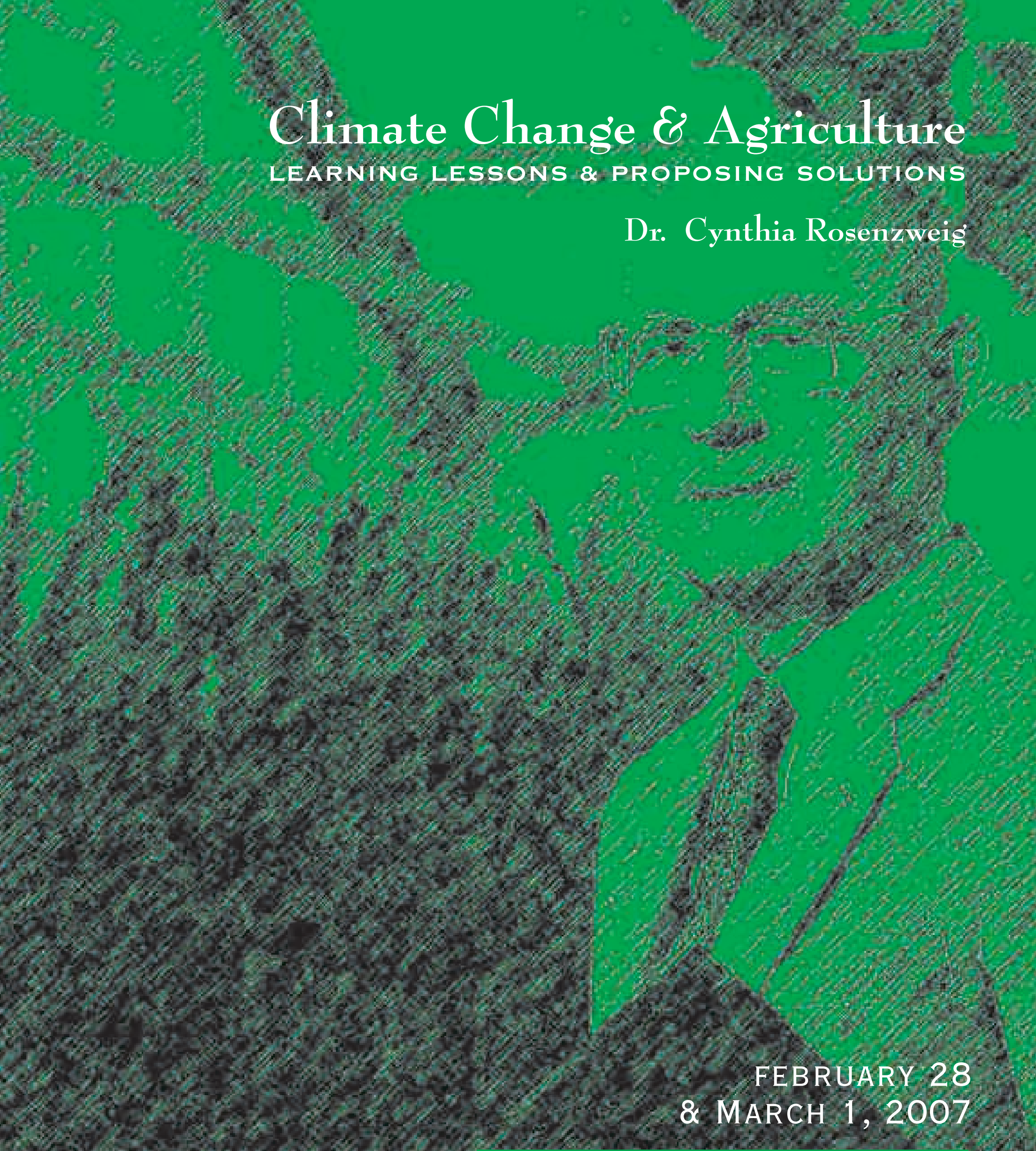

Climate Change & Agriculture

LEARNING LESSONS & PROPOSING SOLUTIONS

Dr. Cynthia Rosenzweig

FEBRUARY 28
& MARCH 1, 2007

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THE SPEAKER

CYNTHIA ROSENZWEIG

Dr. Cynthia E. Rosenzweig is a research agronomist with the National Aeronautics and Space Administration Goddard Institute for Space Studies in New York City. She holds a B.S. in Agricultural Sciences from Cook College, an M.S. in Soils and Crops from Rutgers University, and a Ph.D. in Plant, Soil and Environmental Sciences from the University of Massachusetts – Amherst.

Dr. Rosenzweig's primary research involves the development of interdisciplinary methodologies by which to assess the potential impacts of and adaptations to global environmental change. She has joined impact models with global climate models to predict future outcomes of both land-based and urban systems under altered climate conditions. Advances include the development of climate change scenarios for impact analysis, and the application of impact models at relevant spatial and temporal

scales for regional and national assessments. Recognizing that the complex interactions engendered by global environmental change can best be understood by coordinated teams of experts, Dr. Rosenzweig has organized and led large-scale interdisciplinary, national, and international studies of climate change impacts and adaptation. She is the Co-Leader of the Metropolitan East Coast Regional Assessment of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, sponsored by the U.S. Global Change Research Program. She leads the Climate Impacts research group at the Goddard Institute of Space Studies, whose mission is to investigate the interactions of climate (both variability and change) on systems and sectors important to human well-being.

PRESENTATION AND PAPER

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Introduction

Climate change exacerbates concerns about agricultural production and food security worldwide. At global and regional scales, food security is prominent among the human activities and ecosystem services under threat from dangerous anthropogenic interference in the earth's climate.[i] At the national scale, countries are concerned about potential damages that may arise in coming decades from climate change impacts, as these are likely to affect domestic and international policies, trading patterns, resource use, regional planning, and welfare.

While agro-climatic conditions, land resources and their management are key components of food production, both supply and demand also are critically affected by distinct socio-economic pressures, including current and projected trends in population and income growth and distribution, as well as availability and access to technology and development. In the last three decades, for instance, average daily per capita intake has risen globally from 2,400 to 2,800 calories, spurred by economic growth, improved production systems, international trade, and globalization of food markets. Feedbacks of such growth patterns on cultures and personal taste, lifestyle and demographic changes have in turn led to major dietary changes – mainly in developing countries, where shares of meat, fat, and sugar in total food intake have increased significantly.[ii] Thus, the consequences of climate change on world food demand and supply will depend on many interactive dynamic processes.

Agriculture plays two fundamental roles in human-driven climate change. On the one hand, it is the one key human sector that will be affected by climate change over the coming decades, thus requiring adaptation measures. On the other, agriculture is also a major source of greenhouse gases to the atmosphere. As climate changes as well as socio-economic pressures shape future demands for food, fiber and energy, synergies must be identified between adaptation and mitigation strategies, to allow development of robust options that meet both the climate and societal challenges of the coming

> *As climate changes and socio-economic pressures shape future demands for food, fiber and energy, synergies between adaptation and mitigation strategies can help meet challenges of the coming decades.*

decades. Ultimately, farmers and others in the agricultural sector will be faced with the dual task of contributing to global reductions of carbon dioxide and other greenhouse gas emissions, while having to cope with an already-changing climate.

A changing climate due to increasing anthropogenic emissions of greenhouse gases will induce change in agricultural systems through a set of interactive processes. Both productivity and geographic distribution of crop species will be affected. The major climate factors contributing to these responses include increasing atmospheric carbon dioxide, rising temperature, and increasing extreme events, especially droughts and floods. These factors in turn will affect water resources for agriculture, grazing lands, livestock, and associated agricultural pests. Effects will vary, depending on the degree of change in temperature and precipitation and on the particular management system and its location. Several studies have suggested that recent warming trends in some regions already may have had discernible effects on some agricultural systems.

Climate change projections are fraught with uncertainty regarding both the rate and magnitude of temperature and precipitation variation in the coming decades. This uncertainty arises from a lack of precise knowledge of how climate system processes will change and of how population growth, economic and technological developments, and land use patterns will evolve in the coming century.[iii]

Nevertheless, three points regarding climate change can be made with some confidence. First, the natural presence of greenhouse gases is known to affect the planetary energy balance, causing the planet to be warmer than it would be otherwise. Second, greenhouse gas concentrations have increased progressively since the beginning of the Industrial Revolution. Such increases in greenhouse gases tend to enhance the natural “greenhouse effect.” Third, the planet has indeed been warming over the last century, especially in the most recent three decades.

The Intergovernmental Panel on Climate Change (IPCC) has attributed the observed warming over the last century to anthropogenic emissions of greenhouse gases, especially carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[iv] Thus, anthropogenic emissions of greenhouse gases appear to be altering our planetary energy balance and to be manifested in an overall (though uneven) warming of the planet. If the measurable warming trend continues at the global scale, the association of greenhouse gas emissions, the greenhouse effect, and surface warming will acquire ever greater certainty. The ultimate significance of the climate change issue is related to its global reach, affecting agricultural regions throughout the world in complex and interactive ways. After approximately two decades of research, 10 major lessons may be drawn about climate change and agriculture.

1) EFFECTS ON AGRICULTURAL SYSTEMS ARE HETEROGENEOUS AND UNCERTAIN

Global studies done to date show that negative and positive effects will occur both within countries and across the world. In large countries such as the United States, Russia, Brazil, and Australia, agricultural regions likely will be affected quite differently. Some regions will experience increases in production and some will experience declines.[v] At the international level, this implies possible shifts in comparative advantage for production of export crops. It also implies that adaptive responses to climate change will necessarily be complex and varied. Due to differences in global climate model projections, it is impossible to project exact effects in any one location.

2) DEVELOPING COUNTRIES ARE MORE VULNERABLE

Despite general uncertainties about the rate and magnitude of climate change and especially about consequent hydrological changes, regional and global studies consistently have shown that agricultural production systems in the mid and high latitudes are more likely to benefit in the near term (to mid-century), while production systems in the low latitudes are more likely to decline[vi] (*Fig. 1*). In biophysical terms, rising temperatures likely will push many crops beyond their limits of optimal growth and yield. Higher temperatures will intensify the evaporative demand of the atmosphere, leading to greater water stress, especially in semi-arid regions. Because most developing countries are located in lower-latitude regions (some of which are indeed semi-arid), while most developed countries are located in the more humid mid- to high latitudes, this finding suggests a divergence in vulnerability between these groups of nations, with far-reaching implications for future world food security.[vii]

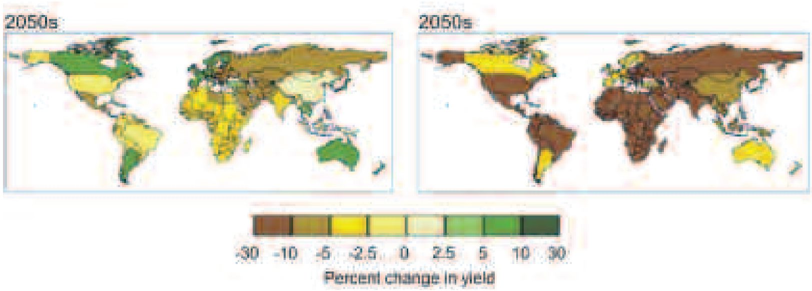


Figure 1: Potential changes (%) in national cereal yields for the 2050s (compared with 1990) under the HadCM3 SRES A1FI with (left) and without (right) CO_2 effects (Parry et al., 2004).

Furthermore, developing countries often have fewer resources with which to devise appropriate adaptation measures to meet changing agricultural conditions. The combination of potentially greater climate stresses and lower adaptive capacity in developing countries creates different degrees of vulnerability between rich and poor nations as they confront global warming. This disparity is due in part to the potentially greater detrimental impacts of a changing climate in areas that are already warm (particularly if such areas are also dry), and in part to the generally lower levels of adaptive capacity in developing countries.

3) DEVELOPMENT PATH MATTERS

Because climate is not the only driving force on agriculture, researchers now conduct scenario analyses that include linked sets of population projections, economic growth rates, energy technology improvements, land-use changes, and associated emissions of greenhouse gases. Parry et al. (2004) have analyzed the global consequences of climate change on crop yields and production using scenarios developed from the

> *Uncertainty arises from lack of precise knowledge of how climate processes will change and of how demographics, economic growth, technology and land-use patterns will evolve.*

HadCM3 (**Had**ley Centre **C**oupled **M**odel, version **3**) global climate model (GCM), in connection with the *Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (SRES) A1FI, A2, B1, and B2*. Projected changes in yield were calculated using transfer functions derived from crop model simulations with observed climate data and projected data scenarios.

Results elucidate the complex regional patterns of projected climate variables, CO_2 effects, and agricultural systems that contribute to aggregations of global crop production. The AIF1 scenario, as expected with its large increase in global temperatures, exhibits the most pronounced decreases in yields both regionally and globally. The contrast between the predicted yield change in developed and developing countries is largest under the A2a-c scenarios. Under the B1 and B2 scenarios, developed and developing countries exhibit less contrast to crop yield changes, with the B2 future crop yield changes being slightly more favorable than those of the B1 scenario.

4) LONG-TERM EFFECTS ARE NEGATIVE FOR BOTH DEVELOPED AND DEVELOPING COUNTRIES

If the effects of climate change are not abated, even production in the mid and high latitudes is likely to decline in the long term (end of 21st century) (*Fig. 2*). These results are consistent over a range of temperature, precipitation, and direct CO_2 effects tested, and are due primarily to the detrimental effects of heat and water stress as temperatures rise. While the beneficial effects of CO_2 may eventually level out, the detrimental effects of warmer temperatures and greater water stress are more likely to progress in all regions. Although the precise levels of CO_2 effects on crops and their contribution to global crop production are still active areas of research,[viii] global impacts are likely to turn negative in all regions sometime around the second half of the century.

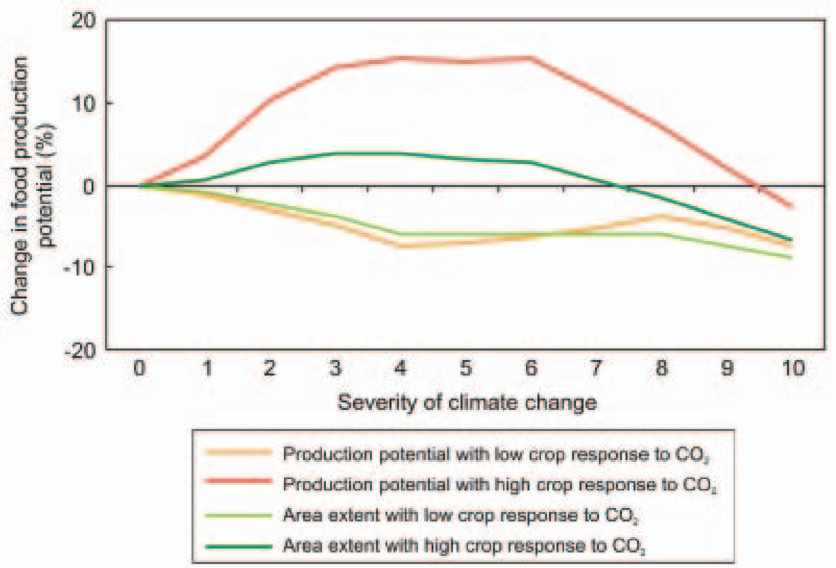


Figure 2: Change in food production potential in relation with severity of climate change.

5) WATER RESOURCES ARE KEY

Recent flooding and heavy precipitation events in the US and worldwide have caused great damage to crop production. If the frequency of these weather extremes were to increase in the near future, as recent trends for the US indicate and as projected by global climate models,[ix] the cost of crop losses in the coming decades could rise dramatically. A dynamic crop model simulated one important effect of heavy precipitation on crop growth: plant damage from excess soil moisture.[x] The study showed that the US corn production losses due to this factor, already significant under the current climate, may double during the next 30 years, causing additional damages totaling an estimated $3 billion per year (*Fig. 3*). These costs either may be borne directly by those impacted or transferred to private or governmental insurance and disaster relief programs.

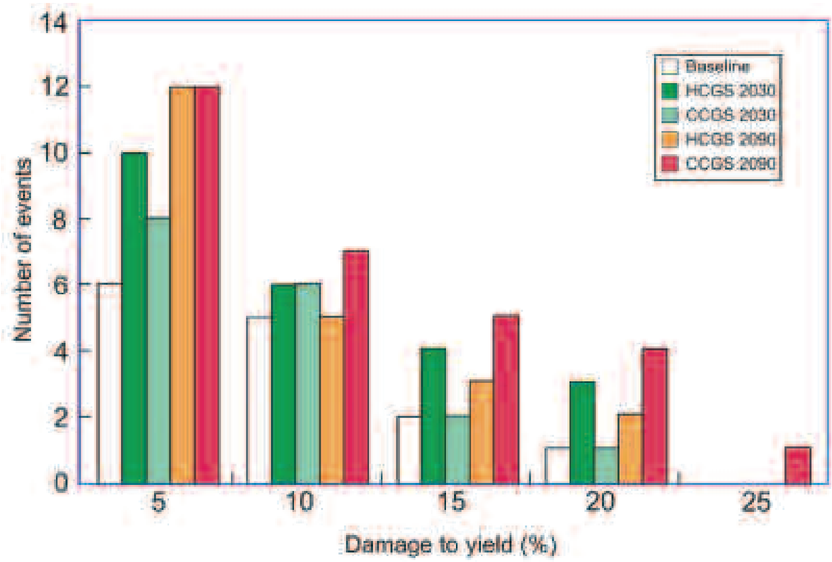


Figure 3: Number of events causing damage to maize yields due to excess soil moisture conditions, averaged over all study sites, under current baseline (1951–1998) and climate change conditions. The Hadley Centre (HC) and Canadian Centre (CC) scenarios with greenhouse gas and sulfate aerosols (GS) were used. Events causing a 20% simulated yield damage are comparable to the 1993 US Midwest floods (Rosenzweig 2001).

Greater climate stresses and lower adaptive capacity in developing countries create differential vulnerability between rich and poor nations as they confront global warming.

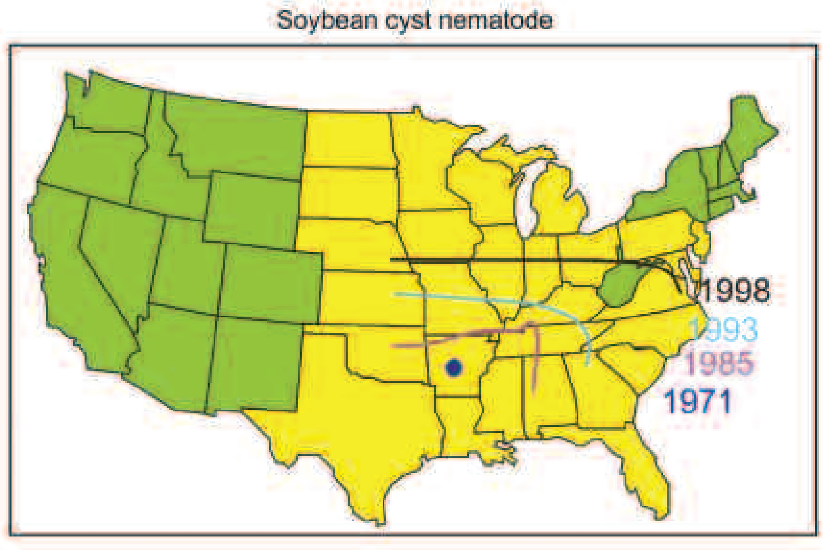
Another integrated study examined the implications of changes in crop water demand and water availability for the reliability of irrigation, taking into account changes in competing municipal and industrial demands, and explored the effectiveness of adaptation options in maintaining reliability. It developed methods of linking climate change scenarios with hydrologic, agricultural, and planning models to study water availability for agriculture under changing climate conditions, to estimate changes in ecosystem services, and to evaluate adaptation strategies for the water resources and agriculture sectors. The models were applied to major agricultural regions in Argentina, Brazil, China, Hungary, Romania and the US, using projections of climate change, agricultural production, population, technology and GDP growth.[xi]

For most of the relatively water-rich areas studied, water supplies appear sufficient for agriculture given the climate change scenarios tested. Northeastern China suffers from the greatest lack of water availability for agriculture and ecosystem services, both in the present and in the climate change projections. Projected runoff in the Danube Basin does not change substantially, although climate change causes shifts in environmental stresses within the region. Northern Argentina's occasional problems in water supply for agriculture under the current climate may be exacerbated and may require investments to relieve future tributary stress. In Southeastern Brazil, future water supply for agriculture appears to be plentiful. Water supply in most of the US corn belt is projected to increase in most climate change scenarios, but this could lead to problems with tractability in the spring and water-logging in the summer.

Adaptation tests implied that only the Brazil case study area can readily accommodate an expansion of irrigated land under climate change, while the other three areas would suffer decreases in system reliability if irrigation areas were to be expanded. Cultivars are available for agricultural adaptation to the projected changes, but their demand for water may be higher than currently adapted varieties. Thus, even in these relatively water-rich areas, changes in water demand due to climate change effects on agriculture and increased demand from urban growth will require timely improvements in crop cultivars, irrigation and drainage technology, and water management.

6) AGRICULTURAL PESTS AND DISEASES MAY SPREAD

Increased pest damage arises from changes in production systems, enhanced resistance of some pests to pesticides, and the production of crops in warmer and more humid climatic regions where plants are more susceptible to pests. Changes in crop management techniques, particularly the intensification of cropping, reduction in crop rotations, and increase in monocultures, have increased the activity of pests. The expansion of worldwide trade in food and plant products also has increased the impact of weeds, insects, and diseases on crops. The geographical ranges of several important insects, weeds, and pathogens in the US have expanded recently, including soybean cyst nematode (*Heterodera glycines*) and sudden-death syndrome (*Fusarium solani* f. sp. *glycines*) (*Fig. 4 on page 10*).[xii]



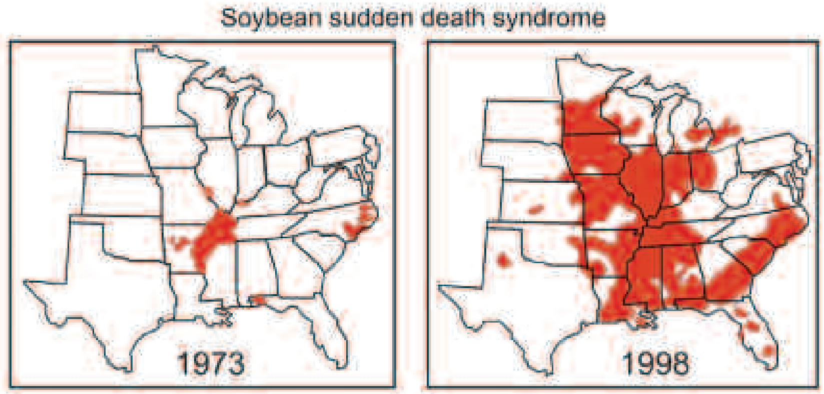


Figure 4: Range expansion of soybean cyst nematode (Heterodera glycines) from 1971 to 1989 (top) and soybean sudden death syndrome (Fusarium solani f. sp. Glycines) from 1973 to 1998 (bottom) in North America (Yang in Rosenzweig 2001).

Current climate trends and extreme weather events may be directly and indirectly contributing to the increased pest damage.[xiii] Recent work simulated future scenarios of downy mildew (*Plasmopara viticola*) epidemics on grapes under climate change, by combining a disease model to output from two global climate models. Downy mildew is the most serious grapevine disease in northern Italy. The simulations obtained by combining the disease model to the two GCM outputs predicted an increase of the disease pressure in each decade: more severe epidemics were a direct

> *Although the direct effect of increased CO_2 on crops is still an active area of research, global climate impacts are likely to turn negative in the second half of the century.*

consequence of more favorable temperature conditions during the months of May and June. These negative effects of increasing temperatures more than counterbalanced the effects of precipitation reductions, which alone would have diminished disease pressure. Results suggested that, as adaptation response to future climate change, more attention should be paid in the management of early downy mildew infections; two more fungicide sprays were necessary under the most negative climate scenario, compared with present management regimes. At the same time, increased knowledge of the effects of climate change on host-pathogen interactions will be necessary to improve current predictions.[xiv]

Such changes must be put into the context of the global increases in pest-induced losses of crops in all regions since the 1940s[xv] and the more than 33-fold increase in both the amount and toxicity of pesticide used over the same period.[xvi] Climate change thus may exacerbate environmental and public health issues related to agricultural chemicals.[xvii]

7) CURRENT CLIMATE STRESS IS A KEY ENTRY POINT FOR CLIMATE CHANGE

Current and future climate stresses interact in important ways. Farmers have dealt with climatic fluctuations since the advent of agriculture, and improving strategies for dealing with present climate extremes such as droughts, floods, and heat waves is an important way to prepare for climate change. Many agricultural regions are affected by the major climate variability systems, including the processes known as the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). The El Niño phase of the ENSO cycle tends to bring rainfall to Uruguay, while La Niña brings drought, as shown in Figure 5 for 1998, an El Niño year, and 2000, the following La Niña.

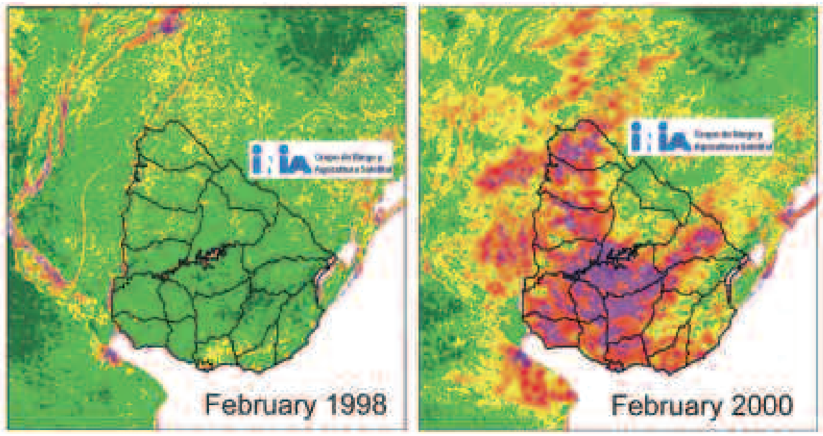


Figure 5: Vegetative Index (NDVI) for El Niño (1998) and La Niña (2000) years in Uruguay. Green = well-watered; red/purple = drought conditions (Baethgen 2002).

In terms of prediction tools, ENSO models provide the opportunity for testing and validation of climate prediction and assessment on shorter seasonal-to-interannual time scales. Skill in predicting climate changes on shorter time scales, particularly the ENSO periods of the last 20 years when good observations exist, may lend credence to projections of global warming over the longer term. As global climate models are further developed with improved parameterizations and higher spatial resolution, they are likely to improve simulations of ENSO and other large-scale variability processes. The interaction of these systems with underlying anthropogenic trends caused by increasing greenhouse gas concentrations in the atmosphere is an active area of contemporary climate science. For regions directly affected by ENSO and other systems, such changes, if they do indeed occur, may become important manifestations of global warming.

8) ADAPTATION IS NECESSARY

"Coping range" is a useful paradigm for improving responses to climate stresses of today and preparing for the climate changes of tomorrow. An agricultural system's coping range of climate variability may be exceeded as incidence of extreme events increases under changing climate conditions (*Fig. 6*). The goal is to increase the coping range over which an agricultural system may thrive under such changes through the process of adaptation.

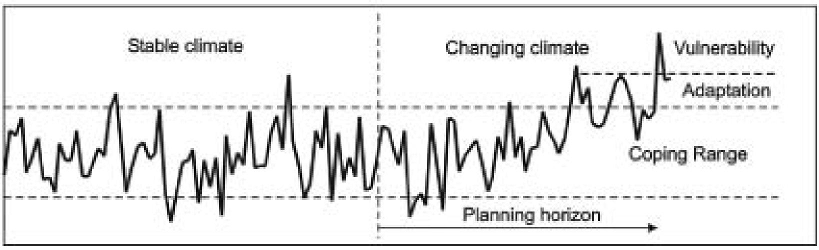


Figure 6: Coping range of climate variability (adapted from Jones 2004).

Adaptation can help farmers to minimize negative impacts of climate on human activities and ecosystems and to take advantage of potential beneficial changes. Adaptation to climate change can be defined as the range of actions taken in response to changes in local and regional climatic conditions.xviii Adaptation responses include both autonomous adaptation actions (i.e., those taken independently by individual farmers or by groups such as agricultural organizations) and planned adaptation actions (i.e., those facilitated by climate-specific regulations and incentives put in place by regional, national and international policies) (see *Table 1*).[xix]

Changes in water demand due to climate change and urban growth will require timely improvements in crop cultivars, irrigation and drainage technology, and water management.

Approach	*Definition*	*Operation*
Autonomous	Responses that can be taken by farmers and communities independently of institutional policy, based on a set of technology and management options available under current climate	• Crop calendar shifts (planting, input schedules, harvesting) • Cultivar changes • Crop-mix changes
Planned	Responses that require concerted action from local, regional and or national policy	• Land-use incentives • Irrigation infrastructure • Water pricing • Germplasm development programs

Table 1. Adaptation approaches to climate impacts on agriculture

In terms of the multiple factors impinging on agriculture, however, system responses to socio-economic, institutional, political or cultural pressures may outweigh response to climate change alone in driving the evolution of agricultural systems. The *adaptive capacity* of a system in the context of climate change can be viewed as the full set of system skills — i.e., technical solutions available to farmers in order to respond to climate stresses — as determined by the socio-economic and cultural settings, plus institutional and policy contexts, prevalent in the region of interest.

Current agronomic research confirms that at the field level crops would respond positively to elevated CO_2 in the absence of climate change,[xx] while the associated impacts of high temperatures, altered patterns of precipitation and possibly increased frequency of extreme events (such as drought and floods) are likely to require a range of adaptation responses, some of which are listed in Table 2.

Agricultural impacts	*Adaptation response*
Biomass increase under elevated CO_2	Cultivar selection and breeding to maximize yield
Acceleration of maturity due to higher temperature	Cultivar selection and breeding of slower-maturing types
Heat stress during flowering and reproduction	Early planting of spring crops
Crop losses due to increased droughts and floods	Changes in crop mixtures and rotations; warning systems; insurance
Increased pest damage	Improved management; increased pesticide use; biotechnology

Table 2. Key agronomic impacts and responses

9) MITIGATION REDUCES RISK

Agriculture has an important role to play in mitigation of climate change. *Mitigation* is defined as intervention aimed at reducing the severity of climate change by reducing the atmospheric concentration of greenhouse gases (GHGs), either by reducing GHG emissions or by enhancing sinks for GHG. The agricultural sector can contribute to climate change mitigation in several major ways.

Carbon Sequestration

Of the 150 gigatons of carbon (GTC) that were lost in the last century due to land conversion to agriculture and subsequent production, about two thirds were lost due to deforestation and one third, roughly 50 GTC, due to cultivation of current agricultural soils and exports as food products.[xxi] The latter figure thus represents the maximum theoretical amount of carbon that could be restored to agricultural soils. In practice, however, as long as 40 to 50 percent of total above-ground grain or fruit production is exported as food to non-agricultural areas, the actual carbon amount that can be restored in agricultural soils is much lower.

Efforts to improve soil quality and raise soil organic carbon (SOC) levels can be grouped into two sets of practices: *crop management* and *conservation tillage*. Both practices evolved as means to enhance sustainability and resilience of agricultural systems, rather than with SOC sequestration in mind. They include so-called "best practice" agricultural techniques, such as use of cover crops and/or nitrogen fixers in rotation cycles, judicious use of fertilizers and organic amendments, soil water management improvements to irrigation and drainage, and improved varieties with high biomass production.

By combining this information with current and future agricultural land use projections, including levels of technology projected by IPCC and FAO,[xxii] we can make a first-order estimate of total future contributions to soil carbon storage from agricultural management of existing agricultural and marginal lands. Over the next 40 years, best practice and conservation tillage alone could store about 8 GTC in agricultural soils.[xxiii] Larger amounts could be sequestered over the same period by increasing carbon inputs into land, for instance by establishing agro-forestry practices in marginal lands (estimated at 20 GTC) or by conversion of excess agricultural land to grassland (about 3 GTC). The total gain from multiple mitigation practices applied to existing agricultural land thus would be roughly 10 GTC (and up to 30 GTC with the inclusion of marginal land conversion for agro-forestry), an amount lower than the 50 GTC lost historically (see *Table 3*).

> *Current climate trends and extreme weather events may be directly and indirectly contributing to increased pest damage.*

Sector	*Total GTC Sequestered*
“Best practice” crop management	8
Agro-forestry improvements	1.6
Cropland conversion to agro-forestry	19.5
Cropland conversion to grassland	2.4
Total arable land	***31.5***

Table 3. Estimated carbon sequestration over the next 40 years, as a function of land use management of existing cultivated and marginal land. Data elaborated from regional and temporal data in LULUCF, IPCC 2000 (Rosenzweig and Tubiello 2007).

An important caveat is that the direct gains of carbon sequestration in reduced tillage systems are limited in time, typically lasting 20 to 40 years. Another caveat is that in the implementation of best practices and reduced-tillage agriculture as a means to enhance SOC sequestration, the carbon emitted from the manufacture and use of additional agricultural inputs may negate all or part of the increased carbon sequestered by soils.[xxiv] Under current practices, the fossil fuel that powers the machinery to sow, irrigate, harvest, and dry crops worldwide, as well as to manufacture and apply fertilizers, is already responsible for atmospheric emissions of about 150-200 megatons of carbon per year (MTC yr^{-1}). Given that total cropland covers about 1.5 gigahectares (Gha) of land globally, this figure corresponds to a world average emission rate of 100 - 130 kilograms of carbon per hectare per year (kg C ha^{-1} yr^{-1}). Efforts to reduce fossil fuel burning to power agricultural activities will contribute to GHG mitigation as well, on a continuing basis.

Biofuels

Agriculture may help to mitigate anthropogenic greenhouse emissions through the production of biofuels. If available marginal land were used for energy crops, the IPCC projects significant displacement of fossil fuels, globally up to 3-4 GTC yr^{-1} of reduced emissions by mid-century through conversion of ~200 megahectares (M ha) of marginal land to biofuel production.[xxv] However, increased biofuel production may result in potential competition with food production, increased pollution from fertilizers and pesticides, and further loss of biodiversity. Biofuels derived from low-input, high-diversity mixtures of native grassland perennials can provide more usable energy, greater greenhouse gas reduction, and less agrichemical pollution per hectare than corn grain ethanol or soybean biodiesel.[xxvi] The higher net energy results arise because perennial grasses require lower energy inputs and produce higher bioenergy yield. Furthermore, all aboveground biomass of the grasses can be converted to energy, rather than just the seed of either corn or soybean. These perennial grasses also sequester carbon at significant rates.[xxvii]

Other Greenhouse Gases

Because of the greater global warming potential of CH_4 (21) and N_2O (310) compared to CO_2 (1), reductions of non-CO_2 greenhouse gas emissions from agriculture can be quite significant and achieved via the development of more efficient rice (for methane) and livestock production systems (for both methane and nitrous-dioxide). In intensive agricultural systems with crops and livestock production, direct CO_2 emissions are predominantly connected to field crop production and are typically in the range of 150-200 kilograms of carbon per hectare per year (kg C ha^{-1} yr^{-1}).[xxviii] Recent full greenhouse gas analyses of different farm systems in Europe showed that such CO_2

emissions represent only 10 to 15 percent of the farm total, with emissions of methane contributing 25 to 30 percent and emissions of N_2O accounting for as much as 60 percent of total CO_2-equivalent greenhouse gas emissions from farm activities. The N2O contribution arises from substantial N volatilization from fertilized fields and animal waste, but it is also a consequence of its very high global warming potential.

In Europe, methane emissions are linked primarily to cattle digestive pathways; its contribution also dominates that of CO_2, due in part to methane's high global warming potential. Mitigation measures for methane production in livestock include improved feed and nutrition regimes as well as recovery of bio-gas for on-farm energy production. Effective reduction of N_2O emissions is far more difficult, given the largely heterogeneous nature of emissions in space and time and thus the difficulty of timing fertilizer applications and/or manure management. Large uncertainties in emission factors also complicate the assessment of efficient N_2O-reduction strategies. Current techniques focus on reduction of absolute amounts of fertilizer N applied to fields, as well as on livestock feeding regimes that reduce animal excreta.

10) CLIMATE CHANGE IS HERE

The final lesson is that climate change is no longer in the future; it is happening now. Agricultural effects already are being documented of the warming that is occurring in many regions of the world (*Fig. 7*). For example, Chmielewski et al. (2004) found that for the period of 1961-1990 the average annual air temperature increased by 0.36 C per decade ($P<0.01$) in Germany, resulting in a 1.4 C increase in temperature over the last 40 years. As a result of this temperature change, over the same time period the beginning of the growing season has advanced 2.3 days per decade ($P<0.10$). The beginning of stem elongation in winter rye advanced 2.9 days per decade ($P<0.01$); the beginning of cherry tree blossom advanced 2 days per decade ($P<0.05$); and the beginning of apple tree blossom advanced 2.2 days per decade ($P<0.05$). All phenophases were well-correlated to the average air temperatures.

Rising temperatures also may be affecting yields in tropical regions. Peng et al. (2004) analyzed weather data from the International Rice Research Institute (IRRI) Farm in the Philippines from 1979 to 2002. They found that mean minimum temperature rose by 1.32 C in the dry season and by 0.79 C in the wet season. Mean radiation also rose during the same period. The authors concluded that rice grain yield declined by about 15 percent for each one-degree increase in growing-season mean temperature. Because there was no relationship between crop growth duration and minimum temperature, this effect was not associated with a change in growth duration.

> *Farmers have dealt with climatic fluctuations since the advent of agriculture. Improving strategies for present-day droughts, floods, and heat waves is an important way to prepare for climate change.*

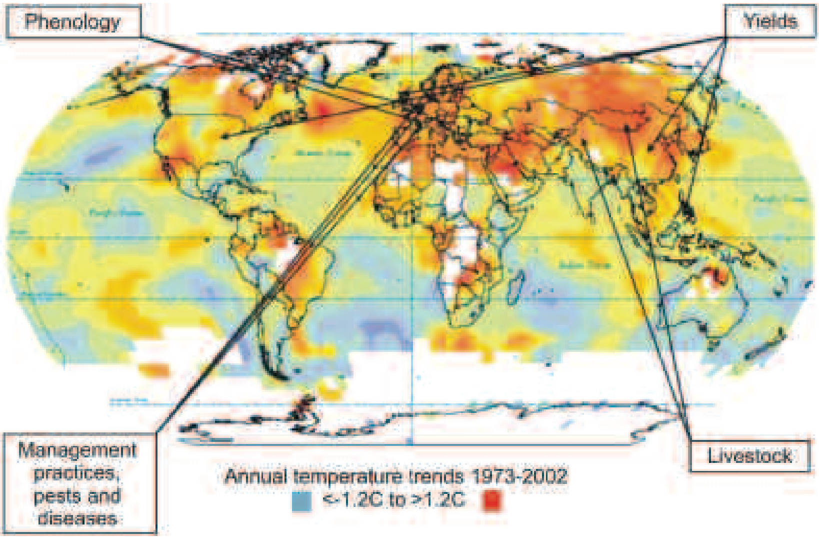


Figure 7: Locations of observed changes in agriculture in response to climate changes.

CONCLUSIONS

These “lessons learned” show that climate change brings both challenges and opportunities to agriculture. Farmers and researchers are being called on to simultaneously adapt to and mitigate climate change through myriad activities involving management practices, crop breeding and new production systems. Some of these can be mutually reinforcing, especially in view of the projected increased climate variability under climate change. This is because most mitigation techniques currently considered in agriculture, including reduced tillage, were originally designed as “best practice” management strategies aimed at enhancing the long-term stability and resilience of cropping systems in the face of climate variability or of increased cultivation intensity.

By increasing the ability of soils to hold soil moisture and to better withstand erosion, and by enriching ecosystem biodiversity through the establishment of more diversified cropping systems, many mitigation techniques implemented locally for soil carbon sequestration also may help cropping systems to better withstand droughts and/or floods, both of which are projected to increase in frequency and severity in future warmer climates. As always, agriculture will play a leading role in responding to both the challenges and opportunities presented by a dynamic environment.

> *Best practices and reduced-tillage agriculture are means to enhance soil carbon sequestration, but carbon emissions from manufacture and use of inputs need to be taken into account as well.*

Endnotes

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DR. JOHN PESEK, IOWA STATE UNIVERSITY EMERITUS PROFESSOR OF AGRONOMY

Dr. John Pesek, Iowa State University Emeritus Professor of Agronomy, has had a long and distinguished professional career. He has made nationally recognized research contributions in agronomy in the areas of soil fertility, crop production, and the economics of soil fertilizer use. His work has led scientists to a better understanding of the effects of management practices on the environment and their combined influence on yields.

In the 1980s, Dr. Pesek chaired a National Research Council committee under the National Academy of Sciences Board of Agriculture that was directed to study alternative methods of soil management. The book resulting from their case studies, *Alternative Agriculture,* was a ground-breaking report that documented how farming systems that used lesser amounts of pesticides, fertilizers, antibiotics, and fuel can be productive and profitable. Its publication generated worldwide attention and brought Dr. Pesek to Washington, D.C., to testify before the Joint Economic Committee of the House and Senate.

Dr. Pesek has been named a fellow of the American Society of Agronomy, the Soil Science Society of America, Crop Science Society of America, the Iowa Academy of Science, and the American Association for the Advancement of Science. He has served as president of both the American Society of Agronomy and the Soil Science Society of America and he helped establish the nation's first National Soil Tilth Center.

Dr. Pesek has authored or co-authored more than 75 publications and has been active in international programs in Brazil, Columbia, Croatia, Czech Republic, Egypt, Lithuania, Mexico, Morocco, Poland, Republic of South Africa, Russia, Tunisia, Ukraine, and Uruguay. He was named a Charles F. Curtiss Distinguished Professor of Agriculture in 1981 and received the Agronomic Service Award in 1989.

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The Henry A. Wallace Endowed Chair for Sustainable Agriculture was established to promote the time-honored philosophical and practical ideas of H.A. Wallace — specifically his commitment to the wise use of science and public policy for the protection and conservation of natural resources and farmland, for the enhancement of vibrant and enduring rural communities, and for the alleviation of worldwide poverty and hunger.

Henry A. Wallace graduated from Iowa State College in 1910, and with his boundless curiosity, energy and scientific prowess, became one of the first developers of hybrid seed corn. He founded the Hi-Bred Corn Company in 1926 which later became Pioneer Hi-Bred. He was appointed Secretary of Agriculture in 1933 by Franklin Roosevelt and later served as his Vice-President. His motto was “Peace, Prosperity, and Equality.”

Each year the Wallace Chair hosts the John Pesek Colloquium in Sustainable Agriculture to provide a format for constructive dialog on critical agricultural issues. Further information about past colloquia as well as other activities of the Wallace Chair can be found at www.wallacechair.iastate.edu or by calling 515-294-6061.

ENDOWMENT FUND ESTABLISHED FOR PESEK COLLOQUIUM

The Wallace Chair has established an endowed fund with the ISU Foundation for the John Pesek Colloquium on Sustainable Agriculture. The endowment establishes a permanent funding base for this annual event which provides a forum for dialogue on critical issues in sustainable agriculture. The first contributor to that endowment was the ISU Department of Agronomy; that contribution was matched by an anonymous donor and has also been supplemented by the Wallace Chair. If you or your business, non-profit or agency would like to contribute to the John Pesek Colloquium Endowment Fund, please contact Rich Bundy of the ISU Foundation at bundy@iastate.edu or 515-294-9088.

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This lecture was made possible in part by the generosity of F. Wendell Miller, who left his entire estate jointly to Iowa State University and the University of Iowa. Mr. Miller, who died in 1995 at age 97, was born in Altoona, Illinois, grew up in Rockwell City, graduated from Grinnell College and Harvard Law School and practiced law in Des Moines and Chicago before returning to Rockwell City to manage his family's farm holdings and to practice law. His will helped to establish the F. Wendell Miller Trust, the annual earnings on which, in part, helped to support this activity.

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