *Climate Change Mitigation and Agriculture*, edited by Eva Wollenberg, Alison Nihart, Maryanne Grieg-Gran, and Marja-Liisa Tapio-Bistrom, 316-332. New York: Routledge, 2012.

High Level Panel of Experts on Food Security and Nutrition (HLPE). *Food Security and Climate Change: A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.* Rome: HLPE, 2012. http://www.ifpri.org/sites/default/files/HLPE-Report-3-Food_security_and_climate_change-June_2012.pdf.

Hijmans, Robert. "Relocating Rice Production in China." *Rice Today* 6, no. 4 (2007): 25-27. http://www.scribd.com/doc/34621863/Rice-Today-Vol-6-No-4.

Huang, Hsin, Martin von Lampe, and Frank van Tongeren. "Climate change and trade in agriculture." *Food Policy* 36 (2011): S9–S13. http://www.sciencedirect.com/science/article/pii/S0306919210001119.

Integrated Cassava Project. "About Us." Accessed April 27, 2014. http://www.cassavabiz.org/aboutICP/aboutus.htm.

Intergovernmental Panel on Climate Change (IPCC). "Annex III: Glossary." Edited by Serge Planton. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press, 2013. http://www.climatechange2013.org/images/report/WG1AR5_AnnexIII_FINAL.pdf.

———. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge: Cambridge University Press, 2012.

———. "Summary for Policymakers." In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller. Cambridge: Cambridge University Press, 2007.

———. "Summary for Policymakers." In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press, 2013. http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf.

International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). *Agriculture at a Crossroads: The Synthesis Report*. Edited by Beverly D. McIntyre, Hans R. Herren, Judi Wakhungu, and Robert T. Watson. Washington, DC: IAASTD, 2009.

International Rice Research Institute. “Coping with Climate Change.” *Rice Today* 6, no. 3 (2007): 10-15. http://www.scribd.com/doc/34620921/Rice-Today-Vol-6-No-3.

———. “The C4 Rice Project.” Accessed April 11, 2014. http://c4rice.irri.org/.

Ivanov, A.L. *Global Manifestations of Climate Change in the Agricultural Sector*. Moscow: Russian Agricultural Academy, 2004.

Ivanov, A.L., and V.I. Kiryushin. *Global Climate Change and Forecast of Weather Risks in Agriculture*. Moscow: Russian Agricultural Academy, 2009.

Jarvis, Andy, Julian Ramirez-Villegas, Beatriz Vanessa Herrera Campo, and Carlos Navarro-Racines. “Is Cassava the Answer to African Climate Change Adaptation?” *Tropical Plant Biology* 5, no. 1 (2012): 9–29. http://link.springer.com/article/10.1007/s12042-012-9096-7.

Jones, Peter G., and Philip K. Thornton. “Croppers to livestock keepers: Livelihood transitions to 2050 in Africa due to climate change.” *Environmental Science & Policy* 12, no. 4 (June 2009): 427-437. http://dx.doi.org/10.1016/j.envsci.2008.08.006.

Kharin, Viatcheslav V., Francis W. Zwiers, Xuebin Zhang, and Gabriele C. Hegerl. “Changes in Temperature and Precipitation Extremes in the IPCC Ensemble of Global Coupled Model Simulations.” *Journal of Climate* 20, no. 8 (2007): 1419-1444. http://journals .ametsoc.org/doi/abs/10.1175/JCLI4066.1.

Khoury, Colin K., Anne D. Bjorkman, Hannes Dempewolf, Julian Ramirez-Villegas, Luigi Guarino, Andy Jarvis, Loren H. Rieseberg, and Paul C. Struik. “Increasing homogeneity in global food supplies and the implications for food security.” *Proceedings of the National Academy of Sciences* 111, no. 11 (2014): 4001-4006. http://www.pnas.org /cgi/content/long/1313490111v1.

Kilimo Salama. “About Kilimo Salama.” Accessed April 27, 2014. http://kilimosalama.wordpress.com/about/.

———. “Fact sheet.” Accessed April 27, 2014. http://kilimosalama.files.wordpress.com/2010/02/kilimosalama_v031.pdf.

Lagi, Marco, Karla Z. Bertand, and Yaneer Bar-Yam. *The Food Crisis and Political Instability in North Africa and the Middle East.* Cambridge, MA: New England Complex Systems Institute, 2011. http://necsi.edu/research/social/foodcrises.html.

Lal, R. “Soil Carbon Sequestration Impacts on Global Climate Change and Food Security.” *Science* 304, no. 5677 (2004): 1623–1627. http://www.sciencemag.org/content/304/5677/1623.abstract.

Livingston, M., R. Johansson, S. Daberkow, M. Roberts, M. Ash, and V. Breneman. *Economic and Policy Implications of Wild-Borne Entry of Asian Soybean Rust into the United States Outlook*. Washington, DC: USDA and University of Tennessee Institute of Agriculture, 2004. http://www.utcrops.com/soybean/diseases/disease_images/ERSreportOnSBR.pdf.

Lobell, David B., Marianne Bänziger, Cosmos Magorokosho, and Bindiganavile Vivek. "Nonlinear heat effects on African maize as evidenced by historical yield trials." *Nature Climate Change* 1, no. 1 (2011): 42-45.

Lobell, David B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor. "Prioritizing Climate Change Adaptation Needs for Food Security in 2030." *Science* 319, no. 5863 (February 2008): 607-610. http://www.sciencemag.org/content/319/5863 /607.

Lobell, David B., and Sharon Gourdji. "The influence of climate change on global crop productivity." *Plant Physiology* 160 no. 4 (October 2012): 1686-1697. http://www.plantphysiol.org/content/early/2012/10/10/pp.112.208298.full.pdf.

Lobell, David B., Wolfram Schlenker, and Justin Costa-Roberts. "Climate Trends and Global Crop Production since 1980." *Science* 333, no. 6042 (July 2011): 616–620. http://www .ncbi.nlm.nih.gov/pubmed/21551030.

Long, Stephen P., Elizabeth A. Ainsworth, Andrew D. B. Leakey, Josef Nösberger, and Donald R. Ort. "Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO_2 Concentrations." *Science* 312, no. 5782 (2006): 1918-1921. http://www.sciencemag.org/content/312/5782/1918.abstract.

Magnan, Nicholas, Douglas M. Larson, and J. Edward Taylor. "Stuck on Stubble? The Non-market Value of Agricultural Byproducts for Diversified Farmers in Morocco." *American Journal of Agricultural Economics* 94, no. 5 (2012):1055-1069. http://ajae.oxfordjournals.org/content/94/5/1055.short.

Major, Julie, Marco Rondon, Diego Molina, Susan J. Riha, and Johannes Lehmann. "Nutrient Leaching in a Colombian Savanna Oxisol Amended with Biochar." *Journal of Environmental Quality* 41, no. 4 (2012): 1076-1086.

Malkin, Elisabeth. "A Coffee Crop Withers." *The New York Times,* May 5, 2014. http://nyti.ms/1htlueM.

Mars, Inc. "Improving Nutrition through African Orphan Crops." Accessed April 14, 2014. http://www.mars.com/global/african-orphan-crops.aspx.

Mekonnen, M. M., and A. Y. Hoekstra. *The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products. Volume 1: Main Report.* Value of Water Research Report Series No. 47. Delft, the Netherlands: UNESCO-IHE, December 2010. http://www.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf.

Melillo, Jerry M., Terese T. C. Richmond, and Gary W. Yohe, eds. *Climate Change Impacts in the United States: The Third National Climate Assessment.* Washington, DC: US Global Change Research Program, 2014. http://www.globalchange.gov/ncadac.

Ministry for Private Industries. "The New Zealand Fund for Global Partnerships in Livestock Emissions Research." Accessed April 14, 2014. http://www.mpi.govt.nz/nzlivestockemissionsfund.

The Montpellier Panel. *Sustainable Intensification: A New Paradigm for African Agriculture.* London: Agriculture for Impact, 2013. https://workspace.imperial.ac.uk/africanagriculturaldevelopment/Public/Montpellier%20Panel%20Report%202013%20-%20Sustainable%20Intensification%20-%20A%20New%20Paradigm%20for%20African%20Agriculture.pdf.

National Aeronautics and Space Administration (NASA). "Climate change: How do we know?" Accessed April 14, 2014. http://climate.nasa.gov/evidence.

———. GISS Surface Temperature Analysis. "Global Land-Ocean Temperature Index (C) (Anomaly with Base: 1951-1980)." Accessed April 30, 2014. http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.txt.

———. "Six Decades of a Warming Earth." Published January 21, 2014. Accessed April 11, 2014. http://www.youtube.com/watch?v=gaJJtS_WDmI.

National Intelligence Council. *The Future of Indian Ocean and South China Sea Fisheries: Implications for the United States*. Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, July 30, 2013.

———. *Global Food Security: Emerging Technologies to 2040*. Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, July 30, 2013.

———. *Global Food Security: Key Drivers – A Conference Report*. Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, February 1, 2013.

———. *Global Food Security: Market Forces and Selected Case Studies*. Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, May 10, 2012.

———. *Natural Resources in 2020, 2030, and 2040: Implications for the United States*. Washington, DC: National Intelligence Council, Office of the Director of National Intelligence, July 25, 2013. http://www.dni.gov/files/documents/NICR%20 2013-05%20US%20Nat%20Resources%202020,%202030%202040.pdf.

National Park Service. "Mississippi River Facts." Accessed April 9, 2014. http://www.nps.gov/miss/riverfacts.htm.

Nelson, Gerald C. "Are Biofuels the Best Use of Sunlight?" In *Handbook of Bioenergy Economics and Policy*, edited by Madhu Khanna, Jürgen Scheffran, and David Zilberman, 15-25. New York: Springer, 2010.

Nelson, Gerald C., Helal Ahammad, Elodie Blanc, Katherine Calvin, Tomoko Hasegawa, Petr Havlik, Edwina Heyhoe, et al. "Agriculture and Climate Change in Global Scenarios: Why Don't the Models Agree." *Agricultural Economics* 45, no. 1 (2014): 85-101. http://onlinelibrary.wiley.com/doi/10.1111/agec.12091/pdf.

Nelson, Gerald C., Mark W. Rosegrant, Amanda Palazzo, Ian Gray, Christina Ingersoll, Richard Robertson, Simla Tokgoz, et al. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options*. Washington, DC: International Food Policy Research Institute, 2010.

Nelson, Gerald C., Hugo Valin, Ronald D. Sands, Petr Havlík, Helal Ahammad, Delphine Deryng, Joshua Elliott, et al. "Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks." *Proceedings of the National Academy of Sciences of the United States of America* 111, no. 9 (2014). http://www.ncbi.nlm.nih.gov/pubmed/24344285.

The New Partnership for Africa's Development (NEPAD). "Comprehensive Africa Agriculture Development Programme (CAADP)." Accessed April 11, 2014. http://www.nepad.org/foodsecurity/agriculture/about.

Nordblom, Thomas L. "The importance of crop residues as feed resources in West Asia and North Africa." FAO Farm Resource Management Program, International Center for Agricultural Research in the Dry Areas. Accessed April 14, 2014. http://www.fao.org/wairdocs/ilri/x5495e/x5495e04.htm.

Open Ag Data Alliance. Accessed April 24, 2014. http://openag.io/.

Organisation for Economic Co-operation and Development (OECD) and Food and Agriculture Organization of the United Nations (FAO). *OECD-FAO Agricultural Outlook 2012-2021*. Washington, DC: OECD Publishing, 2012. http://dx.doi.org/10.1787/agr_outlook-2012-en.

Pardey, Philip G., and Jason Beddow. *Agricultural Innovation: The United States in a Changing Global Reality*. Chicago: The Chicago Council on Global Affairs, April 2013. http://www.thechicagocouncil.org/UserFiles/File/GlobalAgDevelopment/Report/Agricultural_Innovation_Final.pdf.

Park, S., P. Croteau, K.A. Boering, D.M. Etheridge, D. Ferretti, P.J. Fraser, K-R. Kim, et al. "Trends and seasonal cycles in the isotopic composition of nitrous oxide since 1940." *Nature Geoscience* 5 (February 2012): 261–265. www.nature.com/ngeo/journal /v5/n4/full/ngeo1421.html.

Parry, M.L., C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer. "Effects of climate change on global food production under SRES emissions and socio-economic scenarios." *Global Environmental Change* 14, no. 1 (April 2004): 53-67. http://www.sciencedirect.com/science/article/pii/S0959378003000827.

Pathak, H., C. Li, and R. Wassmann, "Greenhouse gas emissions from Indian rice fields: calibration and upscaling using the DNDC model." *Biogeosciences* 2, no. 2 (2005): 113–123. http://www.biogeosciences.net/2/113/2005/bg-2-113-2005.pdf.

Peng, Shaobing, Jianliang Huang, John E. Sheehy, Rebecca C. Laza, Romeo M. Visperas, Xuhua Zhong, Grace S. Centeno, Gurdev S. Khush, and Kenneth G. Cassman. "Rice yields decline with higher night temperature from global warming." *Proceedings of the National Academy of Sciences of the United States of America* 101, no. 27 (2004): 9971-9975. http://www.pnas.org/content/101/27/9971.full.

Porter, John R., Liyong Xie, Andrew Challinor, Kevern Cochrane, Mark Howden, Muhammad Mohsin Iqbal, David Lobell, et al. "Chapter 7: Food Security and Food Production Systems." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Pramod Aggarwal and Kaija Hakala. Geneva: IPCC Secretariat, 2014. http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap7_FGDall.pdf.

President's Council of Advisors on Science and Technology (PCAST). *Report to the President on Agricultural Preparedness and the Agriculture Research Enterprise*. Washington, DC: Executive Office of the President, December 2012. http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_agriculture_20121207.pdf.

Reay, Dave S., Eric A. Davidson, Keith A. Smith, Pete Smith, Jerry M. Melillo, Frank Dentener, and Paul J. Crutzen."Global Agriculture and Nitrous Oxide Emissions." *Nature Climate Change* 2, no. 6 (May 2012): 410–416. http://www.nature.com/nclimate/journal/v2 /n6/box/nclimate1458_BX1.html.

Recha, John, Philip Kimeli, and Vivian Atakos. "Farmers should use trees to cushion their farms from degradation." *CCAFS News Blog* (blog). August 12, 2013. http://ccafs.cgiar.org/blog/farmers-should-use-trees-cushion-their-farms-degradation#.U2lUzIFdVhx.

Redfern, Suzanna K., Nadina Azzu, and Jesie S. Binamira. "Rice in Southeast Asia: Facing risks and vulnerabilities to respond to climate change." In *Building Resilience for Adaptation to Climate Change in the Agriculture Sector: Proceedings of a Joint FAO/OECD Workshop*, edited by Alexandre Meybeck, Jussi Lankoski, Suzanne Redfern, Nadine Azzu, and Vincent Gitz, 295-314. Rome: FAO and OECD, 2012. http://www.fao.org/docrep/017/i3084e/i3084e18.pdf.

Rice, Susan E. "Remarks by Ambassador Susan E. Rice, US Permanent Representative to the United Nations, at a Security Council Session on the Impact of Climate Change on the Maintenance of International Peace and Security." New York: United States Mission to the United Nations, July 20, 2011. http://usun.state.gov/briefing/statements/2011/168828.htm.

Richard, Gigi. Personal communication with Gerald C. Nelson. April 2014.

Rijsberman, Frank. "CGIAR Consortium 2013 Reflections and 2014 Outlook: A Mid-Term Review for the New Billion $ CGIAR." CGIAR. Last modified January 21, 2014. http://www.cgiar.org/consortium-news/cgiar-consortium-2013-reflections-and-2014-outlook-a-mid-term-review-for-the-new-billion-cgiar-2/. http://library.cgiar.org/bitstream/handle/10947/2918/CGIAR%20Consortium%202013%20Reflections%20and%202014%20Outlook%20-%20A%20Mid-Term%20Review%20for%20the%20New%20Billion%20Dollar%20CGIAR.pdf?sequence=1.

Riley, James C. "Estimates of Regional and Global Life Expectancy, 1800-2001." *Population and Development Review* 31, no. 3 (2005): 537-543. http://www.jstor.org/stable/pdfplus/3401478.pdf?acceptTC=true&acceptTC=true&jpdConfirm=true.

Robertson, Richard. "Predicted changes in average annual rainfall between 2000 and 2050 from two climate models." Maps prepared for The Chicago Council on Global Affairs. 2014a.

Robertson, Richard. "Predicted changes in rainfed corn, irrigated rice, and rainfed wheat yields between 2000 and 2050 using the GFDL model." Maps prepared for The Chicago Council on Global Affairs. 2014b.

Robertson, Richard. "Predicted changes in rainfed corn, irrigated rice, and rainfed wheat yields between 2000 and 2050 using the MIROC model." Maps prepared for The Chicago Council on Global Affairs. 2014c.

Samenow, Jason. "Drought and Syria: Manmade climate change or just climate?" *Washington Post,* September 9, 2013. http://www.washingtonpost.com/blogs/capital-weather-gang/wp/2013/09/09/drought-and-syria-manmade-climate-change-or-just-climate/.

Sass, Ronald, and Frank M. Fisher Jr. "Methane emissions from rice paddies: A process study summary." *Nutrient Cycling in Agroecosystems* 49, no. 1 (1997): 119-127. http://link .springer.com/article/10.1023%2FA%3A1009702223478.

Schmidhuber, Josef, and Francesco N. Tubiello. "Global food security under climate change." *Proceedings of the National Academy of Sciences of the United States of America* 104, no. 50 (2007). http://www.pnas.org/content/104/50/19703.full.

De Schutter, Olivier. "Report of the Special Rapporteur on the right to food," United Nations General Assembly, A/65/281. New York: UN, 2010. http://www.srfood.org/images/stories/pdf/officialreports/20101021_access-to-land-report_en.pdf.

Searchinger, Timothy, Steven P. Hamburg, Jerry Melillo, William Chameides, Petr Havlik, Daniel M. Kammen, Gene E. Likens, et al. "Climate Change. Fixing a Critical Climate Accounting Error." *Science* 326, no. 5952 (October 2009): 527–528. http://www.sciencemag.org/content/326/5952/527.short.

Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. "Use of US Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change." *Science* 319, no. 5867 (February 2008): 1238-1240. http://www.sciencemag.org/cgi/content/abstract/1151861v1.

Securing Water for Food. "Securing Water for Food: A Grand Challenge for Development." Accessed April 16, 2014. http://www.securingwaterforfood.org/?utm_source=+SWFF+Newsletter+11&utm_campaign=Newsletter+11&utm_medium=email.

Smeltz, Dina. *Foreign Policy in the New Millennium: Results of the 2012 Chicago Council Survey of American Public Opinion and US Foreign Policy*. Chicago: The Chicago Council on Global Affairs, 2012. http://www.thechicagocouncil.org/UserFiles/File/Task%20Force%20Reports/2012_CCS_Report.pdf.

Smith, Keith A. "The Impact of agriculture and other land uses on emissions of methane and nitrous and nitric oxides." *Envrionmental Sciences* 2, no. 2 (2005): 101-108. http://www.tandfonline.com/doi/full/10.1080/15693430500370423#.U153z3oo7x.

Smith, Pete, Mercedes Bustamante, Helal Ahammad, Harry Clark, Hongmin Dong, Elnour A. Elsiddig, Helmut Haberl, et al. "Chapter 11: Agriculture, Forestry and Other Land Use (AFOLU)." In *Climate Change 2014: Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC Secretariat, 2014. http://report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter11.pdf.

Smith, Pete, Daniel Martino, Zucong Cai, Daniel Gwary, Henry Janzen, Pushpam Kumar, Bruce McCarl, et al. "Greenhouse gas mitigation in agriculture." *Philosophical Transactions of the Royal Society. Series B, Biological Sciences* 363, no. 1492 (2008): 789-813.

Sparkes, Jessica, and Peter Stoutjesdijk. *Biochar: Implications for agricultural productivity.* Canberra, Australia: Australian Bureau of Agricultural and Resource Economics and Sciences, December 2011. http://data.daff.gov.au/data/warehouse/biochar9abcm001 /biochar9abcm00101/TR.2011.06_Biochar_v1.0.0.pdf.

Steinfeld, Henning, and Tom Wassenaar. "The role of livestock production in carbon and nitrogen cycles." *Annual Review of Environment and Resources* 32, no. 1 (2007): 271-294.

Stocker, T.F., D. Qin, G.-K. Plattner, L.V. Alexander, S.K. Allen, N.L. Bindoff, F. M. Bréon, et al. "2013: Technical Summary." In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, 2013. http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf.

Swaminathan, Hema, J. Y. Suchitra, and Rahul Lahoti. *Karnataka Household Asset Survey: Measuring the Gender Asset Gap*. Bangalore: Indian Institute of Management Bangalore, 2011.

Syngenta Foundation for Sustainable Agriculture. "Agriculture Index Insurance: Kilimo Salama." Accessed April 27, 2014. http://www.syngentafoundation.org/index.cfm?pageID=562.

Takle, Eugene S. "Impact of Climate Change on Grain Quality." Iowa State University Climate Science Program. Accessed April 9, 2014. http://climate.engineering.iastate.edu /Document/Grain%20Quality.pdf.

———. Personal communication with Gerald C. Nelson. April 2014.

Takle, Eugene S., David Gustafson, Roger Beachy, Gerald C. Nelson, Daneil-D'Croz, and Amanda Palazzo. "US Food Security and Climate Change: Agricultural Futures." *Economics: The Open-Access, Open-Assessment E-Journal* 7 (August 2013): 13-34. http://www.economics-ejournal.org/economics/journalarticles/2013-34.

The Third Global Conference on Agriculture, Food and Nutrition Security and Climate Change. "About The Conference & Themes." Accessed April 27, 2014. http://afcconference.agric.za/about.

Thompson, Robert L."Feeding the World in 2050: How We Overcome Our Common Food and Nutrition Challenge." Lecture given at University of Natural Resources and Life Sciences, Vienna, October 10, 2013.

Thornton, Philip K., Jeannette van de Steeg, A. Notenbaert, and Mario Herrero. "The Impacts of Climate Change on Livestock and Livestock Systems in Developing Countries: A Review of What We Know and What We Need to Know." *Agricultural Systems* 101, no. 3 (July 2009): 113–127. http://linkinghub.elsevier.com/retrieve/pii/S0308521X09000584.

Thornton, Philip K., and Laura Cramer, eds. *Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate.* Working Paper No. 23. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Security, 2012. https://cgspace.cgiar.org/bitstream/handle/10568/21226/ccafs-wp-23-cc_impacts_CGIAR.pdf?sequence=7.

Tilman, David, Christian Balzer, Jason Hill, and Belinda L. Befort. "Global food demand and the sustainable intensification of agriculture." *Proceedings of the National Academy of Sciences* 108, no. 50 (December 13, 2011). http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3250154/.

United Nations Framework Convention on Climate Change (UNFCC). *UNFCCC: Article I*. New York: United Nations, 1992. https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf.

United Nations Population Division (UNPD), Department of Economic and Social Affairs. *World Population Prospects: The 2000 Revision*. New York: UNPD, 2001. https://www.un.org/esa/population/publications/wpp2000/highlights.pdf.

———. *World Urbanization Prospects: The 2011 Revision*. New York: UNPD, 2012. http://esa.un.org/unpd/wpp/ppt/CSIS/WUP_2011_CSIS_4.pdf.

United States Agency for International Development (USAID). "Famine Early Warning Systems Network." Last modified March 18, 2014. http://www.usaid.gov/results-and-data/data-resources/fews-net.

———. "Storage Sacks Keep Harvests Fresh Longer in Burkina Faso." Last modified November 06, 2013. http://www.usaid.gov/results-data/success-stories/burkina-faso-triple-lined-sacks.

———. "US Global Climate Change Initiative." Last modified March 7, 2014. http://www.usaid.gov/climate/us-global-climate-change-initiative.

United States Department of Agriculture (USDA). "Secretary Vilsack Announces Regional Hubs to Help Agriculture, Forestry Mitigate the Impacts of a Changing Climate." Press Release No. 0016.14. Washington, DC: USDA, February 5, 2014. http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=2014/02/0016.xml.

———. "USDA Regional Hubs for Risk Adaptation and Mitigation to Climate Change." Accessed April 27, 2014. http://www.usda.gov/oce/climate_change/hubs/USDAHubsFactsheet.pdf.

USDA Natural Resources Conservation Service. *Farming with Crop Residues*. Washington, DC: USDA, February 1992. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_029000.pdf.

———. "Highly Erodible Land Conservation Compliance Provisions." Accessed April 15, 2014. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/alphabetical/camr/?cid=nrcs143_008440.

United States Department of Defense. *Quadrennial Defense Review 2014*. Washington, DC: US Department of Defense, 2014. http://www.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf.

United States Geological Survey (USGS). "USGS Threatened and Endangered Stations." Last modified April 14, 2014. http://streamstatsags.cr.usgs.gov/ThreatenedGages/ThreatenedGages.html.

United States Geological Survey (USGS) and United States Agency for International Development (USAID). *Famine Early Warning Systems Network—Informing Climate Change Adaptation Series: Using Observed Warming to Identify Hazards to Mozambique Maize Production*. Fact Sheet 2011–3110. US Department of the Interior and USGS, September 2011. http://pubs.usgs.gov/fs/2011/3110/pdf/fs2011-3110.pdf.

United States Global Change Research Program (USGCRP). *Global Climate Change Impacts in the United States*. Edited by Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson. New York: Cambridge University Press, 2009.

Vermeulen, Sonja J., Bruce M. Campbell, and John S.I. Ingram. "Climate Change and Food Systems." *Annual Review of Environmental Resources* 37 (2012):195-222.

Vitousek, P. M., R. Naylor, T. Crews, M. B. David, L. E. Drinkwater, E. Holland, P. J. Johnes, et al. "Nutrient imbalances in agricultural development." *Science* 324, no. 5934 (June 2009): 1519-1520.

Wade, Henry, Dwight Seal, Charles Clark, Jimmy Perry, Bobby Walls, and Kent Messick. *Chemigation and Fertigation: Anti-Pollution Devices for Irrigation Systems.* Raleigh: North Carolina Department of Agriculture and Consumer Services, 2003. http://www.ncagr.gov/SPCAP/pesticides/chemigation2003.pdf.

Whitaker, Jeanette, Katherine E. Ludley, Rebecca Rowe, Gail Taylor, and David C. Howard. "Sources of Variability in Greenhouse Gas and Energy Balances for Biofuel Production: A Systematic Review." *GCB Bioenergy* 2, no. 3 (June 2010): 99-112. http://doi.wiley.com/10.1111/j.1757-1707.2010.01047.x.

The White House. "President Obama's Plan to Fight Climate Change." Last modified June 25, 2013. http://www.whitehouse.gov/share/climate-action-plan.

The World Bank. *Economics of Adaptation to Climate Change: Synthesis Report*. Washington, DC: The World Bank, 2010. https://openknowledge.worldbank.org/handle/10986/12750.

———. *World Development Report 2008: Agriculture for Development*. Washington, DC: The World Bank, 2008.

The World Bank, National Resources Institute, and Food and Agriculture Organization of the United Nations (FAO). *Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa*. Washington, DC: The World Bank, 2011.

World Meteorological Organization (WMO). *WMO statement on the status of the global climate in 2013*. Geneva: WMO, 2014. https://docs.google.com/file/d/0BwdvoC9AeWjUeEV1cnZ6QURVaEE/edit.

World Resources Institute. "Climate Analysis Indicators Tool (CAIT) 2.0." Accessed April 23, 2014. http://cait2.wri.org.

World Trade Organization. "Food Security." Accessed April 14, 2014. http://www.wto.org/english/tratop_e/agric_e/food_security_e.htm.

Worster, Daniel. *Dust Bowl: The Southern Plains in the 1930s*. Third Edition. New York: Oxford University Press, 2004.

Wrigley, C. "Global Warming and Wheat Quality." *Cereal Foods World* 51, no. 1 (2006): 34–36.

Yan, Xiaoyuan, Hiroko Akiyama, Kazuyaki Yagi, and Hjime Akimoto. "Global Estimations of the Inventory and Mitigation Potential of Methane Emissions from Rice Cultivation Conducted Using the 2006 Intergovernmental Panel on Climate Change Guidelines." *Global Biogeochemical Cycles* 23, no. 2 (June 2009).

Zimmerman, Andrew R. "Abiotic and Microbial Oxidation of Laboratory-Produced Black Carbon (biochar)." *Environmental Science & Technology* 44, no. 4 (February 2010): 1295–301. http://dx.doi.org/10.1021/es903140c.

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