FY 2009 Annual Report
National Program 204—Global Change

Introduction

Global change refers to large-scale changes of the Earth's biological, geological, hydrological, and atmospheric systems, whether of natural or human origin. Global change is increasingly a topic of concern for agricultural managers and strategic decision makers because changes are occurring faster than originally expected by the scientific community.

The ARS Global Change National Program contains four components: Carbon Cycle and Carbon Storage, Trace Gases, Agricultural Ecosystem Impacts, and Changes in Weather and the Water Cycle at Farm, Ranch, and Regional Scales. Over 40 ARS laboratories are conducting research supporting the Global Change National Program, focusing on: 1) understanding the impacts of global change on agricultural systems; 2) developing management practices for agriculture to adapt and/or mitigate the impacts of change; and 3) developing strategies to mitigate the impact of agricultural practices that may contribute to global climate change. A predictive understanding of the effects of global change on agriculture is needed as a basis for development of technologies and policies that will enable farm and ranch adaptation to global change impacts and mitigate factors affecting climate change. The approach for this requires experimental hypothesis testing, development of simulation models and management practices to manage risks associated with anticipated change.

Component 1: Carbon Cycle and Carbon Storage

Research conducted under the Carbon Cycle and Carbon Storage component seeks to identify the best management practices for storing carbon from atmospheric carbon dioxide (CO_2) in soil and plant systems. Increasing carbon sequestration on croplands and grazing lands can reduce increases of potential carbon dioxide concentrations in the atmosphere, helping to lessen global warming. Increasing carbon in soil also has numerous production, conservation, and environmental benefits. Increasing carbon content improves the overall quality of a soil by improving its physical structure and retention of water, nutrients and agricultural chemicals. Doing so reduces both wind erosion and the hydrologic export of sediment and agricultural chemicals thereby improving both air and water quality. Interest in this topic is increasing because of the potential for land managers to receive carbon credits or payments for management practices that increase the amount of carbon stored in soil.

Selected Accomplishments

Rapid measurement of soil carbon using infrared spectroscopy. Our ability to accurately measure soil carbon stocks in agricultural landscapes is limited by accurate analytical methods that can rapidly measure soil carbon content. Both near infrared (NIR) and mid infrared (MIR) spectroscopy hold promise; comparison of these methods is needed to optimize measurement technologies. A study by researchers in Beltsville, MD showed that diffuse reflectance infrared

Fourier transform spectroscopy (DRIFTS) is superior to near-infrared diffuse reflectance spectroscopy for the analysis of carbon in dried soil samples. This research also demonstrated that mid-infrared outperforms remote sensing methods, but requires samples to be dried and analyzed in a proximate mode. Rapid and economical methods for soil carbon are feasible and are important for use in soil quality management and carbon credit trading programs.

New, non-destructive method for measuring carbon in soil. Interest in carbon as a tradable commodity has landowners managing plant systems to enhance soil carbon storage. This has prompted the need for rapid, non-destructive methods for measuring changes in soil carbon content. ARS researchers at Auburn, AL developed a new method for measuring soil carbon using inelastic neutron scattering technology. This nondestructive method can be used in stationary or continuous-scanning modes of operation. Initial findings demonstrated that the method was feasible, and gave reproducible results with a detection limit between 0.5 and 1% carbon by weight.

Model for calculating greenhouse gas emissions from dairy farms. Although livestock operations such as dairy farms are recognized sources of greenhouse gas emissions, little is known about the net emissions from farms. A model, DairyGHG, was developed and made available through the internet by ARS researchers in University Park, PA that provides a simple tool for estimating greenhouse gas emissions and the carbon footprint of dairy farming systems. Since its release in fall 2008, 150 copies have been distributed. Most are used throughout the United States with about a third going to 30 other countries. DairyGHG provides a useful tool for producers, consultants of producers, educators, government agencies and others to rapidly evaluate greenhouse gas emissions from dairy farms and the effectiveness of management strategies used to reduce these emissions.

Mapping soil carbon using airborne hyperspectral data. Rapid methods of measuring soil carbon using near-infrared (NIR) spectroscopy have gained interest, and data mining approaches using partial least squares regression have performed well for extracting carbon information from proximally collected soil spectra. Because of spatial information found in the individual image pixels, hyperspectral remote sensing of soil carbon using either air or space borne platforms, holds even greater promise relative to proximal sensing methods but it is uncertain that sufficient information is present in hyperspectral data remote sensing images for data mining soil carbon content. ARS researchers in Beltsville, MD demonstrated that individual spectra for pixels in an image produced unstable soil carbon predictions but that averaging the spectra for the nearest nine pixels stabilized predictions and produced useful maps of soil carbon. By this approach, accurate maps showing spatial distribution of soil carbon in agricultural landscapes can now be produced using remotely sensed data, leading to a greater understanding of carbon dynamics in agricultural systems.

Mapping carbon assimilation over landscapes using thermal remote sensing. Robust yet simple remote sensing methodologies for mapping instantaneous land surface fluxes of water, energy and CO2 exchange, add significant value to large-scale ground-based monitoring networks, making it possible to scale up tower flux observations to address questions of regional carbon cycling and water availability. ARS scientists at Beltsville, MD developed an analytical, light-use efficiency (LUE) based model of canopy resistance driven primarily by thermal remote sensing inputs. The thermal remote sensing data provide valuable diagnostic information about sub-surface moisture status, obviating the need for precipitation input data and prognostic modeling of the soil water balance. This landscape model was partially parameterized with multi-season and multi-year Landsat thermal band imagery, and flux estimates were validated. Additionally, a technique for optimizing the nominal LUE input to the model using remotely sensed retrievals of leaf chlorophyll content (physiologically related to canopy light-use efficiency) based on shortwave-band data was tested. Incorporation of retrieved LUE maps into the energy/carbon flux model significantly improved seasonal estimates of evapotranspiration and carbon assimilation, indicating potential synergistic use for shortwave and thermal band imagery in modeling regional fluxes.

Component 2: Agricultural Ecosystems

Changes of precipitation and temperature patterns represent the most apparent evidence of global climate change. These changes are the result of increasing concentrations of greenhouse gases that affect the energy balance of the Earth. Not as well publicized is the stimulation of plant growth with increased yields for some crops, by increased atmospheric carbon dioxide concentrations. Although increased crop yields may be considered a benefit, the same effect for invasive weeds is less welcome. Coupled changes of atmospheric carbon dioxide, precipitation frequency of occurrence, and intensity of outbreaks of weeds, pests and pathogens can alter the geographic ranges of many species as well as the viability and integrity of agricultural ecosystems.

The focus of research in this component of the Global Change National Program is to provide the knowledge necessary to assess the impacts of global change on agricultural ecosystems, and to develop successful strategies and practices to adapt to change and/or mitigate its impact, with the overall goal of maintaining and improving agricultural productivity.

Selected Accomplishments

First test of the resource-enemy release hypothesis. Reducing the tremendous economic and environmental costs of invasive weeds requires a better understanding why they are so successful. Several years ago, ARS scientists in Fort Collins, CO, developed a novel hypothesis, originally published in Science, suggesting a mechanistic link between two of the most widely accepted causes of weed invasion: high resource availability and the release from natural enemies. This hypothesis was tested for the first time, producing strong evidence that the predicted patterns in fact occur in nature. Comparing enemy release among 243 European plant species that have been introduced to the U.S. revealed that fast-growing plant species adapted to wet, nitrogen-rich environments escaped significantly more pathogen species than slow-growing plant species adapted to dry, nitrogen-poor environments. These results suggest that global changes that increase plant resource availability, such as increases in atmospheric CO2 and nitrogen deposition, will favor exotic over native species. Conversely, management that reduces resource availability, such as land restoration or vegetation buffers around wetlands, may be key to controlling not just weedy species, but exotic invasive species in particular.

Greater plant diversity stabilizes forage production on grasslands. Plants are the foundation of all life on Earth, providing food that is consumed either directly or indirectly by humans and animals. If we are to support an ever-expanding human population, we must better understand how to maximize plant growth while reducing year-to-year variability in plant production. Together with university collaborators, ARS scientists at the Grassland, Soil & Water Research Laboratory transplanted grassland plants in various combinations into field plots in central Texas to determine whether the amount of plant production and its variability among years depended on the number of plant species in each plot. The amount of plant material produced each year was greater on average and varied less among the 8 years of measurements in plots planted with more species, partly because species responded differently to year-to-year changes in weather. Years during which some species grew poorly were years during which other species grew well. Results indicate that we may both increase the amount of plant material produced and reduce variability in plant production among years by increasing the number of plant species present in grasslands that currently contain few species.

Flooding changes soil microbial community. Flooding can alter soil microbiology and affect organisms that recycle organic materials. In collaboration with the University of Missouri-Columbia, ARS scientists at Pullman, WA are examining the response of different soil microorganisms found in the soil to varying durations of flooding. Flooding changed the composition of the soil biological community. Flooding can restrict the amount of oxygen that some soil organisms require; these organisms decreased when exposed to stagnant water. In contrast, intermittent flooding caused an increase in the populations of all soil organisms. This investigation of soil biological communities will not only help land managers determine the impact of flooding on soil organisms, but will also lead to better post-flood management practices.

Woody plants like trees and shrubs invading historical grasslands in the last century modify soil properties. The Grassland Soil and Water Research Laboratory in Temple, Texas, conducted a 21-year study to determine if tree invasion modified soil properties. Study sites were established in grasslands with a range of mesquite tree densities. After 21 years, the soils with mesquite and other trees had greater soil carbon and nitrogen contents than the original soils. A site maintained as grass had carbon and N contents similar to sites measured 21 years earlier. Central Texas soils with mesquite stored more carbon and nitrogen than grasslands, which may help slow global climate change.

Seed yields among bean varieties vary in response to elevated carbon dioxide. To identify traits useful for adapting crops to rising atmospheric carbon dioxide, the response of seed yield to higher levels of carbon dioxide in four different bean varieties was determined in field trials. The variety with highest yield at the current carbon dioxide level did not have the best yield when carbon dioxide levels were increased. The increase in pod numbers at elevated carbon dioxide was a good predictor of varieties with high yield at high carbon dioxide concentrations. This information will be of use to scientists when adapting crops to take advantage of rising atmospheric carbon dioxide to increase production.

Component 3: Trace Gases

In addition to carbon dioxide, agriculture systems emit other greenhouse gases to the atmosphere. These trace gases include nitrous oxide and methane, both of which have greenhouse warming potentials (GWP) greater than carbon dioxide. The mission of this research component is to develop management practices to reduce trace gas emissions from cropping and animal production systems.

Selected Accomplishments

U.S. Agriculture and Forestry Greenhouse Gas Inventory Report: Increased interest in climate change has highlighted the need for more accurate methods to quantify GHG emissions from the US agricultural sector. Specific-Cooperative Agreement (#58-5402-4-387) was established with Colorado State University to provide access to computer and programmer capabilities for developing the U.S. Agriculture and Forestry Greenhouse Gas Inventory Report. This inventory included soil GHG emission estimates using complex agroecosystem models and the most rigorous uncertainty analyses performed to date. GHG emission analyses were published in the 2nd edition of the U.S. Agriculture and Forestry Greenhouse Gas Inventory, published by the USDA Office of the Chief Economist, and the Inventory of U.S. Greenhouse Gas Emissions and Sinks published by EPA, and reported to The United Nations Framework Convention on Climate Change (UNFCCC). Methods and results from the inventory have been included in The U.S. Climate Change Science Program report "Synthesis and Assessment Product 4.3 (SAP 4.3): The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States," presented to Congress in 2008, The 2008 National Agricultural Research, Extension, Education and Economics Advisory Board Meeting, the 2009 National Dairy Leaders Conference, and to the 2009 Bonn Climate Change Conference. The website hosting the report has received several hundred visits per month (http://www.usda.gov/oce/global_change/gg_inventory.htm).

Tillage and nitrogen fertilizer source influence nitrous oxide emissions. Crop management practices can influence the amount of nitrous oxide (a greenhouse gas) emitted from irrigated cropping systems. Nitrous oxide (N2O) emissions monitored during the 2007 and 2008 growing seasons showed that a no-till continuous corn system had less N2O emissions than a conventional-till continuous corn system. Nitrous oxide emissions were further reduced in the no-till system by up to 50% when enhanced efficiency nitrogen fertilizers (controlled release and stabilized nitrogen sources) replaced urea nitrogen fertilizer commonly used by farmers. This work by ARS researchers in Ft. Collins, CO, provides new knowledge that can be used to develop crop management practices to reduce N2O emissions in irrigated cropping systems of the western U.S.

Fertilizer application timing influences greenhouse gas fluxes over a growing season. The effects of crop fertilizer applications on greenhouse gas fluxes should occur during and shortly after application, yet data indicating how application timing affects both greenhouse gas fluxes and crop yields during a growing season are lacking. ARS researchers at Mandan, ND evaluated how fertilization strategy might impact crop yield and emissions of methane, nitrous oxide, and carbon dioxide within a dryland cropping system. Flux measurements taken over a five month period revealed that the timing of fertilization affected greenhouse gas emissions but not grain production, suggesting that fertilizer timing could be used to reduce the environmental impacts of dryland cropping systems without sacrificing yield.

Effect of a nitrification inhibitor on nitrous oxide emissions. Nitrous oxide emissions are influenced by the timing of fertilizer application, the type of N fertilizer, and weather conditions. ARS researchers in Ames, IA evaluated the influence of the nitrification inhibitor, nitrapyrin, on N2O emissions from a chisel plow corn system with fall-applied anhydrous ammonia. Based on soil nitrate (NO3) and ammonium (NH4) analyses, nitrapyrin addition delayed nitrification. During one year, nitrapyrin reduced late fall/early spring N2O emission, although annual emissions were not significantly reduced. Significantly higher corn grain yields were observed in the nitrapyrin treatment in both years. Using the Intergovernmental Panel on Climate Change (IPCC) default emission factor for direct N2O emission from fertilizer application to soil, it was calculated that a small reduction in N2O emissions (0.07 to 0.22 kg N2O-N/ha) would result from the higher corn grain-N uptake in the presence of nitrapyrin. This information contributes to efforts to manage greenhouse gas emissions from agricultural sources, while maintaining or enhancing production.

Component 4: Changes in Weather and the Water Cycle at Farm, Ranch, and Regional Scales.

General circulation models (GCMs) used to simulate climate responses to rising greenhouse gas concentrations suggest that changes of temperature and precipitation will vary regionally. Some GCMs also predict that weather variability will increase with global warming, introducing yet more uncertainty and risk into agricultural production. Droughts, floods, storms, and periods of excessive heat or cold may occur more frequently, with impacts on agricultural operations, alterations to agricultural water supplies, and increased crop insurance costs and disaster payments. Much of the research required to address these issues involves the projection of climate and weather changes through models at many different spatial scales. This requires special attention to improve the predictive capability that will enable decision makers to manage associated risks, with minimum adverse impacts on U.S. agriculture and economy.

The mission for this research component is to develop management strategies for farm, ranch, rural community, and natural resource decision-makers to conserve, store, and allocate water resources to address the many diverse demands and impacts on the Nation's rural water resources that may be caused by global change. Research on other global change-related drought issues are conducted and reported as part of the Water Availability and Watershed Management NP211 program.

Selected Accomplishments

Assimilation of remotely-sensed soil moisture predictions enhances land surface modeling. Over certain continental areas, numerical weather forecasts can be enhanced via accurate monitoring of surface soil moisture conditions that impact circulation within the lower atmosphere. This type of monitoring is typically done via simple water balance calculations based on observed rainfall, and predictions of the amount of rainfall which runs off into streams and/or evaporates. Unfortunately, these often highly inaccurate predictions cannot be trusted to provide reliable surface conditions for weather forecasting models. Recently, research by ARS in Beltsville, MD has shown that estimates of soil moisture availability obtained from satellite sensors can be used to improve soil moisture estimates obtained from water balance modeling. In particular, research has demonstrated how the assimilation of remotely-sensed soil moisture retrievals can improve surface water balance calculations in three key scenarios: 1) areas exhibiting high water tables, 2) areas with significant crop irrigation and 3) areas in which high-quality rainfall observations cannot be obtained. These circumstances are common in agricultural landscapes worldwide. The research represents an important advancement in our ability to monitor water cycle variations in such areas.

Synthesis and Integration of Research Findings

Adaptation to a changing environment, and mitigation of the changes or their causes, are emerging as priorities for USDA agencies engaged in climate change research and policy making. The altered conditions under which agricultural production must proceed, with emphasis on implications for management practices that producers must adopt, and the potential effects on soil, water and air resources, are major concerns. Bioenergy and carbon trading are seen as opportunities for agriculture to both reduce GHG emissions and strengthen rural economies. Market-based incentives such as integration of carbon sequestration into Conservation Reserve Programs, are considered promising mechanisms for developing carbon trading programs. However, direct quantifications of sequestered carbon, and the effectiveness of management procedures on GHG emissions, are critical needs.

With climate change accepted as a reality, the discussion in agricultural circles is turning to address questions of how best to adapt agriculture to climate change. An international group of climate change experts, including several ARS scientists, developed an approach for carrying out a series of highly integrated research experiments for optimizing agriculture's response to climate change. This generation of experiments would focus on adapting crops to the future environment, specifically to increased concentrations of atmospheric carbon dioxide, using the tools of molecular genetics. However, this research program would be integrated with efforts exploring the responses of crop species to warming and drought. This blueprint for feeding the world in the face of climate change will serve as an important guide to policy makers and scientists.

ARS Global Change Research Program Cycle and Future Status

ARS National Program Research is conducted on five-year cycles. The Global Change National Program entered the final year of the current cycle during 2007. An accomplishment report was assembled for the Program at this time and assessed by an external review panel as per requirements set forth by the ARS Office of Scientific Quality Review (OSQR). This cumulative report was posted as the Global Change National Program progress report for 2007 activities. During May 2008, a workshop was convened in Denver, CO to set the direction for the next cycle of ARS Global Change research. Part of the activities for the Program since the workshop has been working to integrate the program activities with the newly-forming Climate Change, Soils and Emissions National Program (NP212. Research progress for global change topics for 2010 and beyond will be reported as part of this Program (NP212).