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Congress on Adapting Food Production to a Changing Climate

About RNRF

Purposes

The Renewable Natural Resources Foundation (RNRF) is an I.R.C. §501(c)(3) nonprofit, public policy research organization, founded in 1972. It is a consortium of scientific, professional, educational, design and engineering organizations whose primary purpose is to advance science, the application of science, and public education in managing and conserving renewable natural resources. RNRF's member organizations recognize that sustaining the Earth's renewable resource base will require a collaborative approach to problem solving by their disciplines and other disciplines representing the biological, physical and social sciences. The foundation fosters interdisciplinary assessments of our renewable resources requirements and advances public policies informed by science.

Members

RNRF's members are membership-based nonprofit organizations with member-elected leaders. The foundation is governed by a board of directors comprised of a representative from each of its member organizations. Directors also may elect "public interest members" of the board. Individuals may become Associates.

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American Geophysical Union

American Meteorological Society

American Society of Civil Engineers

American Society of Landscape Architects

American Water Resources Association

Geological Society of America

Society of Environmental Toxicology and Chemistry

Society of Wood Science and Technology

Programs

RNRF conducts national conferences, congressional forums, public-policy briefings and round tables, international outreach activities, and a national awards program.

Renewable Resources Journal

The quarterly journal, first published in 1982, features articles on public policy related to renewable natural resources. It also includes news from member organizations, general announcements, meeting notices, and international conservation news. The journal is provided as a program service to the governing bodies of RNRF member organizations, members of the U.S. Congress and staff of its natural resources- and science-oriented committees.

Congress on Adapting Food Production to a Changing Climate

Presented by

Renewable Natural Resources Foundation

at

American Geophysical Union

Conference Facility

Washington, DC

December 9-10, 2014

Congress Program Committee

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Appreciation goes to the **American Geophysical Union** for hosting the congress at its modern conference facility at its headquarters in Washington, D.C.

Congress Program Committee Chair **Richard Engberg** and members of the committee provided essential leadership and guidance. Committee members and friends of RNRF who contributed to the meeting's planning and success are listed on page 3.

Julie McClure, science policy manager, and the science committees of ASA, CSSA and SSSA warrant a special thank you for bringing scientific and practical knowledge to development of the congress program.

RNRF Program Director **Melissa Goodwin** performed admirably in working with our committee, speakers, and delegates, and guiding the earnest efforts of our interns. She managed meeting logistics and contributed to this report as a writer and editor. She was capably assisted by policy intern, and now research associate, **Jennee Kuang.**

Finally, sincere appreciation goes to the speakers and delegates who made such an excellent meeting possible. Speakers and registered delegates are listed in the appendices.

Robert D. Day
Executive Director

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Editorial Policy: The editors seek general interest articles concerning public policy issues related to natural resources management. Recommended maximum length of manuscripts is 4,000 words. All manuscripts will be reviewed by the editors and, where appropriate, by experts in the subject matter. (A "Guide for Contributors" is posted at RNRF's website.) ***Editorial Staff:*** Robert D. Day, editor; Melissa M. Goodwin, associate editor; Jennee Kuang, assistant editor.

Executive Summary

Introduction

Current models predict that the world will have to produce 70% more food by 2050 to feed a global population of 9 billion people. Increasing urbanization and a trend toward richer, more meat intensive diets amplify the burden of a growing population. Climate change threatens the ability of our global agricultural system to meet this demand.

Directors of the Renewable Natural Resources Foundation recognized the importance of an interdisciplinary dialogue to address these challenges and called a national *Congress on Adapting Food Production to a Changing Climate*. The congress brought together a select group of professionals from RNRF member organizations and leaders from government, industry, academia and nonprofit organizations.[1] Delegates met on December 9-10, 2014, at the American Geophysical Union conference facility in Washington, D.C.[2]

The congress identified strategies to sustainably adapt food production to a changing climate and explored the multi-disciplinary and global scale of this challenge. RNRF congress delegates discussed the consequences of a changing climate on agricultural production and identified tactics and priorities to sustain global agricultural productivity. The congress featured discussions of domestic and international policies, management and technical solutions, economics, food security, and distribution. It concluded with a discussion of the future of international agricultural and food institutions.

Summary of Presentations

The Impacts of Climate Change

Charles Walthall, national program leader for the USDA Agricultural Research Service Climate Change, Soils and Air Emissions Research Program, opened the congress with a discussion of the effects of climate change on food production. Rising temperatures and variable precipitation patterns will generally increase plant stress and decrease crop yields. The consequences of these changes are already being observed. As climate effects intensify beyond 20-30 years, the resourcefulness of the average farmer will be insufficient to adapt to climate change impacts.

Economic Effects of Climate Change

Robert Mendelsohn, Edwin Weyerhaeuser Davis Professor of Forest Policy, Professor of Economics, and Professor in the School of Management at Yale University, presented an economic analysis of these impacts. While near-term *global* economic impacts will be modest, significant decreases in agricultural yield and associated revenues are likely beyond 2050. Regional economic impacts, however, are highly dependent upon socioeconomics and geographic location. Temperature increases will confer agricultural yield in high northern latitudes. Meanwhile, production in low latitudes is highly vulnerable to small increases in temperature. These regions, particularly Sub-Saharan Africa and South Asia, are among the world's poorest and have the least adaptive capacity.

Methods and Opportunities to Respond to the Challenge

Multi-sector mitigation and integrated adaptation initiatives are required to mitigate the effects of climate change on food production. Congress speakers and delegates discussed opportunities to adapt food production to climate change via farm production practices, biotechnology and landscape management.

Farm Production Practices

Kenneth Cassman, Robert B. Daugherty Professor of Agronomy at the University of Nebraska–Lincoln, discussed farm-level adaptation tools and opportunities to adapt food production to climate change. Ultimately, maintaining good soil quality and an adequate water supply will be crucial to sustain yields in increasingly harsh and uncertain climate conditions. A wide variety of field-level crop management and strategic adaptation options with varying time and investment requirements are available to farmers to meet these needs. In the years ahead, continued adaptation to climate change will be impossible without ensuring the long-term viability of sustainable irrigated agriculture.

Adequate field and climate assessment infrastructure remains a challenge. Publicly accessible databases, information technologies, improved simulation models, decision-support tools, and agronomic management options will

1 See Appendix B for a list of registered delegates.

2 See Appendix C for a copy of the congress program.

be part of the foundation for dealing with increased risk and uncertainty in the future. Further use and expansion of such tools will be dependent upon an increase in public funding and support.

Biotechnology

Martina Newell-McGloughlin, director of the University of California Systemwide Biotechnology Research and Education Program, discussed biotechnology as a tool within a systems approach to meet global food demand as population increases and climate changes. Genetic modification is a cost-effective way to confer resistance to climate change-induced stresses and enable crops to grow in marginal soil with less water.[3] Developments toward resilience to environmental stress, longer shelf lives, and higher nutritional value in crops can contribute substantially to feeding an increasing global population. This is particularly valuable in poorer, developing nations that will be hardest hit by climate change.

Landscape Management

Sara Scherr, president and CEO of EcoAgriculture Partners, discussed integrated landscape management techniques to sustainably produce food while conserving biodiversity and ecosystem services. Landscape-scale approaches enable stakeholders to integrate climate action into strategic land and water resources management programs.

Adaptation, mitigation and livelihoods are integral to responding to climate change within the land-use sector. Adaptation programs that emphasize restoration of degraded land and water resources have co-benefits for climate mitigation and economic and livelihood resilience. They are dependent, however, on multi-stakeholder support, governance and financing.

Public Policies and Priorities

Susan Capalbo, professor of applied economics at Oregon State University, discussed public policy options to influence and promote climate-smart agricultural practices. When designing policy to address climate change impacts on agriculture, incentives for adaptation are very important. There is no single policy that will work everywhere. Policies should address tradeoffs and opportunity costs while optimizing both landscape- and farm-level economics and production environments.

Inherent uncertainty in the timing and extent of climate change impacts can impede proactive policies. Thus, social and political will for action is necessary. Publicly funded research and development and education are essential to sustain a national effort to respond to climate change impacts.

Climate Change and the U.S. Federal Government: The U.S. Global Change Research Program

Julie Morris, associate director of Implementation and Strategic Planning at the U.S. Global Change Research Program (USGCRP), discussed U.S. federal agency cooperation and decision making for climate change policy and research in the context of that program. USGCRP is a policy relevant but policy neutral confederation of 13 federal agencies that works to help the U.S. and international community understand, predict, assess and respond to climate change. Fundamental to USGCRP's mission is cross-agency work and partnership building, as well as the translation and assessment of current science for popular use.

Global Markets and Food Security

Thomas Hertel, distinguished professor of agricultural economics at Purdue University, discussed the impacts of climate change on global markets and food security. Without adaptation, the variability of the U.S. national crop-yield ratio will double during the first half of this century. Protectionist trade and domestic policies exacerbate the economic impacts of this variability and must be abandoned in favor of free-flowing, international trade. Over the long-term, such international trade and market integration will enable long-range shifts in global production patterns and moderate the most severe impacts relative to food security.

Managing Risk to Agriculture

Åsa Giertz, agricultural specialist within the World Bank's Agricultural Risk Management Unit, discussed the formulation of an agricultural risk management framework to respond to increasing climate volatility. On a national scale, risks are complex and multi-layered and best addressed from a systems approach unique to a particular country. Investing in mitigation while streamlining and prioritizing adaptation measures can minimize the social and economic burden following adverse events.

International Agricultural Programs

Christopher Delgado, senior fellow at the World Resources Institute, provided insight on building support for international agricultural programs. While the role of non-governmental organizations cannot be overstated, substantial and sustained support must come from heads of state. The attention of world leaders is essential to sustain research and investment in agricultural programs even in the absence of a food price crisis. Financing for agricultural programs is well below historical levels, leaving adaptation and assistance programs profoundly under-resourced.

3 See Appendix A for a discussion of the safety of genetically modified crops.

Conclusion

Despite continuing advances in agricultural technology, the ability of our global food system to meet rising demand is threatened by climate change. Rising temperatures and increasing weather variability will ultimately degrade the quantity and quality of food we are able to produce.

By the midpoint of this century, potential impacts on global food production range from modest to severe. For a certainty, however, the end of this century will see significant decreases in agricultural yield unless a concerted global effort is made to reduce greenhouse gas emissions. Meanwhile, the poorest regions of the world with the least adaptive capacity are already experiencing extreme hardship from the effects of climate change.

Technical priorities, management techniques and policy tools highlighted at this meeting include irrigation, weather monitoring, biotechnology, landscape management and market integration. A sustained commitment by world leaders is required to leverage these instruments and move toward global food security and comprehensive climate action.

Appendices

A discussion of the safety of genetically modified crops is included in Appendix A.

Delegates to the congress are listed in Appendix B.

A copy of the congress program is included in Appendix C.

Introduction

Agricultural systems are extremely sensitive to climate change. Deviations from historical patterns of temperature and precipitation affect crop production cycles and yield, and enable the proliferation of disease, insects, pests and weeds. Extreme weather including excessive heat and drought poses an increasing risk to food security as the planet warms. The consequences of a changing climate will vary from region to region and will be alleviated or exacerbated by each region's respective social, economic and political environment. According to the Intergovernmental Panel on Climate Change (IPCC), every decade of climate change is expected to reduce mean crop yields by 1% globally. Meanwhile, a roughly 14% increase in productivity is required per decade to keep pace with rising demand.[4]

Recognizing an opportunity to contribute to the dialogue on increasing the resilience of agricultural systems to climate change, directors of the Renewable Natural Resources Foundation (RNRF) called a national *Congress on Adapting Food Production to a Changing Climate.*[5] The congress brought together a select group of professionals from RNRF member organizations and leaders from government, industry, academia and nonprofit organizations.[6] Over 70 delegates from the United States, Canada, India and the Netherlands met on December 9-10, 2014, at the American Geophysical Union conference facility in Washington, D.C.[7]

The primary goals of this meeting were to identify strategies to sustainably adapt food production to a changing climate and explore the multi-disciplinary and global scale of this challenge. RNRF congress delegates discussed the consequences of a changing climate on agricultural production and identified tactics and priorities for sustaining global agricultural productivity. The congress featured discussions of domestic and international policies, management and technical solutions, economics, food security, and distribution. It concluded with a discussion of the future of international agricultural and food institutions.

This congress report mainly discusses climate change effects and adaptation. Causes and mitigation options (e.g., greenhouse gas management and carbon sequestration) were not a primary focus of this meeting. Nevertheless, agriculture is a major contributor to global climate change. Associated practices, including deforestation, cattle feedlots and fertilizer use, account for approximately 25% of greenhouse gas emissions globally. Agriculture accounts for 14% of carbon dioxide (CO_2) emissions, 48% of methane (CH_4) emissions and 52% of nitrous oxide (N_2O) emissions. Any efforts to limit the extent of global climate change will require considerable mitigation of agricultural sector inputs.

Meanwhile, human population and food demands are increasing. It is more important than ever that we be able to produce food dependably and sustainably to achieve global food security. As one delegate noted, the interplay between the environment and food production cannot be ignored. Resilience through diversity in productive capacity and a strong natural resource base is essential. The National Academy of Sciences thus defines agricultural sustainability in terms of four goals:

1. Satisfy human needs (quantity and nutritional quality) for food, feed, and fiber, and contribute to biofuel;
2. Enhance environmental quality and the natural resources base;
3. Sustain economic viability of agriculture; and
4. Enhance the quality of life for farmers, farm workers and society as a whole.

Climate change and the resilience of the agricultural system are global issues. A sustained and coherent dialogue among consumers, farmers, policymakers and a cross-disciplinary community of scientists is required to limit the consequences of climate change and unsustainable agricultural practices. In support of such a dialogue, this report features a synthesis of information and commentary presented by speakers over the course of a two-day congress. Their presentations are supplemented by insights offered by delegates during each subsequent question-and-answer session.

4 Porter, J.R., et al. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate. 2014.

5 Video of speaker presentations, PowerPoint slides, and materials for further reading are available at www.rnrf.org/2014cong.

6 See Appendix B for a list of registered delegates.

7 See Appendix C for a copy of the congress program.

Summary of Presentations

The Impacts of Climate Change

Global climate conditions will change notably over the course of this century. However, the impacts of that change will be highly dependent on geographic location. **Charles Walthall**, National Program Leader for the USDA Agricultural Research Service Climate Change, Soils and Air Emissions Research Program, opened the congress with a discussion of the effects of climate change on food production. The variables of principal concern for agriculture are rising temperatures and increasing variability in temperature, precipitation, and the intensity of precipitation events. The relative effects of these changes will vary by commodity.

Water is the number one issue for agriculture in the 21st century.

Generally speaking, temperature increases will result in longer growing seasons, less frost and warmer nights.[8] High nighttime temperatures induce physiological changes (e.g., increased respiration and decreased photosynthesis and membrane stability) that reduce crop yield. Timing and spatial shifts of crops will be necessary to sustain and maximize production.

Walthall stressed that water is the number one issue for agriculture in the 21st century. Agriculture is reliant on snowmelt and slow, gentle rain to recharge groundwater and soil moisture. However, changing precipitation patterns will see a rise in both drought and flooding; regions will receive not enough water or too much within a short period of time. These changes will cause major harm to crop growth and the natural resources base.

Changes in precipitation and temperature can increase plant stress and cause reductions in yield in a variety of ways:

- Growing seasons may no longer coincide with when pollinators are active due to differentials between soil and air temperatures.
- Drought will cause erosion, soil and air quality issues. Flooding will cause erosion and water quality issues.
- Variability in weather will minimize the number of appropriate planting and harvesting dates. Farmers will be hard pressed to plant crops at the appropriate time and harvest before fungus or disease can set in.

Anticipated temperature and precipitation changes will come with some beneficial impacts. Among the expected benefits to crops are: reduced exposure to frost, longer growing seasons, and increased concentrations of beneficial compounds within plant tissue. Movement of pests is likely; some will be warmed out of existence in their current habitat range.

Increased atmospheric concentration of carbon dioxide will affect crops and the agroecosystem as a whole. Additional atmospheric CO_2 affects the carbon to nitrogen ratio in plant tissues, which has implications for the strength and ability of plants to stand upright. Carbon dioxide also has a fertilizing effect, promoting the growth of both crop and weed biomass. Meanwhile, herbicide resistance in weeds has been shown to increase with increasing ambient concentrations of CO_2 in greenhouse studies. Herbicide resistance and increased vigor in weeds increase the cost of farming and may lead to expanded use of agrochemicals.

As climate effects intensify beyond 20-30 years, the resourcefulness of the average farmer will be insufficient to adapt to climate change impacts.

Although biomass growth will accelerate with increasing concentrations of atmospheric CO_2 and, to a certain extent, temperature, the nutrient supply will be unable to keep pace. Studies show that such climate impacts reduce

8 The U.S. Forest Service has documented rising nighttime temperatures for decades. Nighttime temperature increases are variable and dependent on location. Nighttime temperatures in the Sequoia National Forest, for example, have risen by 4-5ºF this century. (http://www.fs.fed.us/r5/sequoia/gsnm/feis/FEISClimateTrends.pdf)

the nutritional value of plants.[9] There is concern among livestock farmers that nutrient-poor biomass will necessitate nutritional supplements for cattle.

Climate change will cause a proliferation of biotic stresses, affecting the abundance and distribution of insects, pests and disease. Populations of native and invasive insects will grow and develop increased insecticide resistance over generations. Depending on the species, geographic ranges may increase or decrease. Such habitat shifts gives rise to concerns about host-pathogen response changes and the proliferation of pathogens in plants, insects, and non-crop reservoirs. The frequency, intensity, and distribution of disease and pests are already changing. For example, bluetongue disease has moved from Africa to Southern Europe.

The vulnerability and adaptive capacity of agricultural systems are dynamic and multi-dimensional, and are influenced by complex interactions between social, economic and environmental factors.

Climate change vulnerability is not limited to crops. Animals have a limited temperature-humidity range at which they can comfortably function and live. Heat and humidity stress reduces growth, reproduction, and production of meat, dairy and eggs. Artificially cooling livestock to reduce this stress is possible, but the financial costs of climate control would make this effort infeasible at a large scale. Shifts in livestock production areas to higher latitudes are likely to occur as temperatures rise.

As climate effects intensify beyond 20-30 years, the resourcefulness of the average farmer will be insufficient to adapt to climate change impacts. The soil, water and air necessary for agricultural production are at risk. Sustainable management practices to maximize yield quantity and quality and minimize the cost of production must be encouraged.[10] Meanwhile, plant breeders and geneticists must study every stage of the growing season (i.e., reproductive and vegetative) to develop new varieties that are resilient to climate change.[11]

The vulnerability and adaptive capacity of agricultural systems are dynamic and multi-dimensional, and are influenced by complex interactions between social, economic and environmental factors. The IPCC has identified addressing vulnerability as a way to move forward. Specifically, resources should be directed toward understanding potential exposures (including extremes), understanding sensitivities (i.e., critical thresholds and interactions), and enhancing adaptive capacity (e.g., resilient systems like climate-ready crops and production systems).

The vulnerability of agricultural systems to climate change is ultimately dependent on the responses taken by humans to moderate its effects. We often rely too heavily on genetics to address vulnerabilities in the agricultural system; cross-disciplinary collaboration and approaches are required for any successful effort. Walthall endorsed a Genetics x Environment x Management (GxExM) approach to adapt to climate change. Under this framework, the three components and interactions thereof are optimized to maximize yield given environmental and socio-economic priorities. Crop varieties are developed and/or selected to thrive under specific environmental or management conditions. Similarly, environmental and management conditions are optimized to provide maximum benefit to a particular crop.

Beyond GxExM, post-production issues come into play. Food safety, transportation issues, and processing affect food quality and quantity and must be addressed. Worldwide, 35% of food waste happens during the consumption stage. This number increases to 61% within the United States.[12] It is critical that this number be reduced as the global population and food demand rises.

…the regions of the world that will experience the greatest and most detrimental effects of climate change are among the world's poorest and have the least adaptive capacity.

9 Walthall, C.L. et al. *Climate Change and Agriculture in the United States: Effects and Adaptation.* USDA Technical Bulletin 1935. 2012.

10 Farm production practices to adapt food production to climate change were presented by Dr. Kenneth Cassman and are discussed on page 13.

11 Biotechnology and genetic modification of crops were discussed by Dr. Martina Newell-McGloughlin and are discussed on page 15.

12 The UN Food and Agriculture Organization estimates that 32% of all food produced in the world was lost or wasted in 2009. For more information, see Installment 2 of *Creating a Sustainable Food Future* by the World Resources Institute, "Reducing Food Loss and Waste." June 2013.

Walthall proposed expanding the scope of GxExM to include post-production (GxExMxP).

Agriculture is already changing and will continue to evolve in response to climate change. The availability of adaptation options and access to adequate information to make informed decisions are key to sustaining the economic viability of regional agricultural systems. Production, consumption, prices and trade will affect farmers' decisions.

Climate change… represents an unprecedented challenge to the adaptive capacity of U.S. agriculture.

Economic Effects of Climate Change

Insurance records for the past 10-15 years indicate more frequent extreme events affecting agriculture, causing increasingly large economic impacts. The economic effects of climate change, from extreme events or otherwise, will depend on domestic and global adaptive capacity and will vary by region, sector and group. **Robert Mendelsohn**, Edwin Weyerhaeuser Davis Professor of Forest Policy, Professor of Economics, and Professor in the School of Management at Yale University, presented an economic analysis of these impacts.

Individual crops have particular climates and environmental conditions in which they are able to grow; deviation from these conditions will result in a precipitous drop in yield. Shifting agricultural production to (historically) cooler climates and the fertilizing effect of CO_2 will be insufficient to overcome the compounded consequences of climate change globally.

Mendelsohn indicated that, based on current climate projections, near-term global economic impacts will be modest, even absent strong mitigation policies. Beyond 2050 however, significant decreases in agricultural yield and associated revenues are likely. The IPCC estimates that increases in global food prices by 2050 will range from 3% to as much as 84%.[13, 14]

The direction and scale of economic impacts from climate change are highly dependent on geographic location and further complicated by socioeconomics and adaptive capacity. As global temperatures increase, high, northern latitudes will, in general, see an agricultural boom. Production in low latitudes is vulnerable to even small increases in temperature.

Sub-Saharan Africa and South Asia, the regions of the world that will experience the greatest and most detrimental effects of climate change, are among the world's poorest and have the least adaptive capacity.[15] According to the Asian Development Bank, increased flooding and drought from climate change will reduce annual GDP in East Asia by 5.3% by 2100. Mendelsohn's models predict that China will suffer significant decreases in productivity nationwide; southern regions are already seeing deleterious effects and are most vulnerable to even incremental change. In the past decade, climate change has led to a net economic loss of $200 million to China's corn and soybean sectors. Corn and soybean yields are projected to decline by 4-14% and 8-21%, respectively, by 2100.[16]

The outlook is better within the United States in the short term, although projected impacts vary widely across regions. According to a 2012 study by the USDA Economic Research Service, aggregate impacts of climate change on net returns to crop farmers in 2030 range from an estimated increase of $3.6 billion to a loss of $1.5 billion per year, under four climate change scenarios. The spread and redistribution of agricultural pests may reduce these returns by $1.5 billion to $3.0 billion.[17]

Ensuring the long-term viability of irrigated agriculture is necessary to enable continued adaptation to climate change.

Global climate change will make agricultural management increasingly complex and uncertain. This represents an unprecedented challenge to the adaptive capacity of U.S. agriculture. Not to the exclusion of a sustained global effort to mitigate climate change, Mendelsohn was optimistic about the ability of farmers in the United States to adapt to climate change this century. Individual

13 These numbers account for changes in temperature and precipitation, but do not take into account mitigating effects of CO_2 fertilization. (Porter, J.R., et al. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014.)

14 Dr. Thomas Hertel of Purdue University discussed the effects of climate change on global markets and food security–see page 19.

15 Approximately 2/3 of the world's crops are grown in Asia.

16 Chen, Shuai, et al. *Impacts of Climate Change on Agriculture: Evidence from China.* Environment for Development. March 2014.

17 Malcolm, Scott et al. *Agricultural Adaption to a Changing Climate: Economic and Environmental Implications Vary by U.S. Region,* ERR-136. USDA Economic Research Service. July 2012.

farmers have economic incentive to leverage flexibility within the agricultural system to adjust equipment, crop selection and harvest strategies towards maximizing production for the climate in which they operate.

Methods and Opportunities to Respond to the Challenge

According to 2012 U.N. projections, global population is expected to reach between 8.3 and 10.9 billion by 2050. Since the Green Revolution, food production has kept pace with population growth. However, FAO estimates that the world will have to produce 70% more food by 2050 to feed a projected 2.3 billion additional people.[18] Increasing urbanization and a trend toward richer, more meat intensive diets amplify the burden of a growing population. The ability of our global agricultural system to meet demand is threatened by climate change. Multi-sector mitigation and integrated adaptation initiatives are required to lessen its effects on food production. The remainder of the first day of the congress was dedicated to exploring opportunities to adapt food production to climate change via farm production practices, biotechnology, and landscape management.

Farm Production Practices

Kenneth Cassman, Robert B. Daugherty Professor of Agronomy at the University of Nebraska–Lincoln, discussed farm-level adaptation tools and opportunities to adapt food production to climate change. He identified three principal components of local adaptation needed to sustain yield under increasingly harsh and uncertain climate conditions:

- *Improving and maintaining soil quality.* Soil attributes such as nitrogen supply and water-holding capacity confer yield without additional inputs (e.g. rainfall, energy, fertilizer, etc.). Soil degradation results in a reduction of these inherent soil properties. To restore yield in degraded soil, a farmer must supply inputs. This level of management makes the system more susceptible to error and risk.

A global public system of data collection and access must be established to support sustainable intensification of crop and livestock production.

- *Tactical field-level crop management options.* Tactical field-level crop management options have varying barriers to adoption and, accordingly, require different time frames for implementation. Options with low barriers can be implemented quickly. Adjusting plant density, planting date and crop maturity are readily available techniques that farmers can and do use to respond to interannual variability. For example, Nebraska farmers have planted maize and soybean crops earlier in the spring for decades in response to the availability of improved planting equipment, seed treatments protecting from disease and insects, and warming spring temperatures. Adjusting the seeding rate to lower plant density increases yield in regions with high water deficits (i.e., rainfall vs. evapotranspiration) during the growing season. This compensates for lower seasonal rainfall rates by leaving enough water in the soil profile to support the grain filling stage of plant growth. Options with larger barriers require longer time frames for implementation. Examples include changing tillage practices and constructing soil and water conservation structures. In Nebraska, no-till farming saves 25-75 ml of water per hectare. The resulting gain of 20 kg of maize grain per ml of water yields an additional 0.5-1.5 tons of maize per hectare.
- *Strategic options.* Adaptation options requiring substantial new expertise, equipment, and investment in research and development include switching crops entirely, developing new crops, adopting alternative cropping systems, and investing in irrigation equipment and infrastructure.

A key component of climate change adaptation is sustaining the water supply available to plants. A fundamental relationship in rainfed agricultural systems is a strong negative correlation between yield and risk. In favorable rainfed systems featuring adequate and reliable rainfall and good quality soils, yields are high and risk is low. The eastern edge of the U.S. Corn Belt, for example, is the largest and most productive agroecosystem zone in the world. By contrast, yields are low and risk is high in harsh rainfed systems featuring less rainfall and/or shallow soils with low water holding capacity.[19] As climate change makes areas home to rainfed crops "harsher" with less reliably available or inadequate rainfall to meet plant demand,[20] agroecosystem zones will become increasingly low yield and high risk.

18 *Global Agriculture Towards 2050: How to Feed the World in 2050.* Food and Agriculture Organization of the United Nations. 2009.

19 The magnitude of the water deficit in the western Corn Belt is 8-fold greater than that in the eastern Corn Belt.

20 Rainfall, temperature, soil depth and texture determine the water supply available for crops, as well as the length of the growing season.

In such regions, irrigation can restore high stable yields. Irrigated fields account for approximately 18% of crop area globally and 40% of total food production. In high-producing areas, irrigated agriculture is threatened by over-drafting and/or salinization of aquifers. The largest over-drafted aquifers supporting irrigated agriculture are the North China Plain, Indo-Gangetic Plain, and the Ogallala Aquifer beneath the U.S. Great Plains.

The success of a green revolution in Sub-Saharan Africa will be dependent on irrigated agriculture. Approximately 5% of arable land in this region is currently irrigated. For comparison, 33% of arable land is irrigated in Asia. There is enough groundwater in Sub-Saharan Africa to expand irrigated agriculture substantially using rechargeable, sustainable aquifers. Given a sustainable water source, investment in irrigation will have the greatest payoff in regions with highly uncertain crop yields due to high annual variability in rainfall.

Indeed, ensuring the long-term viability of irrigated agriculture is necessary to enable continued adaptation to climate change. Doing so must be sustainable and requires:

- Maintaining the integrity of existing reservoirs and conveyance structures. Water withdrawal must not exceed the annually renewable supply of water, whether from surface or groundwater.
- Having informed, effective, and efficient policies, regulations and institutions to avoid over-drafting and negative environmental impacts.
- Encouraging active and proactive public and private sector investment in research, development and human resources to improve efficiency and advance irrigation technologies for large- and small-scale farms and farming systems.

The ability to forecast the variability and duration of weather events is vital for risk management decision-making. As such, Cassman stressed weather data as an essential public good. Access to good quality daily time step weather data and historical records enables farmers to assess the probability of yield and make management decisions accordingly. A global public system of data collection and access must be established to support sustainable intensification of crop and livestock production. Current trends, however, show rising private investment in weather data collection systems. This may have implications for access to data and a withdrawal of public sector support.

Publicly accessible databases, information technologies, improved simulation models, decision-support tools, agronomic management options, and genetic improvement of crops and livestock will be the foundation for dealing with increased risk and uncertainty in future years.

Existing weather data collection systems are not ideal. NOAA weather stations are typically located in cities and airports and only record daily temperature and precipitation. The temperatures recorded at these stations are 1.5-2 degrees Fahrenheit warmer, on average, than those on farmland 10 km away and are thus unusable for accurate assessment of climate conditions by farmers.

State mesonet[21] systems, however, were developed for agriculture and are located within agricultural areas. These stations monitor daily radiation, temperature, precipitation, humidity and wind speed. Only 26% of weather stations that record daily data are mesonet, and spatial density and coverage varies by state. Many of these stations are no longer active or do not have more than 15 years of daily records. Of the mesonet stations, only 42% have more than 15 years of data and are thus useful to forecast yield based on historical conditions. Oklahoma is the only state with extensive coverage. In most states, coverage is poor. The cost of acquiring required data with adequate spatial coverage is modest and steadily decreasing due to technological advances.

In a world threatened by climate change, there is a critical need in both developed and developing countries for good quality, publicly available weather data relevant for crop production (i.e., daily time step, real-time and long-term [20+ years minimum]). Open weather data has value beyond the individual farmer; it enables the development of metrics to quantify environmental performance, prioritize research and development, and inform policies to help countries develop appropriate food security and land-use strategies.

Nearly all future climates with potential to produce food exist somewhere in the world today. Learning how farmers currently deal with today's harsh and variable climates provides important insight on how to mitigate risk and continue to raise yields despite climate change. To feed the world without destroying natural resources, science and technology must drive the development of modern agriculture. Publicly accessible databases, information technologies, improved simulation models, decision-support tools, agronomic management

21 A mesonet is a network of automated weather stations designed to observe mesoscale meteorological conditions.

options, and genetic improvement of crops and livestock will be the foundation for dealing with increased risk and uncertainty in future years.

Biotechnology

Humans have been genetically modifying crop plants since the dawn of agriculture 10,000 years ago. Artificial selection and subsequent genetic modifications enabled settled agriculture and led to the first anthropogenic effects on climate. Genetic modification and associated agricultural technology are pervasive throughout modern-day agriculture. It is the subject of a vast international research enterprise.

Martina Newell-McGloughlin, Director of the University of California Systemwide Biotechnology Research and Education Program, discussed biotechnology as a tool within a systems approach to meet global food demand as population increases and climate changes. She provided an overview of the extensive scope of ongoing research in crop engineering. Much work in biotechnology research goes toward developing plants with increased resistance to biotic stress (e.g., pests, disease, weeds) and abiotic stress (e.g., drought, heat, salinity, submergence, marginal soils) while maximizing yield and nutrient efficiency. Development in biotechnology can contribute to food waste reduction by improving post-harvest characteristics of crops including shelf life, processing requirements and taste.

If current trends (i.e., rising population, richer diets and increasing livestock feed needs) continue, we will be required to increase crop production by at least 70% above current levels to feed a world population of 9 billion by 2050. However, the physiological optimum using traditional breeding has already been maximized for many crops. Biotechnology is thus an essential tool to sustainably grow affordable, high yielding, high quality food and feed. This is particularly true in our current environment characterized by a changing climate and diminishing resources—including degraded and less abundant water—and the need to use less fossil fuels, fertilizer and pesticides. Genetically modified crop varieties[22] are the most cost-effective way to sustain farming in marginal areas and to restore degraded lands to production.[23]

Climate change poses a real challenge in terms of available agricultural land and fresh water use. Solutions must be developed to adapt crops to new and harsher conditions. Out of the world's total land area of 14.9 billion hectares, 30% (4.4 billion hectares) is arable land. The total land area currently cultivated is 1.6 billion acres, 20% of which is on marginally suitable lands.[24]

Agriculture accounts for 70% of water consumed by humans. This share will rise with temperature and increased reliance on irrigated crop systems. Although greatly beneficial to crop growth in regions with highly variable or low precipitation rates, irrigation increases the salinity of soil. Salinization from irrigation causes 24.7 million acres of farmland to be lost worldwide annually. Crops are limited by salinity on 40% of the world's irrigated land. In the United States, 25% of land is no longer arable due to salinization. Development of crops resilient to saline environments can mitigate such losses. Meanwhile, increasing resistance to water stress is important to sustain crop yields and grower incomes and to reduce the need for irrigation.

Abiotic stresses are a primary cause of crop yield losses worldwide. Genes connected to heat and drought stress have been identified and characterized, but most efforts to manipulate those genes currently fail under field conditions. The inherent complexity of a system with multiple stresses occurring simultaneously is a challenge in genetically modified crop development. Newell-McGloughlin indicated that abiotic stress-tolerance research focusing on the reproductive stage of crops has promise in field study.

Given the contributions of agricultural practices to climate change and the impacts of climate change on agricultural productivity, the agricultural sector must play a substantial role in the fight against climate change. Green biotechnology offers tools to help farmers in this effort by enabling greenhouse gas emission reductions and protecting and increasing yields in marginal soils under less desirable conditions.

Sustainable Intensification

"The goal of sustainable intensification is to increase food production from existing farmland while minimizing pressure on the environment. It is a response to the challenges of increasing demand for food from a growing global population, in a world where land, water, energy and other inputs are in short supply, overexploited and used unsustainably. Any efforts to 'intensify' food production must be matched by a concerted focus on making it 'sustainable.' Failing to do so will undermine our capacity to continue producing food in the future."

The Oxford Martin Progamme on the Future of Food

22 The three most widely grown genetically modified crops are herbicide-tolerant (HT) soybean, Bacillus thuringiensis (BT) corn and BT cotton. Of the 27 countries that grow them, 19 are emerging economies; 90% of the 18 million farmers growing them are resource poor.

23 See Appendix A for more information on the safety of genetically modified crops.

24 *The State of the World's Land and Water Resources for Food and Agriculture: Managing Systems at Risk.* Food and Agriculture Organization of the United Nations. 2011.

Biotechnology and farm-scale management techniques alone are insufficient to fully sustain agricultural production in the face of climate change. **Sara Scherr**, president and CEO of EcoAgriculture Partners, discussed integrated landscape management techniques to sustainably produce food while conserving biodiversity and ecosystem services. She explained that climate change has accelerated a rethinking of the role of agriculture beyond food production, particularly concerning its effect on climate, biodiversity, and ecosystems. The reasons for this are threefold:

1. Agriculture is the sector that will be the most impacted by climate change in many parts of the world, particularly in low-latitude regions like Sub-Saharan Africa where impacts are already apparent. To increase the resilience of the agricultural system, management at both farm and landscape scales is required.
2. Agriculture is a significant source of greenhouse gas emissions. The world will be unable to meet targets for emissions reduction without large reductions from agriculture and agricultural landscapes.
3. The land-use sector currently provides the only economically viable large-scale potential for greenhouse gas sequestration. There is significant carbon storage capacity in agricultural, forest, rangeland, wetland, and peat systems.

Responding to climate change impacts is not a farm-by-farm process; this decade has seen growing recognition that landscape-scale approaches are required to fully address these issues. For example, the U.N. Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) utilizes a landscape approach to coordinate management of regional land uses, including agriculture, to meet its goals.

Key Features of Integrated Landscape Management

1. Long-term collaboration among different groups
2. Management objectives to achieve multiple benefits
3. Maximize synergies and mitigate tradeoffs
4. Participatory, adaptive management
5. Supportive market and policy frameworks

In Ethiopia, a systematic multipronged investment program in landscapes has restored some of the most degraded areas of the country, tripling and quadrupling agricultural yields, as well as restoring water capacity for irrigation and increasing biodiversity.

The traditional approach of segregating land based on usage is highly inefficient and too demanding on the natural resource base to be viable. Landscape-scale action presents the opportunity for economies of scale and leveraging synergies. This new paradigm for the management of a shared land and water resources base enables strategic negotiation of land management tools and the provision of a multi-stakeholder platform for involvement. Making land management decisions that are ecologically appropriate and that make sense to local people enables the integration of climate action into mainstream development programs.

When responding to climate change within the land-use sector, adaptation, mitigation and livelihoods cannot be separated.

The integration of climate adaptation and mitigation objectives within integrated landscape management requires the following elements:

- *Climate-smart field and farm practices.* Field and farm scale practices that enable mitigation and adaptation include restoration of degraded lands, farming perennial crops, enriching soil carbon, promoting sustainable livestock systems and efficient water management, and protecting natural habitat. Priorities include reducing emissions and sequestering carbon. These practices have benefits for livelihoods, production and costs, but require several (2-7) years of investment before profit is generated. The economic threshold for providing financing to switch to climate-smart agriculture must be overcome.
- *Diversified land use across the landscape in response to increased risk from climate change.* Priorities include reducing risk, providing strategic food and feed reserves, and sustaining habitat as carbon stocks.
- *Management of interactions across the landscape to enhance mitigation and adaptation.* Co-investment and co-management of different landscape elements provide cross-boundary ecological, economic and social support. Sustainable landscape interactions enhance field-level benefits of climate-smart practices, increase the effectiveness of mitigation efforts, and secure ecosystem functions.
- *Strengthened landscape resilience.* Resilient landscapes are dependent on livelihood resilience, agroecosystem resilience, institutional resilience and ecosystem resilience.

Key processes for implementing climate-smart landscape management include multi-stakeholder planning, supportive landscape governance and resource tenure, financing for integrated landscape investments, and tracking multiple dimensions of change.

When responding to climate change within the land-use sector, adaptation, mitigation and livelihoods cannot be separated. A high proportion of adaptation programs have cobenefits for mitigation, particularly those that emphasize restoration of degraded land and water resources. Multi-sector, cross-stakeholder support is critical to avoid conflict and provide opportunities for structured planning of sustainable, multifunctional landscapes.

Public Policies and Priorities

Susan Capalbo, professor of applied economics at Oregon State University, addressed public policies available to influence and promote climate-smart agricultural practices. As defined by FAO at the 2010 Hague Conference on Agriculture, Food Security and Climate Change, climate-smart agriculture comprises three main pillars:

1. Sustainably increasing agricultural productivity and incomes,
2. Adapting and building resilience to climate change, and
3. Reducing and/or removing greenhouse gas emissions, where possible.

This framework promotes coordinated action toward climate-resilient pathways by reducing vulnerabilities, increasing adaptive capacity, and promoting technically feasible and economically viable action.

Opportunities to promote food security within a climate-smart agricultural framework include:

- Reducing global food needs by eliminating waste in the food chain, increasing equity and access to food, and shifting to vegetable-rich diets that demand fewer resources.
- Improving maximum food production by investing in agricultural research and development to improve yields or by adapting crops to future climates through improved genetics and matching crops to environments.
- Mitigating climate change by intensifying production on existing agricultural land (i.e., sustainable intensification), decreasing onsite agricultural greenhouse gas emissions, and reducing deforestation.

The United States has not been idle. In February 2014, Agriculture Secretary Tom Vilsack announced the creation of seven Regional Hubs for Risk Adaptation and Mitigation to Climate Change. These "climate hubs" deliver region-specific information to farmers, ranchers and forest landowners to help them adapt to climate change and weather variability. They are part of a broad commitment on the part of the federal government to ensure that farmers have the technology and tools they need to "adapt and succeed in the face of a changing climate."[25]

> *Easy access to good data and information is the best way to enable individual producers to make smart decisions on-the-ground.*

As part of this commitment to promoting climate-smart agricultural practices, the United States has joined a new Global Alliance for Climate-Smart Agriculture.[26, 27] The Global Alliance aims to achieve sustainable increases in agricultural productivity and incomes, greater resilience of food systems and farming livelihoods, and the reduction of greenhouse gas emissions. It will work with stakeholders to improve food security, food systems and social practices in support of climate change adaptation and sustainable use of natural resources. To facilitate this mission, regional efforts are underway. The Africa Climate-Smart Agricultural Alliance has been launched to work with existing development and non-governmental organizations toward these goals. A North American Climate Smart Agriculture Alliance was launched in September 2014.

Meanwhile, the Farm Bill is the primary domestic agricultural policy tool of the federal government. Most recently signed into law on February 7, 2014, the Farm Bill contains provisions that reshape farm policy (e.g. commodity support and crop insurance coverage), consolidate conservation programs, reauthorize and revise nutrition assistance, and fund USDA programs.[28] Titles within this legislation with the greatest

25 "*Secretary Vilsack Announces Regional Hubs to Help Agriculture, Forestry Mitigate the Impacts of a Changing Climate.*" Press Release No. 0016.14. U.S. Department of Agriculture. February 5, 2014.

26 The Global Alliance for Climate-Smart Agriculture was launched on September 24, 2014 and is a coalition of 14 countries and 32 organizations. Alliance members include governments, farmers, scientists, businesses, civil society, and regional and international organizations representing 25% of the world's cereal production and 16% of agricultural greenhouse gas emissions. For more information see http://www.fao.org/climate-smart-agriculture/85725/en/.

27 The U.S. also supports several related initiatives including the Global Research Alliance on Agricultural Greenhouse Gasses, Feed the Future, the Climate and Clean Air Coalition on Short-Lived Pollutants, and the U.S. Global Climate Change Initiative.

28 Chite, Ralph M. *The 2014 Farm Bill (P.L. 113-79): Summary and Side-by-Side.* Congressional Research Service. February 12, 2014.

potential to significantly affect climate-smart agriculture are Commodities, Conservation, and Crop Insurance:[29]

- Direct Payment programs for commodities have been replaced with two new safety net programs: price only protection (*PLC*, individual commodities) and revenue protection (*ARC*, farm-wide). These programs provide a safety net for producers, thereby increasing their resilience, but do not encourage adaptation.
- Conservation compliance within the Farm Bill links conservation requirements to crop insurance premium subsidies and commodity support programs. Farms with highly erodible land or wetlands are required to follow a conservation program to be eligible to receive government payments.
- Crop Insurance is a risk management tool which helps stabilize farm income across boom-bust cycles typical in agriculture, thus stabilizing food production over time. Whole-Farm Revenue Protection encourages diversity by providing coverage for all commodities on a farm under one insurance policy. Despite these benefits, the crop insurance program has encouraged growth in hazard-prone areas and can discourage agricultural innovation. Increases in extreme weather events from climate change will increase insurer liabilities in the coming decades.

When designing policies to address climate change effects on agriculture, incentives for adaptation are very important; critical components include prices (i.e., taxes, subsidies), markets, quantity and quotas, and best practices. There is no one policy that will work everywhere; a menu of options must be assessed in the context of regional environmental and production systems. Policies must address tradeoffs and opportunity costs and optimize both landscape- and farm-level economics and production environments. A delegate noted that successful land management and farm production policies must also emphasize the importance of ecosystem services to promote resilience.

To sustain this effort, we must invest in technology and human capacity to adapt to climate impacts. Easy access to good data and information is the best way to enable individual producers to make smart decisions on-the-ground.

Inherent uncertainty in the timing and extent of climate change impacts can act as an impediment to proactive climate adaptation and mitigation policies. Political will for change and the human capacity to drive and implement adaptation is critical. Farmers, communities, governments, and other stakeholders must embrace climate adaptation and mitigation goals and strategies. Publicly funded research and development and education are essential to sustain a national effort to respond to climate change impacts.

Climate Change and the U.S. Federal Government: The U.S. Global Change Research Program

The next speaker gave an overview of U.S. federal agency coordination to address climate change issues under the guidance of the U.S. Global Change Research Program (USGCRP).

USGCRP is a confederation of 13 federal agencies. It was mandated by Congress in the Global Change Research Act of 1990 (GCRA) to help the United States and international community understand, predict, assess and respond to climate change. USGCRP is implemented through interagency working groups focusing on science (e.g., process research, observation, carbon cycle, etc.), as well as human health, social sciences, and adaptation. **Julie Morris**, Associate Director of Implementation and Strategic Planning at USGCRP, discussed U.S. federal agency cooperation and decision making for climate change policy and research in the context of that program.

USGCRP's strategic plan for 2012-2021 directs the program to focus resources on advancing science, conducting sustained assessments, informing decisions, and communication and education in support of the GCRA mandate. Within the USGCRP research enterprise, current science is used to support the translation and assessment of knowledge for societal use.[30] Strategic planning goals cut across different programs, integrating efforts by different working groups.

Cross-agency work is fundamental to USGCRP implementation. To foster coordination across the agencies and help link activities at the administrative, agency, and working group levels, annual priorities are established that require a collective effort. For example, the following are current USGCRP interagency priorities:

- *Extremes, thresholds and tipping points:* building observational capability, understanding the interplay of cascading effects, and understanding how potential thresholds in the climate system might lead to tipping points in the social system.
  - Drought, Arctic
- *Coupled earth and human systems:* developing the capacity to make predictions from an intra-seasonal to centennial scale
  - Actionable science for informed policy making and management
- *Reaching decision makers*
  - National Climate Assessment, Global Change Information System

29 Of the total funding within the 2014 Farm Bill, Commodities account for 5%, Conservation for 6%, and Crop Insurance for 9%. Nutrition received 79% of the total allocation. The remaining 1% of funding was directed toward all other titles including Research.

30 Dr. Morris stressed that this work is policy-relevant, but policy neutral.

The Third National Climate Assessment (NCA) was released in May 2014. The report had broad and deep science foundations; its development engaged stakeholders and decision makers throughout the country. Over 500 contributions were received from outside of the federal government, and 25 federal agency-, academic- and NGO-developed technical input reports for regions or sectors were integrated within. High-level findings within the NCA are linked to detailed science background and source-material through the Global Change Information System.

Since its release, the NCA has been widely cited and distributed and was used in the development of products including teaching and adaptation resources, FEMA Regional Climate Change Readiness and Resilience Exercises, and the Risky Business Climate Risk Assessment. Looking ahead, future assessments will address climate change and human health, food security,[31] and the Arctic.

USGCRP recognizes that an assessment cannot be used to make decisions unilaterally. There is, therefore, a wide and sustained effort to build partnerships and develop products customized to meet specific needs. NCAnet, for example, is an online network of partner organizations built to facilitate this work.

Global Markets and Food Security

Key and competing drivers of global climate change and food security are population, per capita income, biofuels, and farm productivity.[32] According to the IPCC, climate change has the potential to affect all aspects of food security, including food access, utilization and price stability. **Thomas Hertel**, Distinguished Professor of Agricultural Economics at Purdue University, discussed the impacts of climate change on global markets and food security.

The first half of his remarks featured models assessing interannual variability in climate and extreme weather events. These year-to-year climate impacts are reflected in the changing frequency of extreme events and have implications for commodity markets and potential for adaptation.

Protectionist trade and domestic policies like the Renewable Fuel Standard mandate will become increasingly problematic in the future.

Throughout the mid-latitudes, whatever constituted an extreme event relative to maximum temperature historically (1986-2005) will become ordinary in the latter half of this century.[33] The increased frequency of extreme events and combination of hot and dry weather is problematic for crop growth. In the U.S. Corn Belt, for example, a limited temperature increase will be beneficial for corn yields. However, increasing temperature extremes and, to a lesser extent, changes in precipitation will drive increased yield volatility. There is a significant drop in crop yield with an accumulation of growing degree days above 29 degrees Celsius (84.2 degrees Fahrenheit).

Under future climate conditions (2020-2040) absent adaptation, the variability of the national yield ratio will be twice as high as that under historic climate conditions (1980-2000). In other words, farmers would be more likely to have a very bad year following a good one relative to crop production.

This interannual variability has implications for commodity markets. Hertel discussed corn markets, particularly ethanol and associated renewable fuel policies, as a case study. In the U.S. Corn Belt, 40% of corn harvested is used to produce ethanol. Corn and crude oil prices began to correlate significantly in 2007-2008 when oil prices increased dramatically. When oil prices fell in 2008, corn prices remained elevated because of the Renewable Fuel Standard Mandate. This mandate introduced an important source of institutional rigidity and a potential increase in maladaptation from a climate change point of view. The coincidence of increasing volatility with increased rigidity is potentially disastrous economically should the corn market need to respond to a shortfall.

Hertel demonstrated the impact of corn supply shocks on U.S. corn price volatility without adaptation. Based on recent economic conditions, a doubling in yield volatility under future climate conditions (2020-2040) will quadruple price volatility. Future (2020) economic conditions (i.e., growth and integration) will diminish price volatility unless the biofuel mandate remains in place, in which case price volatility is exacerbated.

Two types of economic adaptation are intersectoral integration and

31 USDA will release a report, *Global Climate Change, Food Security and the U.S. Food System,* in Fall 2015 as a technical input to the National Climate Assessment. The report will explore connections between climate and food security and implications thereof, and present implications for U.S. producers and consumers.

32 A delegated noted that the most powerful and cost effective goals relative to climate change adaptation are increasing farm productivity and reducing population growth. These should be explicit goals going forward.

33 Diffenbaugh, Noah S. and Christopher B. Field. *Changes in Ecologically Critical Terrestrial Climate Conditions.* Science. Vol. 341 no. 6145, pp. 486-492. August 2013.

international integration. Intersectoral integration can be market driven (e.g., higher energy prices) and beneficial or it can be policy driven (e.g., the Renewable Fuel Standard mandate) and maladaptive, exacerbating volatility risks. Protectionist trade and domestic policies like the Renewable Fuel Standard mandate will become increasingly problematic in the future. International integration can be partial, fixing tariffs at currently applied rates, or take the form of full trade liberalization, eliminating tariffs. Free-flowing, international trade is an increasingly important vehicle for climate change adaptation and the moderation of economic impacts.

The IPCC Working Group II report on Impacts, Adaptation and Vulnerability concludes that climate change will render future productivity growth more challenging: negative impacts on average yields become likely as early as the 2030s and become increasingly pronounced through the end of this century.[34] The second half of Hertel's talk focused on the decadal changes and long-run impacts of climate change and examined projected agricultural impacts and elements of food security.

Food security impacts of climate change were projected in the context of two views of future (2050) world food economy: one framework retaining a historical degree of segmentation (i.e., tariffs) and the other featuring integrated markets (i.e., food traded with low-trade barriers). Baseline impacts are driven by population, income and productivity growth. Projected global yield impacts in 2050 due to climate change vary widely by region, crop model and the inclusion (or lack thereof) of CO_2 fertilization effects.

In the worst-case scenario, global malnutrition (a function of food security) will increase by as much as 50% relative to baseline by 2050. Best-case scenario models show a slight improvement globally in 2050 relative to the baseline. The worst projected regional impacts are in South Asia (120% rise in malnutrition) and Sub-Saharan Africa (80%), while impacts in the rest of the world are relatively modest.[35]

The magnitude of projected climate impacts and subsequent effects on malnutrition are variable and highly dependent on complicated environmental, political and socioeconomic interactions. International trade and market integration moderate the most severe impacts relative to food security by allowing for long-range shifts in global production patterns. For example, integrating markets and reducing trade barriers decreases the rise of malnutrition in South Asia from 120% to 40% in these models. Hertel emphasized that the global community must prepare for the worst-case scenario but recognize that the outcome may not be that bad.

International trade and market integration moderate the most severe impacts relative to food security by allowing for long-range shifts in global production patterns.

Crop impact models do not reflect the full extent of uncertainty relative to climate change's effects on food security and global markets. Most biophysical crop models were developed for other purposes and do not focus on the impacts of extreme temperature. Only a small proportion of crop models consider the effects of elevated CO_2 on canopy temperature or direct heat effects on key stages of crop development. Omitted processes such as these are particularly damaging with climate change and empirically more important in low-income tropical regions. Thus, the full magnitude of adverse impacts in South Asia and Sub-Saharan Africa may be understated because of limitations in the crop models. Most overstate the capacity for adaptation in the poorest countries, failing to account for credit constraints and other market failures, weak institutions and corruption, and limited capacity for adaptive research and extension work.

Managing Risk to Agriculture

It is therefore important that nations assess their relative risks and develop frameworks within which to mitigate and adapt to climate change. **Åsa Giertz**, Agricultural Specialist within the Agricultural Risk Management Team of the World Bank's Agriculture Global Practice, shared insight into how to formulate an agricultural risk management framework to respond to increasing volatility. This framework enables countries to mitigate systemic risks within the agricultural sector through sector-wide risk management.[36]

Risks, on a national scale, are complex and multi-layered and most effectively addressed from a systems approach unique to the circumstances of a particular country. Work at this scale allows countries to better target resources and to minimize losses from risks.

34 IPCC. *Climate Change 2014: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014.

35 This data is derived from a HADGEM/LPJmL combination model of segmented markets to be published in a forthcoming report by Baldos and Hertel.

36 The World Bank additionally works with commodity-specific risks through supply chain risk management. This approach was not directly addressed in this presentation.

The process flow by which the World Bank supports countries in developing a risk management framework begins with a request from a client nation. Work begins with a risk assessment wherein, via a desk review, in-country assessment and consultation workshop, existing risks are mapped, quantified and prioritized, and root causes and vulnerable groups are identified. Following final analysis, stakeholders are asked to rank multiple solutions based on relative sustainability, implementation potential, degree of profitability, etc., to ensure that recommended solutions are applicable to the local context. Depending on interest from the client countries, identified solution areas are assessed and/or a risk management plan is generated and incorporated into existing government programs and development plans. The World Bank provides technical support to facilitate this effort and finances the development and implementation of risk management mechanisms. Following implementation, risks continue to be monitored and evaluated.

The main concern of governments seeking assistance from the World Bank is often food security. These countries often have limited fiscal resources to manage risk. Significant resources are frequently diverted to coping mechanisms for vulnerable populations ex-post adverse events. Inadequate risk management also negatively affects household incomes, poverty, malnutrition, sustainability and economic growth, and the government's economic health.[37]

During the risk assessment phase, three types of risk are evaluated. The effects of these risks on the largest commodities are assessed qualitatively and quantitatively. Recent risks, future risks according to climate change projections, and potential future risks given existing policies and the strategic vision for the sector are assessed in turn. The three types of risk are:

37 A diverse economy can protect national GDP from agricultural market volatility.

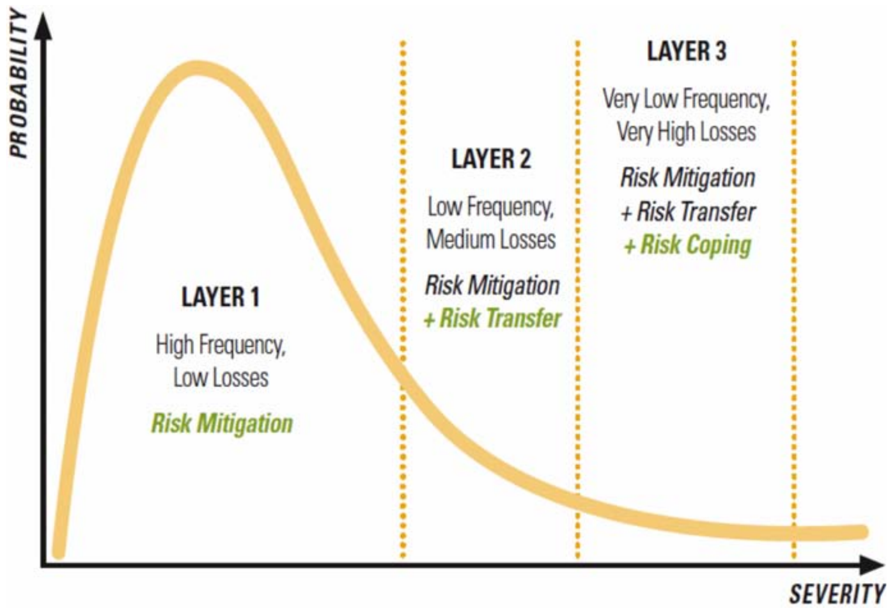

Figure 1: Risk Management Through a Layering Approach
Risks are managed via a layering approach comparing relative frequency and severity of risks. High frequency, low loss events are effectively managed via risk mitigation: agricultural practices (e.g., irrigation and drought-tolerant seeds), education, streamlining supply chains, good hygiene practices, food safety standards, etc. Low frequency, medium loss events require both risk mitigation and risk transfer, i.e., transferring the cost of risk to a third party via insurance or price hedging. In addition to risk mitigation and risk transfer, very low frequency events characterized by very high losses require risk coping mechanisms via social safety nets, humanitarian relief and food aid, etc.

1. *Production risks (e.g., drought, pests, disease, climate).* Production risks within the agricultural sector are assessed at national and regional scales according to crop vulnerability and the frequency and size of losses. With this information, a government with limited resources can reevaluate growth strategies and/or prioritize low-risk crops in appropriate regions.
2. *Market risks (e.g., price volatilities).* The impacts of price risks on the sector as a whole are difficult to quantify. Output price volatilities can be offset or caused by changing input prices. Relative impacts on producer and retail prices are not always equal, resulting in disparate effects for different actors. Lower commodity prices tend to be better for net consumers, and thus may have a positive effect depending on the sector's composition. It is important to assess volatilities to understand uncertainties in the sector and the root causes of these volatilities.
3. *Enabling environmental risks (e.g., erratic policy changes).* Enabling environment risks include unpredictable trade restrictions related to food safety, volatile exchange rates, erratic export and import regulations, and erratic sector policies (e.g., subsidies, market interventions, etc.). These are disincentives to production and contribute to market volatilities.

Effective risk management is crucial for the food security and resilient economic growth of agriculture-based economies. Agricultural risks contribute to significant volatility in production and household incomes. They contribute to increased expenditures, often by diverting resources from longer-term development objectives to help people cope with losses. In more urbanized economies, agricultural risk management is important for those engaged in the sector, for the agriculture investment climate, and for natural resource management. Adapting a systems approach and investing in mechanisms that increase resilience and productivity while reducing emissions as a co-benefit[38] ultimately reduces the social and economic burden following adverse events.

Risk management is an ongoing process that evolves with the environment in which a sector operates. Different countries present different challenges and require alternate solutions to address risk. These choices are dependent on a variety of factors including the overall economy, income levels, natural resource environment, available resources, systems in place (e.g., information systems and social safety nets), rural vs. urban economic landscapes, net consumers vs. net producers, and the political economy.

It is not without its challenges:

- Data is often inaccurate and debated within a country and information at subnational levels is often difficult to obtain.
- Climate change projections are beyond the scope of an assessment and existing projections are often not conducted at subnational levels, which is necessary for recommendations on adaptation.
- Implementation is often impeded by the limited capacity of in-country systems and resources, and by the political economy.

International Agricultural Programs

A global effort is required to sustain agriculture internationally and achieve economic growth while also addressing climate change. **Christopher Delgado**, Senior Fellow at the World Resources Institute, provided insight on building support for international agricultural programs. These programs improve food security, reduce poverty, promote economic growth and facilitate structural transformation. They also increase the resilience of livelihoods and promote climate change mitigation.

Increased research and investment support for agriculture internationally will require the attention of heads of state. This support can be achieved through either concern over an impending global food crisis or an appreciation of agriculture as a relatively fast and cost-effective pathway to successfully address big issues of concern.

African financing needs for adaptation are $35-50 billion per year, yet total adaptation financing in 2012 to Africa was only $1.6 billion. Since 2000, the amount disbursed from the five main multilateral funds for adaptation has been less than $53 million per year.

Official development assistance to agriculture rose sharply in response to the 1973-1974 food price spike, resulting in an expansion of aid programs and organizations and, ultimately, a successful response. Beyond the 1980s however, the percentage of public spending on agriculture declined significantly. A rise in food prices in 2008 broke this trend, causing an increase in government and private sector response. The share of agricultural loans at the World Bank increased from 7% in the early 2000s to 12% in 2010-2012. (In 1980, the share of agricultural loans was 30%.) This response has brought more attention to the transparency of the food market, as well as more direct foreign farm investments in least developed countries (LDCs). The majority of production response, however, has been in developed and emerging countries.

Today, global food prices are down and supplies are up. The FAO's November 2014 grains and oilseed price index, for example, was down 12% relative to 2013. In this environment, the post-2008 funding gains by international agricultural organizations are likely to be lost as limited resources are directed toward more pressing needs, as perceived by sponsoring countries and organizations. Meanwhile, food security concerns not solved by improved global agricultural production remain: 800 million people remain chronically hungry. Global climate change and complications from non-sustainable agriculture are driving a very large amount of uncertainty regarding future outlook.

Agricultural resilience to climate change is essential for national resilience but greatly underfunded. Poor communities in tropical countries have the most to lose from climate change in terms of yield and income.[39] For example, the United Nations Development Programme estimates that African financing needs for adaptation are $35-50 billion per year, yet total adaptation

38 The "triple win" of climate-smart agriculture.

39 IPCC. *Climate Change 2014: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate. 2014.; Challinor et al. *A meta-analysis of crop yield under climate change and adaptation.* Nature. 2014.

financing in 2012 to Africa was only $1.6 billion. Since 2000, the amount disbursed from the five main multilateral funds for adaptation has been less than $53 million per year.[40]

Increased research and investment support for agriculture internationally will require the attention of heads of state.

International agricultural programs must be sustained even in the absence of a food price crisis. Delgado identified four priorities that must be embraced and acted upon by heads of state:

1. Food productivity research focused on traits to sustainably raise crop, animal and forest productivity in specific regions with specific resource issues;
2. Investment in efficient ruminant livestock production to increase profitability and reduce emissions;
3. Stopping deforestation by enforcing land use laws and utilizing monitoring technology; and
4. Restoring agricultural and forest landscapes for resilience and mitigation.

Looking forward, the role of agriculture in the developing world will continue to be determined by supply and demand challenges and opportunities. Today, land use (specifically tradeoffs of land and water usage) and the carbon budget are new drivers of policy and practice. With growth and productivity contributions, land use can provide 30% of the mitigation needed to limit global climate change to 2 degrees Celsius. According to FAO, 25% of all agricultural land is severely degraded and another 8% is moderately degraded.[41] It is difficult to measure the expansion of degraded land but estimates are in the range of 50 million hectares each year. The cost of reduced agricultural production to a country is far more than that of remediation.

Meanwhile, agriculture contributes 24% of global greenhouse gas emissions, 46% of which are emissions from land use, land use change and deforestation. Delgado stressed that addressing land use issues—namely deforestation[42]—is central to sustaining economic growth and mitigating climate change. Only 7% of the world's forests are under currently sustainable management. From 2000 to 2010, annual net deforestation was 5.2 million hectares per year.[43] Sustainable intensification of agriculture requires adjacent forest protection and appropriate land governance.

With growth and productivity contributions, land use can provide 30% of the mitigation needed to limit global climate change to 2 degrees Celsius.

40 Courtesy of the Overseas Development Institute for the New Climate Economy. Forthcoming. Additional information is available in Watkins, K. *Climate Risk in African Agriculture.* 2014.

41 *The State of the World's Land and Water Resources for Food and Agriculture: Managing systems at risk.* Food and Agriculture Organization of the United Nations. 2011.

42 The majority of deforestation today is characterized by land use conversion to agriculture. Agriculture is not, however, driving the removal of trees (forest degradation). The majority of tree removal is due to timber logging, particularly in Latin America and Subtropical Asia. Where trees are cut and what happens to the land afterwards is a matter of governance. For more information see G. Kissinger et al. *Drivers of Deforestation and Forest Degradation: Synthesis Report for Policymakers.* September 2012.

43 *Global Forest Resources Assessment 2010.* Food and Agriculture Organization of the United Nations. 2010.

Conclusion

To feed a projected population of 8.3-10.9 billion people living in increasingly urban areas with richer diets, global food production will have to increase 70% by 2050. Despite continuing advances in agricultural technology, the ability of our global agricultural system to meet this demand is threatened by climate change. Rising temperature and increasing weather variability will ultimately degrade the quantity and quality of food we are able to produce.

The near-term extent of climate change impacts on agricultural production is both uncertain and varied. Different models project a range of possible outcomes while on-the-ground climate impacts can be exacerbated or mitigated by a region's location, social and economic infrastructure, and ecological resilience. By the midpoint of this century, potential impacts on global food production range from modest to severe. For a certainty, however, the end of this century will see significant decreases in agricultural yield unless a concerted global effort is made to reduce greenhouse gas emissions. Meanwhile, the poorest regions of the world with the least adaptive capacity are already experiencing extreme hardship from the effects of climate change.

A new revolution in food production characterized by multi-sector mitigation and integrated adaptation initiatives is essential to sustain future agricultural productivity. In support of this objective, speakers highlighted several technological priorities, management techniques and policy tools. Highlights include:

- ***Irrigation.*** Sustainable irrigation is essential for climate change adaptation. Water withdrawal must not exceed renewable water supply. Research and development is needed to improve efficiency and advance irrigation technologies.
- ***Weather monitoring.*** A global public system of weather data collection and access is vital for risk management decision-making. Farmers require good quality, daily time step weather data and historical records to assess the probability of yield and make decisions accordingly. Existing weather data collection systems in the U.S. are lacking in spatial density and frequently do not collect data usable by farmers.
- ***Biotechnology.*** When utilized as part of a systems approach, genetic modification of crops and livestock can increase resistance to biotic and abiotic stresses while maximizing affordability, yield and nutrient efficiency.
- ***Landscape Management.*** Landscape-scale approaches maximizing synergies and mitigating tradeoffs are required to fully address climate change impacts. Critical elements of this management paradigm include climate-smart field and farm practices, diversified land use, sustainable landscape interactions, and strengthened landscape resilience.
- ***Market integration.*** Free-flowing, international trade is an important vehicle for climate change adaptation and the moderation of economic impacts relative to food security by allowing for long-range shifts in global production patterns.

It will be impossible to achieve global food security and address climate change without a sustained commitment by world leaders. Agricultural assistance programs are greatly underfunded and must be maintained even in the absence of a discrete crisis. An adequate response to the issues outlined within this report necessitates investment in human capacity development, infrastructure, research and development, and land management and restoration. Meanwhile, the need to reduce greenhouse gas emissions and mitigate the effects of climate change cannot be ignored. Climate change mitigation must be balanced and integrated with efforts to sustainably increase agricultural production and reduce world hunger.

The cost of adapting to climate change will be not be trivial. However, failure to act could be catastrophic. Addressing global food security requires reconciliation of a complex combination of issues in both developing and developed nations. Local capacity building and the elimination of hunger must be integrated in global and regional policies and plans. Careful and systematic planning will maximize the odds of getting adaptation right.

Appendix A: The Safety of Genetically Modified Crops

Potential human health and environmental impacts of genetically modified (GM) crops have been the subject of intense public interest and discussion. Respected scientific and health organizations have investigated the potential impacts, including the American Association for the Advancement of Science,[44] European Commission,[45] The National Academies,[46] and World Health Organization.[47] None of these organizations have reported that GM crops are inherently harmful to human and environmental health.

GM crops are technically produced through several different methods, but today's GM (also popularly referred to as transgenic, genetically engineered, and GMO) crops typically refer to those produced through recombinant DNA (rDNA) methods. These methods allow the genetic makeup of a food or organism to be altered in some way. This 'recombination' can be accomplished by moving genes from one organism to another, or by changing genes in an organism that are already present.[48, 49]

As used in this appendix and report, GM crops refer solely to crops produced through rDNA methods. Foods derived from GM crops have been consumed by hundreds of millions of people across the world for over 15 years, with no reported ill effects or legal cases related to human health.[50] In the U.S., commercially available GM crops include corn, soybean, cotton, canola, alfalfa, sugar beets, papaya, and squash.[51]

As with all other technologies for genetic modification, rDNA methods carry the potential for adverse effects on human health and the environment.[52] As such, it is important that safety assessments be conducted before GM crops are commercialized. The U.S. Food and Drug Administration (FDA) is responsible for regulating the safety of GM crops eaten by humans and animals. The FDA considers most GM crops "substantially equivalent" to non-GM crops. This designates them as "Generally Recognized as Safe" under the Federal Food, Drug, and Cosmetic Act (FFDCA), and therefore not requiring pre-market approval. If the insertion of a transgene into a food crop results in the expression of foreign proteins that differ significantly in structure, function, or quality from natural plant proteins and are potentially harmful to human health, FDA reserves the authority to apply more stringent provisions of FFDCA.[53] GM crops are the most extensively tested crops ever added to our food supply.[54]

44 *Statement by the AAAS Board of Directors on Labeling of Genetically Modified Foods*. American Association for the Advancement of Science. October 20, 2012.

45 *A Decade of EU-Funded GMO Research (2001-2010).* Food, Agriculture & Fisheries & Biotechnology, European Research Area, European Commission. 2010.

46 *Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects.* National Research Council and Institute of Science. The National Academies. 2004.

47 *Frequently asked questions on genetically modified foods.* World Health Organization. May 2014.

48 Schneider, Keith R. et al. *Genetically Modified Food.* FSHN02-2. University of Florida IFAS Extension. November 2014.

49 Key, Suzie et al. *Genetically modified plants and human health.* Journal of the Royal Society of Medicine. Vol. 101 No. 6. pp. 290-298. June 1, 2008.

50 Ibid.

51 "FAQs on GE Crops." *A Science-Based Look at Genetically Engineered Crops.* The National Academies. Accessed March 1, 2015. http://nas-sites.org/ge-crops/2014/06/04/faq-on-ge-crops/

52 *Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects.* National Research Council and Institute of Science. The National Academies. 2004.

53 Tucker, Jonathan. "U.S. Regulation of Genetically Modified Crops." *Case Studies in Agricultural Biosecurity.* Federation of American Scientists. 2011.

54 *Statement by the AAAS Board of Directors on Labeling of Genetically Modified Foods*. American Association for the Advancement of Science. October 20, 2012.

Common human health and environmental concerns regarding GM crops include the following:

- *"GM crops that confer resistance to an antibiotic may spread antibiotic resistance to the bacterial population."* However, these antibiotic resistance genes were initially isolated from bacteria and are already widespread in the bacterial population.[55]
- *"Unnecessary DNA is transferred into the plant genome as a consequence of the engineering and transfer process."* There is no reason that DNA per se should be harmful, as it is consumed by humans in all foods. However, plant breeders have responded by designing "minimal cassettes" in which only the gene of interest is transferred into the plant.[56]
- *"GM crops may carry more mutations than their untransformed counterparts as a result of the production method."* This may mean that plants may be produced with, for example, reduced levels of nutrients, or increased levels of allergens or toxins. These safety concerns are addressed through assessments prior to commercialization of the crop.[57]
- *"Gene transfer may occur between GM and non-GM crops."* There are strategies to prevent gene flow from GM plants to the environment. These include physical isolation and genetic containment, which can be achieved, for example, through sterility and incompatibility systems to limit the transfer of pollen, or Genetic Use Restriction Technologies which interfere with fertility or seed formation.[58]
- *"GM crops can breed superweeds."* U.S. farmers have widely adopted GM cotton engineered to tolerate the herbicide glyphosate. Eventually, this spurred the evolution of herbicide resistance in many weeds. Herbicide resistance is a problem for farmers regardless of whether or not they plant GM crops. Currently, herbicide-resistant GM crops are less damaging to the environment than conventional crops grown at industrial scale. However, it is uncertain how long these benefits will last, since herbicide use on GM crops is rising with the proliferation of resistant weeds.[59]

As with any other crops produced through genetic modification technologies, GM crops are clearly not without their environmental and health risks. The crop varieties that are commercialized today, however, receive more regulation than older technologies have in the past. When assessed and approved on a case-by-case basis, crops produced through rDNA technology are no more harmful than conventional foods already available.

55 Key, Suzie et al. *Genetically modified plants and human health.* Journal of the Royal Society of Medicine. Vol. 101 No. 6. pp. 290-298. June 1, 2008

56 Ibid.

57 Ibid.

58 Ibid.

59 Gilbert, Natasha. *A hard look at GM crops.* Nature. Vol 497 No. 7447. pp 24-26. May 2, 2013.

Appendix B: Congress Registrants

Kristen Bishop
Graduate Student
University of Illinois at Urbana-Champaign
Urbana, IL

Drew Black
Director of Environmental Policy
Canadian Federation of Agriculture
Ottawa, ON

Ethan Butler
Graduate Student
Department of Earth and Planetary Sciences
Harvard University
Washington, DC

Susan Capalbo
Department Head and Professor
Applied Economics
Oregon State University
Corvallis, OR

Kenneth Cassman
Robert B. Daugherty Professor of Agronomy
University of Nebraska-Lincoln
Lincoln, NE

Tom Chase
Director
Coasts, Oceans, Ports & Rivers Institute
American Society of Civil Engineers
Reston, VA

Allison Chatrchyan
Director
Institute for Climate Change and Agriculture
Cornell University
Ithaca, NY

Charles Chesnutt
Coastal Engineer
Institute for Water Resources
U.S. Army Corps of Engineers
Alexandria, VA

Netra Chhetri
Associate Professor
School of Geographical Sciences and Urban Planning and Consortium for Science, Policy and Outcomes
Arizona State University
Tempe, AZ

Zach Conrad
Ph.D. Candidate
Food Systems and Public Health
Tufts University
Brighton, MA

Christine Crudo
Ph.D. Student
Washington State University
Pullman, WA

Kyle Davis
Graduate Student
University of Virginia
Charlottesville, VA

Robert Day
Executive Director
Renewable Natural Resources Foundation
North Bethesda, MD

Christopher Delgado
Senior Fellow
World Resources Institute
Washington, DC

John Dickey
RNRF Board Member
Quebradillas, PR

Paolo D'Odorico
Professor
Department of Environmental Sciences
University of Virginia
Charlottesville, VA

John Durrant
Senior Managing Director
Engineering & Lifelong Learning
American Society of Civil Engineers
Vice Chairman
RNRF Board of Directors
Reston, VA

Dick Engberg
Technical Director
American Water Resources Association
Chairman, RNRF Board of Directors
Middleburg, VA

Elizabeth Felter
NOAA Digital Coast Fellow
American Planning Association
Coastal States Organization
Washington, DC

Wade Foster
Manager
Regulatory and Scientific Affairs
The Fertilizer Institute
Washington, DC

Jamie Gerber
Co-Director and Lead Scientist
Global Landscapes Initiative
University of Minnesota Institute on the Environment
St. Paul, MN

Kalyan Ghadei
Post Doc Research Scholar
Virginia Tech
Blacksburg, VA

Åsa Giertz
Agricultural Specialist
The World Bank
Washington, DC

Lael Goodman
Analyst
Tropical Forest and Climate Initiative
Union of Concerned Scientists
Washington, DC

Melissa Goodwin
Program Director
Renewable Natural Resources Foundation
North Bethesda, MD

Michael A. Grusak
Plant Physiologist
Children's Nutrition Research Center
USDA Agricultural Research Service
Houston, TX

Neal Halvorson-Taylor
Senior Advisor for Sustainability
Morvan Farm
University of Virginia
Charlottesville, VA

Erik Hankin
Public Affairs Specialist
American Geophysical Union
RNRF Board Member
Washington, DC

Eric Hansen
Policy Analyst
National Young Farmers Coalition
Washington, DC

Peyton Harper
Manager
Stewardship and Sustainability Programs
The Fertilizer Institute
Washington, DC

Paul Heisey
Agricultural Economist
Economist, Structure, Technology and Productivity Branch
Resource and Rural Economics Division
USDA Economic Research Service
Washington, DC

Thomas Hertel
Distinguished Professor of Agricultural Economics
Purdue University
West Lafayette, IN

Steve Hodges
Professor
Soil Science & Ecology of Managed Ecosystems
Crop and Soil Environmental Sciences
Virginia Tech
Blacksburg, VA

Mitch Hunter
Ph.D. Candidate, Agronomy
Penn State University
University Park, PA

Larry Jacobson
Professor & Extension Engineer Biosystems and Agricultural Engineering
University of Minnesota
St. Paul, MN

Randy Johnson
National Program Leader
Genetics and Global Change Research
USDA Forest Service
Arlington, VA

Bruce Knight
Principal and Founder
Strategic Conservation Solutions
Washington, DC

Jennee Kuang
Research Associate
Renewable Natural Resources Foundation
North Bethesda, MD

Laura Lengnick
Co-Director, Resilience Initiatives
Second Nature
Asheville, NC

Don McCabe
Director
Ontario Federation of Agriculture
Inwood, ON

Julie McClure
Science Policy Manager
American Society of Agronomy
Crop Science Society of America
Soil Science Society of America
Washington, DC

Robert Mendelsohn
Professor of Forest Policy, Professor of Economics, and Professor in the School of Management
Yale University
New Haven, CT

Dawn Moncrief
Executive Director
A Well-Fed World
Washington, DC

Julie Morris
Associate Director of Implementation and Strategic Planning
U.S. Global Change Research Program
Washington, DC

Martina Newell-McGloughlin
Director
University of California Systemwide Biotechnology Research and Education Program
Davis, CA

Megan O'Rourke
Assistant Professor
Department of Horticulture
Virginia Tech
Blacksburg, VA

Karen Paczkowski
Science Policy Fellow
Geological Society of America
Washington, DC

Davia Palmeri
Climate Adaptation Assistant
Association of Fish and Wildlife Agencies
Washington, DC

Brian Parsons
Director
Environmental & Water Resources Institute
American Society of Civil Engineers
Reston, VA

Alyssum Pohl
NOAA Digital Coast Fellow
National Association of Counties
National States Geographic Information Council
Washington, DC

Debbie Reed
Executive Director
Coalition on Agricultural Greenhouse Gases
Washington, DC

Howard Rosen
Volunteer
USDA Forest Service
Society of Wood Science and Technology
RNRF Board Member
Washington, DC

Alex Rosenberg
Senior Policy Advisor
Ontario Ministry of Agriculture, Food and Rural Affairs
Guelph, ON

Yashar Saghai
Director
Global Food Ethics Project
Postdoctoral Fellow
Berman Institute of Bioethics
John Hopkins University
Baltimore, MD

Sara Scherr
President and CEO
EcoAgriculture Partners
Washington, DC

Roberta Schoen
Director
Board on Agriculture and Natural Resources
National Research Council
Washington, DC

William Sischo
Professor
Food and Waterborne Disease, Animal Health, and Food Security Policy
Washington State University
Pullman, WA

David W. Smith
Deputy Chief
Soil Science and Resource Assessment
Natural Resources Conservation Service
Beltsville, MD

Maureen Sondag
Assistant to the Agricultural Counselor
Royal Netherlands Embassy
Washington, DC

Jean Steiner
Supervisory Soil Scientist
Grazinglands Research Laboratory
USDA Agricultural Research Service
El Reno, OK

Mark Svendsen
Water Resource Consultant
Oregon State University
Philomath, OR

Katie Thomas
Program Officer
Board on Atmospheric Sciences and Climate
National Academies of Science
Washington, DC

Allison Thomson
Research Scientist and Group Leader
Joint Global Change Research Institute
Pacific Northwest National Laboratory
College Park, MD

Frederi Viens
Professor of Statistics and Mathematics
Purdue University
West Lafayette, IN

Margaret Walsh
Senior Ecologist
Climate Change Program Office
U.S. Department of Agriculture
Washington, DC

Charles Walthall
National Program Leader
Climate Change, Soils and Air Emissions Research Program
USDA Agricultural Research Service
Beltsville, MD

Billy Williams
Director of Science
American Geophysical Union
Washington, DC

Mike Wilson
Research Soil Scientist
National Soil Survey Center
Natural Resources Conservation Service
Lincoln, NE

Keith Yearwood
Professor
College of Behavioral and Social Sciences
University of Maryland
College Park, MD

Osei-Agyeman Yeboah
Professor and Director
International Trade Center
North Carolina A&T State University
Greensboro, NC

Eric Young
Executive Director
Southern Association of Agricultural Experiment Station Directors
North Carolina State University
Raleigh, NC

Peter Ziegler
Research Assistant Professor
College of Agriculture and Life Sciences
Academic Programs
Virginia Tech
Blacksburg, VA

Lewis Ziska
Research Plant Physiologist, Crop Systems & Global Change
USDA/ARS/NRSAS
Beltsville, MD

Appendix C: Congress Program

Tuesday, December 9

8:00 am – 8:50 am	Registration and Continental Breakfast
9:00 am – 9:30 am	Welcome and Opening Remarks **Richard Engberg** RNRF Chairman Technical Director, American Water Resources Association Middleburg, Virginia
9:30 am – 10:10 am	**Effects of climate change on the agroecosystem (to 2050)** An overview presentation. What weather patterns and climatic changes are anticipated between now and 2050? How will these changes affect crop productivity, the range and extent of pests and disease, and ecosystem structure and function? **Charles Walthall** National Program Leader Climate Change, Soils and Air Emissions Research Program, USDA Agricultural Research Service Beltsville, Maryland
10:10 am – 10:40 am	Questions/Discussion
10:40 am – 11:00 am	Break
11:05 am – 11:35 am	**An economic analysis of the impact of climate change on agriculture** A comparison of economic impacts in developed versus developing nations. What economic consequences are anticipated with different degrees of warming? To include a discussion of the implications for adaptation policy. **Robert Mendelsohn** Professor of Forest Policy, Professor of Economics, Professor in School of Management Yale University New Haven, Connecticut
11:35 am – 12:05 pm	Questions/ Discussion
12:05 pm – 1:05 pm	Lunch
1:10 pm – 1:40 pm	**Tools to adapt food production to climate change: agronomic responses** An exploration of early response farm production practices including crop diversification, change in intensification, fallow/tillage practices, irrigation, and timing changes. What are the barriers to the adoption of climate smart agriculture practices? How do we address them? **Kenneth Cassman** Robert B. Daugherty Professor of Agronomy, University of Nebraska-Lincoln Lincoln, Nebraska

1:40 pm – 2:10 pm	Questions/Discussion
2:15 pm – 2:30 pm	Break
2:35 pm – 3:05 pm	**Tools to adapt food production to climate change: technological solutions**
	Technological solutions for climate change adaptation include new crop varieties, resilient seed stock, early weather warning systems, and appropriate mechanical cropping technologies for developing countries. This segment will feature an overview of the role of genetically modified organisms, including safety and ethical considerations, technological frontiers and benefits.
	Martina Newell-McGloughlin Director, University of California Systemwide Biotechnology Research and Education Program Davis, California
3:05 pm – 3:35 pm	Questions/ Discussion
3:40 pm – 4:10 pm	**Landscape planning to mitigate and adapt to climate change**
	A discussion of integrated landscape management techniques to sustainably produce food and conserve biodiversity and ecosystem services. What tools can be used to simultaneously reduce greenhouse gas emissions and promote sustainable agriculture in the face of climate change?
	Sara Scherr President & CEO, EcoAgriculture Partners Washington, District of Columbia
4:10 pm – 4:40 pm	Questions/ Discussion

Wednesday, December 10

8:00 am – 8:50 am	Continental Breakfast
9:00 am – 9:30 am	**Adopting public policies and priorities to encourage climate-smart agricultural practices**
	What are the policy tools available to influence and promote climate-smart agriculture? What is the role and impact of farm subsidies? Do current policies incentivize resilience to climate stresses? What adjustments are required?
	Susan Capalbo Department Head and Professor, Applied Economics, Oregon State University Corvallis, Oregon
9:30 am – 10:00 am	Questions/ Discussion
10:05 am – 10:35 am	**U.S. federal agency coordination and decision-making for climate change policy and research**
	A holistic exploration of how the federal government and U.S. federal agencies are coordinating climate change science, policy and research in support of the White House Global Climate Change Initiative. What are the opportunities to improve federal programs and response?
	Julie Morris Associate Director of Implementation and Strategic Planning, U.S. Global Change Research Program, Office of Science and Technology Policy Washington, District of Columbia
10:35 am – 11:05 am	Questions/ Discussion
11:05 am – 11:25 am	Break

11:30 am – 12:00 pm	**How will climate change affect the international food market, production, and distribution system?** An overview of current global food consumption and distribution patterns. How will food prices, trade and distribution be affected by climate change? **Thomas Hertel** Distinguished Professor of Agricultural Economics, Purdue University Founder and Executive Director, Global Trade Analysis Project West Lafayette, Indiana
12:00 pm – 12:30 pm	Questions/ Discussion
12:30 pm – 1:30 pm	Lunch
1:35 pm – 2:05 pm	**Understanding and managing risk in the international food market** Formulating a risk-management framework to respond to increasing volatility driven by climate change and increasing demand for food. **Åsa Giertz** Agricultural Specialist, The World Bank Washington, District of Columbia
2:05 pm – 2:35 pm	Questions/ Discussion
2:40 pm – 3:10 pm	**Building support for international agricultural and food programs in developing countries** Agricultural assistance programs must become a higher international priority. How can political and financial support be increased? What are the opportunities for international institutions to become more effective and efficient? Are there opportunities to increase coordination and cooperation among international organizations? **Christopher Delgado** Senior Fellow, World Resources Institute Washington, District of Columbia
3:15 pm – 3:45 pm	Questions/ Discussion
3:50 pm – 4:10 pm	Congress Wrap-up and Discussion **Robert Day** Executive Director, Renewable Natural Resources Foundation North Bethesda, Maryland

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