# FY 2008 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 as the impacts of change are being documented as 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. Research is focused 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 global change effects 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 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 the rate of increase of the carbon dioxide concentration of the atmosphere and help lessen the potential for global warming and other effects of climate change caused by its greenhouse effect. Sequestering and storing carbon in soil also has numerous production, conservation, and environmental benefits. Soils with greater carbon content have benefits for the overall quality of soil (through improved physical structure and retention of water, nutrients, and agricultural chemicals), water (through lessened inputs of eroded sediments and agricultural chemicals), and air (through lessened wind erosion). Interest in this topic is increasing because of the possibility for farmers, foresters, and other land mangers to receive carbon credits or payments for using management practices that could increase the amount of carbon stored in soil.

### Selected Accomplishments

On-going research projects being conducted under the ARS Global Change National Program Carbon and Carbon Cycle Component are increasing our knowledge base on soil carbon storage and sequestration, in turn enabling predictions of how carbon may be stored under different environmental and management conditions, thus leading to science-based decision support for land managers and policy makers. The basis for carbon credit trading will expand as the knowledge base grows and as this knowledge is used in cases similar to the NDFU example. Over 60 ARS scientists at 30 locations across the United States are conducting a coordinated project called Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) to provide information on soil carbon status, net greenhouse gas emissions, and environmental benefits from current and experimental agricultural practices. The GRACEnet project has identified four products, which represent an integration of its objectives:

**Product 1.** A national database of greenhouse gas (GHG) flux and carbon (C) storage. All relevant project data from every network unit are entered into a common data base for use by project scientists and potential users.

**Product 2.** Regional and national guidelines of management practices (in the form of a decision aid) that reduce GHG intensity (emissions per unit…..what, in this case?), applicable for use by producers, federal and state agencies, and C brokers. These guidelines will be produced in consultation with the USDA Global Change office and others to insure that they are in a format to meet public needs.

**Product 3.** Development and evaluation of computer models created to assess management effects on net GHG emission. GRACEnet data will be used to evaluate the adequacy of Intergovernmental Panel on Climate Change (IPCC) emission factors and models such as CQESTR, Century, Daycent, and COMET.

**Product 4.** Summary papers for action agencies and policy makers, based on the current state of knowledge. The information generated by GRACEnet will be used to produce synthesis documents for action agencies such as NRCS, the USDA Global Change Program Office and other policy makers. These documents will address the feasibility of adopting the practices studied in GRACEnet and the amount of C sequestration and GHG reduction that is likely to result from their adoption as well as other issues of concern to them.

The GRACEnet work plan, milestones and products were finalized during a planning workshop held at Fort Collins during October, 2005. This network of research locations works together to better characterize management practices that can limit net greenhouse gas emissions from agriculture, as well as provide other possible environmental benefits such as limiting nitrogen losses to water and air. Information from this network approach will benefit policy makers, farmers, and the nation at-large by helping establish agricultural systems with lowered impact on the environment, increased capability of offsetting GHG emissions in non-agricultural systems, and support of market-based environmental incentives such as carbon credit trading. This research also contributes directly to the ARS Global Change Program National Program Trace Gases Component and to the Soil Resource Management National Program (NP-202) Soil Carbon Component.

ARS GRACEnet researchers produced the U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005, published by the Global Change Program Office, Office of the Chief Economist, U.S. Department of Agriculture. (Technical Bulletin No. 1921. 159 pp. printing by the Government Printing Office). This 112 page report and the included appendices inventories the emissions of the three most important long-lived greenhouse gases (GHG) that have increased measurably over the past two centuries. Carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) concentrations in the atmosphere have increased by approximately 35%, 155%, and 18%, respectively, since 1750. Within the U.S., agriculture accounted for close to 7% of total GHG emissions (7260 Tg $CO_2$ eq.) during 2005. Livestock, poultry, and crop production contributed a total of 481 Tg CO2 eq. to the atmosphere during 2005. This total includes an offset from agricultural soil carbon sequestration of roughly 32 Tg $CO_2$ equivalents. The primary agricultural sources are N2O emissions from cropped and grazed soils (263 Tg $CO_2$ eq.), $CH_4$ emissions from enteric fermentation (112 Tg $CO_2$ eq.), and $CH_4$ emissions from managed livestock waste (41 Tg $CO_2$ eq.). Forests in the United States contributed a net reduction in atmospheric GHG of approximately 787 Tg $CO_2$ eq. in 2005, which offset total U.S. GHG emissions by approximately 11%. The U.S. agricultural sector (including GHG sources for crop, poultry, and livestock production and GHG sinks for forests and wood products) as a whole was estimated to be a net sink of 306 Tg $CO_2$ eq. during 2005.

Research conducted under the Carbon and Carbon Cycling component of NP204 successfully predicted the spatial variation in soil organic carbon and crop yield with a process-based model. Computer simulation models can be useful tools to predict changes in crop yields and environmental consequences from soil management practices. However, these models need to be checked or validated against data from long-term field experiments in order to have confidence in model predictions and improve their usefulness. A collaboration among ARS scientists in Watkinsville, Georgia, and Auburn, Alabama; Auburn University researchers; USDA-Natural Resources Conservation Service experts in Temple, Texas; and Joint Global Change Research Institute personnel in College Park, Maryland, tested the performance of a highly technical environmental model (EPIC v. 3060) against five years of crop yield and soil data collected from a corn–cotton rotation in central Alabama. The cropping system had additional variables of dairy bedding manure and conventional and conservation tillage systems. The model accounted for 88% of the variation in corn grain and cotton lint yields during the five years. Model predictions varied appropriately with landscape characteristics. Predictions of soil organic carbon at the end of five years of the different management schemes were acceptably accurate, although distribution with depth and within various fractions of organic matter were not as accurate as desired. This research demonstrated that EPIC modeling has challenges to overcome, but could be an acceptable tool to predict yield, carbon sequestration, and other environmental consequences for the greater than 10 million acres of corn and cotton land in the southeastern USA.

Also notable is a finding showing that soil carbon sequestration in organic cropping systems can be greater than in no-till and conventional-till systems**.** Management of soil carbon maintains soil quality and helps reduce carbon dioxide in the atmosphere that contributes to climate change. Organic cropping systems were assumed to result in less carbon sequestration than no-till systems, despite relatively large carbon inputs to soil via animal and green manures, due to the large amount of tillage required for organic systems, which mixes oxygen into the soil and stimulates microbial conversion of organic carbon to $CO_2$. The net impact of low tillage and large carbon inputs on carbon sequestration compared to conventional practices, especially no till, were investigated at the long-term Beltsville Farming Systems Project by ARS researchers in Beltsville, MD. Carbon sequestration in 2-, 3-, and 6-year organic crop rotations was greater than in a conventional till system by 10 to 19%, and was greater than in a no-till system by 3 to

11%. Such information can support management decisions when there is a desire to balance organic production goals, tillage options, and carbon sequestration or net greenhouse gas emissions goals. These data also will be useful for C sequestration models, including models eventually used by NRCS to establish conservation payments to farmers.

**Component 2: Agricultural Ecosystems**

The most apparent evidence of global climate change has been changes of precipitation and temperature patterns. 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 by increased atmospheric carbon dioxide concentrations of plant growth and, for some crops, increased yield. Although increased yields may be considered a benefit, the same effect on invasive weeds is not so welcomed. Coupling changes of atmospheric carbon dioxide with changes of precipitation and temperature also may cause weeds, pests, and pathogens to be altered in geographic ranges, frequency of occurrence, and intensity of outbreaks, thus altering agricultural ecosystems.

The focus of research on 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 towards maintaining and improving agricultural productivity.

**Selected Accomplishments**

An understanding of the physiology of the impacts of changing climate factors is fundamental to the formulation of strategies to cope with deleterious effects of climate change and take advantage of opportunities for increasing yields and/or yield quality.

**Elevated atmospheric carbon dioxide and ozone concentrations alter leaf area index (LAI) through changes in phenology and leaf growth**. Although the effects of elevated $CO_2$ and $O_3$ on leaf expansion have been studied individually, few studies examine leaf expansion in more realistic simulations of future conditions, with simultaneously elevated $CO_2$ and $O_3$. This research examined leaf growth and expansion in soybean and aspen exposed to elevated [$CO_2$] and elevated [$O_3$] in a field setting to determine how growth parameters such as final leaf area, leaf number, and growth rate are altered by climate change. Leaves were larger upon unfolding in elevated $CO_2$ and smaller in elevated $O_{3,}$ which compounded over time to alter final leaf area, even though relative growth rates were similar. Furthermore, carbohydrate concentrations were altered in old but not young leaves, indicating that changes in leaf size result from whole-plant, not leaf-level, responses. These results, presented at three national and international meetings, suggest that leaf growth is altered by $CO_2$ and $O_3$ very early in growth, contrary to previous findings that only fully expanded, older leaves are sensitive to $O_3$.

**Weed invasions increase greenhouse gas emissions of rangeland soils.** Weeds appear to fare well under enhanced atmospheric $CO_2$ levels, and thus appear to offer an especially challenging impact on future agriculture. Rangelands are especially vulnerable as weed invasions can significantly alter rangeland ecosystem structure. Weed invasions are considered one of the highest priority problems facing ranchers and rangeland mangers, and new research suggests that weeds may enhance climate change as well. Soil emissions of two important greenhouse gases, carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$), plus soil carbon and N were monitored in adjacent pastures dominated by Wyoming big sage (*Artemisia tridentata ssp. Wyomingensis*) with and without cheatgrass (*Bromus tectorum*) infestations. The results indicated that soil release of $CO_2$ and $N_2O$, plus C mineralization and nitrification all responded more strongly to simulated precipitation events in areas of cheatgrass infestation compared to non-invaded areas where native grasses like western wheatgrass (*Pascopyrum smithii)* were more abundant. In addition to their negative impacts on forage quality and biodiversity, weed invasions may contribute to the release of greenhouse gases by terrestrial ecosystems.

## Component 3: Trace Gases

Agriculture systems emit greenhouse gases other than carbon dioxide to the atmosphere. These trace gases include nitrous oxide and methane, both of which together have greenhouse warming potential (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

The studies conducted by ARS scientists across the U.S. will develop a knowledge base on trace gas emissions from agriculture under different cropping and management systems. By knowing how these emissions are related to cropping systems and management practices, new cultivation strategies will be developed to lessen the emission of these gases while maintaining/improving agricultural productivity. A challenge associated with trace gases is obtaining a reliable measurement and thus, the development of measurement technologies is an important task associated with the trace gas research component.

**Development of improved method for analysis of errors in estimating chamber-based greenhouse gas flux estimates from agricultural soils**. Although chamber methods for measuring greenhouse gas fluxes from agricultural soils are widely used, it is well known that these methods are prone to potentially large errors resulting from the alteration of near-surface concentration gradients. In general, these errors result in an underestimation of the actual rate of gas transfer from soil to atmosphere. However, there is little information available for quantifying these errors. A numerical model was developed and theoretical analysis was performed, which can be used together with soil physical property data to quantify method-specific chamber-based measurement errors. Application of these error analysis tools will result in more accurate estimates of emissions of greenhouse gases including carbon dioxide and nitrous oxide from agricultural soils. In turn, this will result in improved national- and global-scale estimates of agricultural contributions to greenhouse gas emissions.

**Nitrogen source effects on $N_2O$ emissions from irrigated no-till (NT) continuous corn.** Strategies to reduce trace gas emissions from agricultural lands are a goal of the Trace Gas research component. During 2007, a study was initiated under irrigated, no-till continuous corn production to determine the effects of N source on $N_2O$ emissions. Research from 2005 and 2006 suggested that applying a polymer-coated urea would reduce $N_2O$ emissions from conservation tillage (CT) and NT corn fields. Several N sources were evaluated: urea ammonium nitrate (UAN), UAN plus AGROTAIN Plus®, dry granular urea, dry granular urea treated with AGROTAIN Plus®, polymer-coated urea (ESN®, 30 to 60 day release period), and polymer-coated urea (Duration Type III®, about 120 day release period). Fluxes of $CO_2$, $CH_4$ and $N_2O$ were measured one to three times per week from May through October. Preliminary results (May through July, 2007) show reduced $N_2O$ emissions from the polymer-coated urea and AGROTAIN Plus® treated N fertilizers. These preliminary results confirm that $N_2O$ emissions can be reduced by selecting certain N fertilizer sources.

**Agricultural greenhouse gas emissions and mitigation strategies examined**. Periodic synthesis of the scientific literature is conducted to maintain awareness of trace gas research conducted by the larger scientific community as well as that of the ARS Global Change Research community. Such efforts often provide information of use to scientists, producers and policy makers. Based on a literature synthesis, current agricultural contributions to greenhouse gas emissions and C sequestration were summarized, and strategies for how agriculture might lessen its burden on the greenhouse effect were proposed. Modification of agricultural management has the potential to shift agriculture from a net source of greenhouse gases to a net sink; thereby, agriculture could play a role in mitigating global climate change. This information may broaden the management and policy options that may be considered so that agriculture will help mitigate greenhouse gas emissions and lessen the risk of further global climate change.

## 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 indicate changes of temperature and precipitation that 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 projection of climate and weather changes through models at many different spatial scales, which requires special attention to improve the predictive capability that will enable decision makers to manage the associated risks with minimum adverse impacts on U.S. agriculture and economy.

The mission of the research for this 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 Resources Management NP201 program.

## Selected Accomplishments

Climate tools must be integrated into the day-to-day decision making of agricultural operations for agricultural to adapt to climate change. Decision support tools that incorporate global change-related elements (precipitation and temperature changes, enhanced atmospheric carbon dioxide, trace gas emission as a function of cropping system, etc.), and that address multiple aspects of farm and ranch operations are expected to be able to address the changing environment that agriculture of the future may experience.

**Improving satellite-based precipitation estimates using remotely sensed soil moisture and data assimilation.** Large-scale measurements of precipitation intensity and accumulation are critical for a range of climate forecasting and water resource monitoring applications. For many areas of the world, highly uncertain remote sensing retrievals offer the only possible method for obtaining such measurements. Based on the application of novel land surface modeling and data assimilation techniques, ARS scientists have developed a technique for enhancing satellite-based precipitation estimates over land using spaceborne surface soil moisture retrievals. Their approach has been demonstrated to improve the accuracy and reliability of short-term (2- to 10-day) precipitation accumulation estimates derived from satellite-based sensors. Such enhancements should lead to an improved ability to globally monitor continental-scale precipitation for critical hydrologic, climate, and water resource applications.

**Land surface hydrology in the Cloud Land Surface Interaction Campaign**. Land surface properties in the Southern Great Plains (SGP) of the U.S may influence cumulus convection, and the effect may be affected by human activities, particularly agriculture. As agricultural practices shift in response to climate variations, these mechanisms may be modified even further. The harvest of winter wheat in the SGP may be an example of this. The Cloud Land Surface Interaction Campaign (CLASIC) was conducted in the summer of 2007 to contribute to our understanding of the interactions between the atmosphere and the land surface. Land surface observations and monitoring during CLASIC included soil moisture and surface flux at intensively characterized super sites, selected fields, watershed units, and over the regional domain (50,000 $km^2$). Two aircraft-based microwave instruments were used to provide soil moisture products. The month of June 2007 was one of the wettest on record resulting in extensive and frequent flooding throughout the region and conditions were not what had been hoped for in the experiment design. However, the soil moisture observations provide valuable information on the spatial characteristics of flooding over the period. Knowledge gained from this study will lead to better prediction tools that will benefit a broad spectrum of applications in agriculture ranging from more accurate weather forecasting to improved water management decisions and crop yield estimation.

## 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.

Global change research activities sponsored by ARS and other USDA agencies contribute to the U.S. Global Change Research Program (USGCRP) and the U.S. Climate Change Science Program (CCSP). Responding to Congressional mandate, the U.S. Climate Change Science Program commissioned an assessment (Synthesis and Assessment Product [SAP] 4.3) of the likely impacts on agriculture over the next 30 years (corresponding to an increase in $CO_2$ concentration from 380 ppm to about 440 ppm and an increase in temperature of about 1.2°C). Among the many findings, the increasing $CO_2$ will likely increase crop yields from about 1% for corn to 9% for cotton. In contrast, temperature increases likely will suppress yields except in more northern regions, where warmer temperatures probably will stimulate yields. Thus, the net result of combined $CO_2$ and temperature increases on yields likely will range from suppressions of about 8% to increases of about 10%. At the same time, the elevated $CO_2$ likely will slightly decrease water use by crops, but that probably will be offset by increased water demands caused by higher temperatures. Thus, changes in water use by crops probably will be largely unchanged. This highly visible synthesis and integration report was prepared by scientists from ARS locations at Ames, IA; Maricopa, AZ; Urbana, IL; Ft. Collins, CO; Temple, TX; and Clay County, NE; and from several universities and other organizations.

## 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. During 2007, an accomplishment report was assembled for the Global Change National Program and assessed by a review panel composed of non-ARS scientists 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 directions for the next cycle of ARS Global Change research. A part of the activities for the Global Change National Program since the workshop has been working to integrate its activities with the newly-forming Climate Change, Soils and Emissions National Program (NP212), together with the Air Quality and Soil Resources National Programs. Research progress for global change topics for 2009 and beyond will be reported as part of the Climate Change, Soils and Emissions National Program National Program (NP212).