Action Plan: National Program 212 – Climate Change, Soils and Emissions Research
(January 6, 2009)

Goal: National Program (NP) 212, Climate Change, Soils and Emissions Research supports research to improve the quality of atmosphere and soil resources that both affect and are affected by agriculture, to understand the effects of climate change on agriculture, and to prepare agriculture for adaptation to climate change.

Agricultural systems function within the soil-atmosphere continuum. Mass and energy exchange processes occur within this continuum and agriculture can significantly affect the processes. Emissions from agriculture to the atmosphere affect air quality and increase atmospheric greenhouse gas (GHG) concentrations. While GHG emissions result from the natural cycling of carbon (C) and nitrogen (N), these emissions also contribute to climate change. A changing climate impacts agriculture, range and pasture systems, and soils through alterations in precipitation and temperature patterns, and increased atmospheric carbon dioxide (CO_2) concentration. The impacts of climate change create challenges to agriculture and its soil resources, but also offer new opportunities for agricultural production and enhancement of soil quality.

Soils are a crucial boundary resource between agriculture and the atmosphere. Soils in agricultural systems must be managed to meet rising global demands for food, feed, fiber, fuel and ecosystem services while maintaining soil productivity and limiting undesirable interactions between soils and the atmosphere.

The variability of the atmosphere, soils, and plants, and the complexity of interactions among these systems require collaborations by ARS scientists conducting NP212 research. Formal and informal Cross Location Research (CLR) projects including the Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet), the Renewable Energy Assessment Project (REAP), and field campaigns focused on air quality are successful examples. Synthesis and integration of information, including sources outside NP212, by CLR projects increases the utility and impact of ARS research. Efficient assimilation of data from NP212 projects into existing and future collaborative data bases will enhance synthesis and integration analyses and expand research opportunities.

Relationship of This National Program to the ARS Strategic Plan: Outputs of NP 212 research support the "Actionable Strategies" associated with the performance measures shown below from the *ARS Strategic Plan for FY2006 – 2011, Strategic Goal 2.0 Enhance the Competitiveness and Sustainability of Rural and Farm Economies; Strategic Goal 4.0 Enhance Protection and Safety of the Nation's Agriculture and Food Supply; and Strategic Goal 6.0 Protect and Enhance the Nation's Natural Resource Base and Environment.*

> **Performance Measure 2.1:** Enhance the competiveness and sustainability of rural and farm economies. Objective 2.1: Expand domestic market opportunities.

Target: New products and strategies will be developed to mitigate environmental concerns, such as the use of carbon sequestration to offset greenhouse gas emissions.

Performance Measure 4.2: Reduce the number, severity and distribution of agricultural pest and disease outbreaks. Objective 4.2.1: Provide scientific information to protect animals, humans, and property from the negative effects of pests, infectious disease, and other disease-causing entities. **Target**: Research that has significant impact on the scientific community, leading to development of technologies for the integration of prevention and treatment strategies to manage top priority endemic and exotic threats to livestock, humans, and property.

Performance Measure 6.2: Improve soil and air quality to enhance crop production and environmental quality. Objective 6.2.1: Develop practices and technologies to enhance soil resources and reduce emissions of particulate matter and gases from crop production lands, agricultural processing operations, and animal production systems. **Target: A**gricultural practices and technologies will be developed and used by customers and partners to enhance soil and air natural resources.

Relationship of this National Program to other related National Programs: Given the global impact of climate change and the fact that air and soil resources are of universal importance, research conducted under NP212 is relevant to all other ARS National Programs. Other ARS programs that more intimately complement NP212 research include:

NP 108 Food Safety (animal and plant products)
NP206 Manure and Byproduct Utilization
NP207 Integrated Agricultural Systems
NP211 Water Availability and Watershed Management
NP215 Pasture, Forages and Rangeland Systems
NP216 Agricultural System Competitiveness and Sustainability
NP303 Plant Diseases
NP305 Crop Production
NP306 Quality and Utilization of Agricultural Products
NP307 Bioenergy and Energy Alternatives

<u>Component 1. Enable Improvements of Air Quality via Management and Mitigation of Emissions from Agricultural Operations</u>

Atmospheric emissions from agriculture are under increased scrutiny due to potential negative environmental effects and threats to human and animal welfare. Emissions contribute to tensions between agriculture and residential communities from visibility impairment (haze) and nuisance odors. Major classes of emissions include particulate matter (PM), volatile inorganic compounds (primarily ammonia and hydrogen sulfide), volatile organic compounds (VOCs), and those from pesticides. Often these emissions exist as mixtures and, thus, adjustments to production practices for abatement may decrease the release of one material while changing the emission character or magnitude of other materials.

Problem Statement 1A: Understand, predict, and manage emissions from agricultural systems

Pesticides used in agricultural production systems may contain significant quantities of volatile and semi-volatile organic chemicals, or compounds that become volatile. Fumigant products applied into soil can quickly evaporate and require measures to reduce losses to the atmosphere. Pesticide residues remaining in the soil after application are also susceptible to offsite transport by wind via windblown fugitive dust particles. Once in the air, emitted compounds and PM can react with other air components and be transported to, and deposited on, non-target species in neighboring ecosystems. Limited knowledge exists concerning the effects of weather and climate, soil conditions, application methods, cropping systems, crop species, and management practices on emissions, fate, transport, and deposition of agrochemicals and PM from agricultural sources. ARS will conduct studies to gain a more comprehensive understanding of these processes, develop and evaluate measurement techniques and protocols, develop and evaluate models describing and predicting emission, fate, transport, and deposition, and develop emission abatement and mitigation technologies and practices.

Research Needs

A better understanding is needed of meteorological factors, soil properties, and agricultural practices influencing the emission, fate, and transport of PM, VOCs, pesticides, and ammonia. Current instrumentation requires modification and evaluation for better PM, pesticide, and VOC measurements. Physically-based models of land management practices are needed to quantify the susceptibility of soil to transport by wind. Experimental protocols and approaches are needed to characterize PM, VOCs, pesticides, and ammonia emissions, and to identify their sources. Characterization of the temporal and spatial variability of these emissions is required to determine their effects on local and regional ecosystems and on regional air quality. Currently, there are only a few management practices which can be used to curtail emissions and more are needed. Mitigation strategies to decrease the effects of cropping system emissions on non-target organisms and ecosystems require evaluation. VOC and pesticide assessment and prediction tools, as well as PM models for cropping systems, need improvement. Models to predict the interactions of cropping system and urban emissions and resulting effects on air quality are urgently needed.

Anticipated Products

- Knowledge of fundamental processes and mechanisms controlling emissions, transport, and deposition of PM, VOCs, pesticides, and ammonia from agricultural systems.
- Scientifically-sound protocols for measuring emissions appropriate for various agricultural systems.
- Standardized datasets with transport parameters and emission rates for emission and transport model improvement, evaluation, and validation.
- Abatement and mitigation technologies, and best management practices (BMPs) documented in guidelines (factsheet/whitepaper) for controlling emissions.

- Improved models to simulate emissions that can help with decision support.
- ARS Air Quality Emissions Research Workgroup.

Potential Benefits

- Improved air quality resulting in an improved environment and human health.
- Regulations based on best available science for emissions of reactive VOCs, pesticides, PM, and PM precursors.
- More economically and environmentally sustainable agricultural systems.
- Science-based understanding of agriculture's impact on residential communities.

Problem Statement 1B: Understand, predict, and manage emissions from animal operations

Ammonia, VOCs, hydrogen sulfide, and PM are released from animal operations. Once in the air, emitted compounds and PM can interact with other air components, in poorly-understood processes, and be transported to and deposited on other ecosystems. Some of these compounds also produce nuisance odors which impact surrounding communities. Difficulties exist in regulating these materials due to limitations of existing measurement methodologies and a lack of knowledge on the effects of weather and climate, soil conditions, and management practices on emissions, fate, transport, and deposition. ARS will conduct studies to gain a more comprehensive understanding of emission, fate, transport, and deposition processes. The increased understanding of these processes will be used to develop and evaluate measurement techniques and protocols, develop and evaluate models describing and predicting emission, fate, transport, and deposition, and, develop emission abatement and mitigation technologies.

Research Needs

A better understanding of factors influencing the emission, fate, and transport of PM, VOCs, hydrogen sulfide, and ammonia is needed. Instrumentation to adequately measure volatile compounds requires modification and evaluation. Experimental protocols and approaches to characterize PM, VOCs, hydrogen sulfide, and ammonia and to identify their sources must be developed. The temporal and spatial variability of these emissions and their effects on local and regional ecosystems need to be understood. The amounts and processes of wind-driven emissions from animal facilities and grazing lands need further investigation. The interactions of animal operations and urban emissions and the resultant effects on air quality require examination. The effects of changes in animal production systems to help meet bioenergy production demands on air quality need to be examined. Mitigation strategies to decrease animal operation emissions must be developed and evaluated. Assessment and predictive tools for VOCs, hydrogen sulfide, and ammonia, as well as PM models for animal operations require evaluation.

Anticipated Products

- Knowledge of fundamental processes and mechanisms controlling PM, VOCs, hydrogen sulfide, and ammonia from animal operations including lifecycle analysis of emissions.
- Scientifically-sound protocols for measuring emissions from animal operations.

- Standardized datasets that include transport parameters and emission rates for model development, evaluation, and validation.
- Abatement and mitigation technologies, guidelines and best management practices (BMPs) for controlling emissions.
- Improved model simulations and develop decision support tools to predict emissions.
- ARS Air Quality Emissions Research Workgroup.

Potential Benefits
- Improved air quality.
- Regulations based on best available science for emissions of materials from agricultural sources.
- More harmonious coexistence of agricultural and urban communities.

Problem Statement 1C: Understand, predict, and manage emissions from post harvest processing systems

Agricultural post harvest processing operations are encountering difficulties complying with current air pollution regulations for PM and VOCs. Scientifically sound emissions data are needed when new air quality standards are enacted and for existing or new processing technologies. The current methods for determining emission levels for many post harvest operations are subject to high error rates associated with sampling technologies, methodologies and predictive modeling tools inappropriate for agricultural settings. Estimates of the effectiveness of abatement technologies may also suffer from the same errors. ARS will conduct studies to gain a more comprehensive understanding of emission processes, develop and evaluate measurement techniques and protocols, develop and evaluate models describing and predicting emissions, and develop emission abatement and mitigation technologies.

Research Needs

A better understanding of factors influencing the emission of PM and VOCs from post harvest processing systems is needed. Experimental protocols and approaches to characterize total PM emissions and VOCs from silage, cotton processing, nut hulling, feed mills, and other operations are lacking. Mitigation strategies to decrease VOC and PM emissions require development and evaluation. Assessment and predictive tools including models for VOC and PM emissions require evaluation and validation.

Anticipated Products
- Fundamental baseline knowledge of processes and mechanisms controlling VOC and PM emissions from post harvest processing systems.
- Scientifically-sound protocols for measuring emissions from post harvest systems and standardized data sets.
- Abatement and mitigation technologies and practices (BMPs).
- Improved models and new decision support tools to predict emissions and manage processes for reducing emissions.
- ARS Air Quality Emissions Research Workgroup.

Potential Benefits

- Improved air quality.
- Regulations based on best available science for emissions of PM precursors and VOCs.
- More sustainable post harvest processing systems.

Component 1 Resources

Twenty (20) ARS CRIS projects coded to National Program 212 address the research problems identified under Component 1. ARS locations and lead scientists who are assigned to these projects include:

Ames, IA	Prueger, John; Kerr, Brian
Beltsville, MD	Hapeman, Cathleen; Gish, Timothy; Shelton, Daniel
Bowling Green, KY	Sistani, Karamat
Bushland, TX	Cole, Noel
Fayetteville, AR	Moore, Philip
Kimberly, ID	Leytem, April
Lubbock, TX	Buser, Michael; Zobeck, Ted
Manhattan, KS	Wagner, Larry
Mesilla Park, NM	Hughs, Sidney
Riverside, CA	Yates, Scott
Pullman, WA	Sharratt, Brenton
Tifton, GA	Potter, Thomas
University Park, PA	Rotz, Alan
West Lafayette	Flanagan, Dennis
Wooster, OH	Derksen, Richard; Zhu, Heping

Component 2. Develop Knowledge and Technologies for Reducing Atmospheric Greenhouse Gas Concentrations Through Management of Agricultural Emissions and Carbon Sequestration

Agriculture GHG emissions to the atmosphere are among the documented anthropogenic factors driving climate change. Land management practices may be altered to reduce GHG emissions. Agriculture also provides an opportunity to sequester C in soils, thus offsetting GHG emissions and offering a partial solution to slowing the forces of climate change.

Problem Statement 2A: Understand and measure emissions of greenhouse gases from agricultural sources

The human influence on global climate change is primarily from activities that increase atmospheric concentrations of GHG, especially CO_2, methane (CH_4) and nitrous oxide (N_2O). Agriculture contributes about 20% of the world's global radiative forcing from CO_2, CH_4 and N_2O emissions. Agriculture produces 50% of the CH_4 and 70% of the N_2O attributed to human-induced emission of these gases. However, changes of management, including minimizing or eliminating tillage, adding organic matter (e.g., cover crops and manure), and improving nitrogen management for enhanced efficiency can result in agriculture serving as a net sink for GHG. ARS will conduct research focused on developing soil C and GHG measurement methods. ARS will also provide information on the soil C status and GHG emission of current agricultural practices as well as the effects of new alternative practices on net GHG emission and soil C sequestration, through the activities of the ARS coordinated cross location effort, GRACEnet (Greenhouse gas Reduction through Agricultural Carbon Enhancement network).

Research Needs

Research to develop precise information on how agricultural management practices impact soil C sequestration and the amount of GHG emitted in different regions of the country is critically needed. Standardized, portable and inexpensive methods for quantifying soil C and GHG emissions are needed to better measure spatial and temporal variability. The required research needs to generate and summarize current and emerging information, be region-specific within the US, inventory current and future agricultural soil C sequestration and emission data, and increase development and application of predictive mathematical models. Such research is a prerequisite for the widespread adoption of C-credit trading in the US and elsewhere.

Anticipated Products

- A national database of current GHG flux and C storage that can serve as a baseline for verifying C credits.
- Standardized protocols and improved methods for making soil C and GHG emissions measurements.
- Synthesis of net agricultural GHG emissions data on regional and national levels.
- Regional and national guidelines of best management practices for minimizing GHG emissions from and maximizing C sequestration on agricultural lands.
- Improved computer models to assess management effects on soil C and GHG emissions.
- Summary documents for use by action agencies and policy makers.

Potential Benefits

- Assessment and improvement of soil and agricultural management will provide information to producers, scientists, action agencies, C traders, policy-makers, and the general public that can be used to quantify the impact of agriculture on GHG emission and soil C storage.
- Timely assimilation of data into standardized data bases using good data management technologies will enhance research opportunities by ARS and the broader scientific community.

Problem Statement 2B: Develop process level understanding of GHG emissions

The processes of GHG emission and C sequestration in soils are complex. Process controls include climatic variables, soil type, pH, and crop management. The role and interpretation of CH_4 and N_2O emissions and soil C sequestration must be considered within the context of soil organic carbon (SOC) and soil nitrogen (SN) dynamics. To do so often requires data from analytically derived pools and fluxes of soil organic matter (SOM) and understandings of soil biological, physical, and chemical processes. Soils include numerous C pools such as microbial biomass and products, light fraction (LF), particulate organic matter (POM), and hydrolysable and non-hydrolysable SOC components. These pools interact with silt and clay, cations, N content, and aggregates to control SOM dynamics. Physical protection, biochemical complexity, and mineral surface-cation interactions all play a role in stabilizing SOM components. Nitrogen, a primary component of N_2O, is closely tied to C as a SOM constituent as well as in microbial biomass and soil enzymes. Its mineralization influences soil fertility, ecosystem functioning, environmental pollution, and climate change. ARS will fill gaps in our understanding of emission processes and formalize this knowledge within process models that can be used to predict emissions as a function of soil, plant, and atmosphere states.

Research Needs

The mechanisms whereby gaseous forms of C and N move within and between the soil and the atmosphere, transform chemically, and are transported are poorly understood. An understanding of the spatial and temporal variability of GHG emissions is needed. A formalized representation of process and mechanistic controls over GHG emissions (e.g., interactions among climate/soil/crop/fertilizer management) is fundamental to a mature understanding of GHG emissions. Understanding of process and mechanistic controls over soil C storage is a critical element. Understanding C, N, and water cycling relationships with GHG emissions and environmental quality is needed to develop management strategies to control GHG emissions while meeting production and environmental stewardship goals. Combinations of biogeochemical and hydrology/transport models are required for a systems-level emissions prediction capability. Models must be developed that can be scaled up for use at landscape and regional levels.

Anticipated Products

- Improved models of GHG emission processes.
- Scientific basis for developing and standardizing methods to capture dynamics.
- Basic information regarding principles and processes of C, N, and water cycles.
- Synthesis of net GHG emissions data to allow development of strategies and practices to reduce net GHG emissions and provide inputs for decision support tools.
- Better understanding of processes as the basis for improved mitigation practices.

Potential Benefits

- Improved mitigation practices.
- Enhance role for agriculture in mitigating national and global GHG emissions.
- User evaluation of economic and environmental trade-offs among mitigation practices.
- More scientifically based regulations of GHG emissions.
- Improved technologies for scientifically sound carbon credit trading.
- Management practices that result in improved agricultural C sequestration, efficient use and recycling of applied nutrients (especially N), and minimal GHG emissions.

Problem Statement 2C: Develop improved technologies and agricultural systems to manage greenhouse gas emissions

High uncertainty exists in system-specific net GHG emissions and CO_2 equivalent footprint analysis for conventional and alternative agro-ecosystems. Inadequate understanding of process controls over net GHG emissions hampers the development of emission management strategies. Lack of succinct and targeted information for customers regarding management impacts on GHG emissions and mitigation strategies impairs adoption of effective GHG emission controls. ARS will develop new management practices to reduce net GHG emission and increase soil C sequestration. Management strategies that balance production goals, environmental stewardship objectives, GHG emission reductions, and C sequestration will be developed.

Research Needs

Information is lacking on how specific management practices can be altered in different regions of the country to increase soil C sequestration, coincidently mitigate GHG emissions and meet acceptable conservation and production objectives.

Anticipated Products

- Strategies and recommendations for regionally specific practices to reduce net GHG emissions.
- Decision support tools for developing management strategies for balancing production goals, environmental stewardship objectives, GHG emission reductions, and C sequestration.

Potential Benefits

- Strategies and recommendations for mitigating net GHG emission and increased soil C sequestration via soil and agricultural management will provide information to producers, scientists, action agencies, C traders, and policy-makers that facilitate mitigation of GHG emissions.
- Agriculture will contribute to a decrease in atmospheric GHG concentrations.

Component 2 Resources

Twenty-six (26) ARS CRIS projects coded to National Program 212 address the research problems identified under Component 2. ARS locations and lead scientists who are assigned to these projects include:

Akron, CO	Vigil, Merle
Ames, IA	Parkin, Tim; Sauer, Thomas; Hatfield, Jerry
Athens, GA	Franzluebbers, Alan
Auburn, AL	Prior, Stephen
Beltsville, MD	McCarty, Gregory; Bunce, Jim
Brookings, SD	Osborne, Shannon
Bushland, TX	Howell, Terry
Florence, SC	Busscher, Warren
Ft. Collins, CO	Follett, Ron; Del Grosso, Steve; Halvorson, Ardell; Morgan, Jack

Kimberly, ID	Lentz, Rodrick
Lincoln, NE	Wienhold, Brian
Mandan, ND	Liebig, Mark
Morris, MN	Johnson, Jane; Papiernik, Sharon
Pendleton, OR	Wuest, Stewart
Pullman, WA	Smith, Jeff
St. Paul, MN	Baker, John
Temple, TX	Polley, Wayne
Tifton, GA	Potter, Thomas
University Park, PA	Rotz, Alan
West Lafayette, IN	Stott, Diane

Component 3. Enable Agriculture to Adapt to Climate Change

Mechanisms for adapting to climate change are critical for continued agricultural production and stewardship of natural resources. An understanding of the impacts of climate change on natural and managed ecosystems provides insights needed to formulate strategies for addressing vulnerabilities and exploiting potentially beneficial aspects of climate change. Mechanisms for identifying and detecting indicators of impacts are key to formulating management responses. Adaptive responses to climate change must be evaluated for impacts on ecosystem function and potential feedbacks on the climate system and subsequent consequences for sustainability and reinforcement, or offset of, climate change mitigation strategies.

Problem Statement 3A: Understand the responses of agricultural systems to anticipated climate change.

Changing precipitation and temperature patterns and increasing atmospheric CO_2 are impacting agroecosystems at national, regional, and local scales. Current ambient ozone (O_3) levels are phytotoxic to sensitive crops and increases in O_3 are projected under future climate change scenarios. Enhanced atmospheric CO_2 concentrations may increase growth and yield with most, but not all, crops and there may be detrimental impacts on crop and forage quality. The interactions of rising temperature, excess and deficit soil moisture stresses, ambient O_3, increasing atmospheric CO_2 concentrations, and changing length of growing season on yield quantity and quality, plant phenology, productivity, rangeland species composition, and biogeochemical cycling are largely unknown. The impacts of climate change are expected to vary geographically and temporally. Improved knowledge of the physiological and biochemical mechanisms governing crop response to elevated CO_2 and O_3 concentrations as well as improved process understanding of basic soil-plant-water-atmosphere interactions under changing climate will enable better risk management. ARS will conduct research to better understand agroecosystem responses to changes of temperature and precipitation patterns, atmospheric CO_2 and O_3 levels, and their interactions.

Research Needs

Understanding the impacts of interacting factors of global change on production quantity and quality of managed and natural ecosystems has emerged as a priority research need. Improved models are needed to more accurately predict how climate change will alter water availability, water use efficiency, nutrient requirements, and pools and fluxes of C, N, and other potentially limiting elements for plant productivity. The interactive effects of soil moisture, soil fertility, temperature, and O_3 on C_3 and C_4 crop responses to elevated CO_2 must be understood. Improved knowledge of the spatial and temporal dynamics of soil-plant-atmosphere interactions is needed. Knowledge is lacking on how shifts in rangeland plant species composition affect pools and fluxes of C and N to impact plant biomass productivity. It is also crucial to understand how landscape soil variation interacts with phenology and species change to mediate CO_2/climate impacts on productivity. How grazing will interact with climate change to further influence species composition and productivity is largely unknown.

Anticipated Products

- Understanding of how climate change affects crop and forage quality.
- Understanding of the interacting impacts of elevated CO_2, O_3, precipitation, and temperature on agricultural systems including nitrogen requirements, yield and quality responses.
- Data on impacts of elevated CO_2 on plant stomatal responses to soil water deficits and air vapor pressure deficits.
- Models of the mechanisms underlying improved water use efficiency at elevated CO_2 and its effects on yield.
- Management systems, including crop selection, to improve water use efficiency.
- Improved methods to measure and model interactions in soil-plant-atmosphere systems.

Potential Benefits

- Continued production of food, fiber, fuel and ecosystem services will be enabled.
- Understanding how climate affects the content of phytochemicals important for human health in various crops will enable society to better address human nutrition needs.
- Information needed to adapt crops to new environmental conditions.
- Knowledge of global climate change impacts on crop water and nutrient requirements and on fundamental plant processes at the whole plant, cellular, biochemical, and metabolic levels that regulate response to climate change will lead to management strategies for adapting crops to climate change through targeted manipulation of key biological processes.
- Physiological and biochemical markers to aid in the identification and development of cultivars adapted to climate change.
- Enhanced ability to define limitations of plant response to climate change.
- Enhanced accuracy of economic and environmental risk assessments associated with various climate change scenarios.
- Decreased variability and increased security of agricultural production.

Problem Statement 3B: Understand the impact of anticipated climate change on endemic and exotic pests, weeds and diseases.

Endemic and exotic pests, weeds and diseases are becoming an increasing concern for agriculture, with widely seen consequences for productivity and ecosystem health.

Although the negative influence of these factors is increasingly recognized by scientists and policy makers, the role of climate change (specifically anticipated changes of water, temperature and CO_2) on their vigor and proliferation are not well understood. ARS will conduct basic and applied research on the interacting effects of climate change on endemic and exotic pests, weeds and diseases. Resistance to management actions designed to control these types of species will be addressed.

Research Needs

Assessment of trophic interaction changes under global change, including interactions of pests and pathogens, grazers and weeds, and measurement and modeling of the impact of these trophic interactions on agricultural production are needed. The ability to predict changes in the locations and severity of invasive agricultural pests, weeds, and diseases with current and projected changes in CO_2, temperature, and water availability are needed. Quantification of the degree to which warming, changes of precipitation, and CO_2 enrichment increase the susceptibility of agro-systems to invasion; understanding how invasions are exacerbated by interactions of the availability of natural enemies with CO_2, temperature, and precipitation; understanding how CO_2 enrichment and warming interact with disturbances to influence plant invasion and native ecosystem recovery; understanding how nutrient availability affects invasive species growth and native rangeland susceptibility. Other needed predictions include latitudinal range shifts and likely impacts of invasive species as a result of warming, changes in precipitation, and CO_2 enrichment. Changes in management that will mitigate and control future infestations associated with expected range shifts, including herbicide management and impact of increased CO_2 and temperature on plant resistance to invasive pests and diseases, need to be identified.

Anticipated Products

- Risk assessment tools for predicting the effects of anticipated global change on weeds, pests, and diseases in different agricultural systems.
- Characterization of likely impacts of climate and CO_2 on the establishment, success and spread of invasive weeds, pests, and diseases including anticipated production losses for U.S. agricultural systems.
- Assessment of climate change and CO_2 increases on current agricultural management techniques (chemical, biological and physical) for endemic and invasive weeds, pests, and diseases, and establishment of new IPM guidelines.
- New conceptual knowledge, databases, and parameters for input to mechanistic models of C and nutrient cycling, plant biomass productivity, species phenology, and species changes.
- Guidelines on impacts of increasing atmospheric CO_2 and climate change on plant biomass productivity and rates of C cycling and storage in rangeland systems.
- Best management practices for sustainable rangeland production and maintenance of ancillary ecosystem services under future climate change.
- Statistical and spatial models of future invasive species ranges.
- State/transition models to predict invasions in rangelands under future CO_2 and climate scenarios.

- Delineation of identity and attributes of likely future invasive species.
- Guidelines for management practices to mitigate future invasions and control of existing invasive populations.

Potential Benefits

- Continued production of food, feed, fiber, fuel and ecosystem services will be enabled.
- Information needed to guide new crop selection and pest management strategies.
- Enhanced ability to define limitations of plant response to climate change.
- Increased security for agricultural production via decreased climate-driven variability in yield.
- Better decision-making due to improved understanding of the likely consequences of climate change impacts on managed and natural ecosystems.
- Improved models of C and nutrient cycling and forage quantity under future climate scenarios in non-crop systems as a basis for decision-support tools.
- Development of decision support tools for land managers describing likely spatially explicit forage quantity and sustainability of land use and management practices in non-crop systems.
- Improved function of C trading markets based on better knowledge of soil C pool sizes and fluxes in rangelands and its association with forage quantity and livestock carrying capacity under future climate scenarios.
- Improved ability of managers to design grazing systems that are resilient to climate change.
- Improved capacity to predict and control weed problems in rangelands under future CO_2 /climate scenarios.
- Improved ability to restore disturbed ecosystems under future CO_2 /climate scenarios.
- Advanced warning of likely range shifts of problematic invaders.

Problem Statement 3C: Evaluate germplasm and identify genetic variation that will respond positively to climate change.

Current varieties may not adequately adapt to stress or take advantage of potential opportunities associated with global climate change. Molecular markers and cultivars that will generate higher yield with improved tolerance to changing factors of climate are needed to secure a stable supply of food, feed, fiber, and fuel. ARS will conduct research to identify genetic resources that can adapt to and, where possible, benefit from climate change.

Research Needs

A better understanding of the genomic and genetic basis for the variability of crop responses to climate change is required. Optimal germplasm for enhanced performance under elevated levels of atmospheric CO_2 and O_3, increased temperatures, and precipitation excesses and deficits need to be identified. There is a need to evaluate and utilize wild relatives and ancestral germplasm of crop species as unique sources of genes to adapt crops to all aspects of climate change.

Anticipated Products

- Germplasm that is adapted to factors of climate change including improved tolerance to O_3, water use efficiency.
- Crop cultivars that maximize productivity at elevated CO_2 and/or elevated temperature.
- Molecular markers for crop CO_2 responsiveness, O_3 tolerance, and temperature limitations.
- Identify and characterize key genes regulating effects of temperature on phenology and reproductive growth factors.
- Identification of crop ancestors exhibiting variation in response to O_3 and CO_2.

Anticipated Benefits

- Maximizing crop yields and food production in the future would be the ultimate potential benefit.
- Germplasm designed for future environments that will generate sustainable, high crop yields with improved economic value for the American farmer.
- A secure and stable supply of both small and large grain crops for export, domestic consumption, industrial uses, and animal feed in the context of potential climatic uncertainty.
- Improved mechanistic understanding of plant responses to elevated CO_2, elevated O_3, and elevated temperature.
- Identification of molecular markers or genes involved in crop responses to elements of climate change would allow for biotechnological development of improved cultivars.
- Genetic material for plant breeders to develop new soybean and wheat cultivars with sustained or enhanced performance under future climate scenarios of elevated CO_2 and O_3.
- Identify specific lines of red rice that could provide phenotypic traits suitable for adaptation to projected changes in temperature, drought or CO_2 in cultivated rice lines as a means of maintaining food security.

Problem Statement 3D: Evaluate and adapt agronomic management to climate change.

Climate change presents threats to agricultural production systems as well as opportunities to improve and expand production. Adjustments to production system inputs, tillage, crop species, crop rotations, and harvest strategies, as well as altered use and assessment of natural resources are anticipated responses to both threats and opportunities of climate change. ARS will conduct research to increase the resilience of agronomic systems to climate change and to enable exploitation of opportunities that may arise.

Research Needs

Evaluate and develop sustainable agricultural management strategies to maximize crop production and minimize detrimental environmental impacts due to climate change. Develop management practices that maximize crop productivity and C sequestration under global climate change scenarios. Determine whether current management practices for weed, pest, and disease control as well as nutrient inputs need to be adapted under various global climate change scenarios.

Anticipated Products

- Management practices that increase the resilience of cropping systems to temperature and precipitation extremes.
- Information that quantifies the interactions among agronomic systems, management practices, and climate variation that can be used to assess future food security.
- Improved plant growth and agronomic models that can be used to evaluate potential management scenarios across a wide range of cropping systems, soils, and climate.
- Information on the capacity of cropping systems to sequester C in response to CO_2 and knowledge of underlying mechanism for residue decomposition.
- Suitable management strategies and methods to control invasive agronomic weeds with climate change.
- Improved understanding of weed community shifts under climate change scenarios.

Anticipated Benefits

- Continued production of food, feed, fiber, fuel, and ecosystem services will be enabled.
- Management practices that increase crop resilience to climate extremes and decrease risk of crop failure due to changing climate.
- Cropping systems that will have increased productivity under climatic stresses.
- Information for producers to evaluate potential management options to cope with climate stress in agronomic systems.
- Better information on C sequestration in different agronomic systems under climate change.
- Improved weed management strategies under climate change.

Problem Statement 3E: Identify and develop scalable methodologies for assessing potential impacts and adaptation of agriculture to climate change.

A strengthened capacity is needed to predict potential impacts of climate change on agricultural production and on natural resources, including water and nutrients. Better predictions are sought by growers, processors, agricultural industries, and local, state, and federal agencies. Improved prediction at different geographic scales will allow stakeholders to more effectively assess how climate change will impact agricultural production and the environment, and identify specific opportunities or vulnerabilities. ARS will conduct research to improve crop growth and ecophysiological models, develop technologies for merging data from different spatial and temporal scales, and structure research outcomes for use by decision makers at local to global scales.

Research Needs

Evaluate and extend the capacity and robustness of crop models and ecophysiological models for higher CO_2 and altered temperature, water and nutrient availability.

Develop and evaluate methods for integrating data across spatial and temporal scales, from the leaf level to the global level. Develop local, regional, national, and global datasets to assess impacts of global change.

Anticipated Products

- Models of crop responses to climate change and evaluation protocols for those models.
- Algorithm for moving information across spatial and temporal scales.
- Methods to handle complex biophysical interactions across scales.
- Meta-analysis of major crop responses to climate change.
- National database for characterization of crop or system responses to climate change.
- Recommendations for best management practices for adapting agriculture to global change.
- High resolution local database for detailed case studies characterizing crop or system responses to climate change.

Potential Benefits

- Continued production of food, feed, fiber, fuel and ecosystem services will be enabled.
- Improved models will strengthen our capacity to predict the potential impacts of climate change on agricultural production and on natural resources.
- Increase reliability of assessments of potential impacts on agricultural production.
- Improved strategic decisions relating to future agricultural production and resource availability by growers, processors, agro-industry, and local, state, and federal agencies.
- Greater utilization of information that can assist decision makers in understanding the implications of climate change on agricultural production.
- Reliable extrapolation of information that can assist commodity groups in planning for changes in agricultural systems.
- Assurance that underlying data for climate-change related decisions are of high quality, and within various constraints, that the data are comparable in terms of underlying assumptions.
- Developing and distributing base datasets for global change studies will facilitate impact studies and stakeholder confidence in the outputs, thus improving the quality of decisions in a broad range of fields relating to impacts of climate change on agriculture.

Component 3 Resources

Sixteen (16) ARS CRIS projects that are coded to National Program 212 address the research problems identified under Component 3. ARS locations and lead scientists who are assigned to these projects include:

Ames, IA	Hatfield, Jerry
Auburn, AL	Prior, Stephen; Raper, Randy
Beltsville, MD	Bunce, James; McCarty, Greg; Britz, Steve
Cheyenne, WY	Morgan, Jack

Gainesville, FL	Allen, L. Hartwell
Lincoln, NE	Wienhold, Brian
Mandan, ND	Hanson, Jon
Maricopa, AZ	Kimball, Bruce
Pullman, WA	Smith, Jeff
Raleigh, NC	Burkey, Kent
Temple, TX	Polley, Wayne
University Park, PA	Rotz, Alan
Urbana, IL	Ort, Don

Component 4. Maintaining and Enhancing Soil Resources

Soil productivity must be enhanced to meet increasing global food, feed, fiber, and fuel demands. Soil degradation through erosion and decreased physical (e.g., structure, compaction, infiltration), chemical (e.g., acidification, salinization, nutrient depletion), and biological (e.g., biodiversity, nutrient cycling, soil organic matter) properties and processes must be mitigated to ensure critical goods and services provided by soil resources are maintained.

Problem Statement 4A: Controlling soil erosion

Soil erosion continues to be the principal threat to the long-term sustainability of U.S. agriculture. Current estimates indicate that over 2 billion tons of soil per year is lost from U.S. cropland because of rain- and wind-induced erosion. On a worldwide basis, water-, wind-, tillage-, and irrigation-induced erosion are major causes of soil degradation and environmental damage including air quality and sedimentation of lakes and reservoirs. Soil erosion control is essential to sustain agricultural production systems because erosion affects soil properties progressively over time, generally diminishing soil quality and the resistance of agricultural systems to stresses induced by increased climate variability. ARS will conduct research to understand the states and processes of erosion and develop technologies and management practices that can be used to reduce soil erosion.

Research Needs

There is a critical need for improved understanding of soil erosion, sediment movement, and depositional processes as a function of the interactions between water, wind, and gravity and intensity determined by landscape structure, soil characteristics, management practices, and vegetative cover. Models to predict soil erosion processes are needed. Development of technologies and management practices to limit soil erosion that can be adopted by land managers are needed.

Anticipated Products

- Databases and decision support tools for sediment loads, yields, and off-site impacts considering fractional sediment transport and deposition, geomorphic aspects of stream evolution, and reservoir/pond sedimentation.
- Guidelines for reducing the risk of dam breaching and subsequent failure due to concentrated flow.

- Multi-scale models to predict wind, water, and tillage erosion, and downstream impacts of sediment movement on agricultural landscapes.
- Best management practices and design tools for in-field erosion control, gully and ephemeral channel erosion prevention, riparian corridor stabilization, and sediment retention structures.

Potential Benefits

- Improved soil management systems and more reliable national modeling of conservation efforts based on improved assessments of how climate, topography, and management affect soil erodibility and threshold velocities.
- Reduced sediment losses from fields and streams to lakes and rivers due to adoption of improved conservation practices.

Problem Statement 4B: Preventing soil degradation

Soil degradation is initiated by the processes of soil erosion, loss of vegetative cover, and oxidation of soil organic matter. These processes result in impaired soil physical, chemical, and biological properties and processes, eventually leading to reduced soil productivity and damaged ecosystems. Poor land management decisions contribute to soil degradation through loss of soil organic matter, soil compaction, accelerated soil acidification, and buildup of salts, toxic elements, and nutrients. Widespread use of pesticides contributes to soil degradation. Excessive removal of crop residues for bioenergy could have long-term economic, environmental, and sustainability costs. ARS will conduct research to develop strategies for preventing soil degradation and remediating degraded soils that balance increasing production demands with sustainability requirements.

Research Needs:

Guidelines documenting the amount of crop residue that must remain on the soil to prevent long-term degradation for a variety of yield levels and production practices are needed. Strategies, such as guidelines for use of biochar and other soil amendments, are needed for remediating degraded soils, especially soils that have been adversely impacted by erosion, compaction, trace element contamination, salinity, or other natural or human-induced phenomena. An improved understanding of pesticide fate and behavior in various soil environments is integral to reducing soil degradation. Simulation models describing pesticide movement and behavior for use in decision support tools are needed.

Anticipated Products

- Cross-location Renewable Energy Assessment Project (REAP) team to coordinate sustainability issues regard feedstock production for biofuel and bio-products.
- Guidelines for management practices supporting sustainable harvest of crop residue.
- Algorithm(s) estimating the amount of crop residue that can be sustainably harvested.
- Decision support tools and guidelines defining the economic trade-off between residue harvest and retention to sequester soil C.

- Management practices and guidelines to correct soil compaction and poor soil structure/aggregate stability.
- Assessments of biochar production and use as a soil amendment.
- Remediation techniques and amendments to remove or sequester trace elements, excess nutrients, or other contaminants in soil.
- Techniques and guidelines to map, monitor, and remediate saline soils and to assess their quality spatially and temporally.

Potential Benefits (Outcomes)

- Biofuel and bio-product production systems that significantly contribute to US energy independence, reduce GHG emissions, and support rural communities without degrading soil resources.
- Soils that are more productive and less likely to contaminate water and air resources.
- Effective and economically feasible management practices that prevent soil degradation and help remediate degraded soils.

Problem Statement 4C: Improving soil management and the efficient use of soil water

Impaired soils have reduced precipitation use-efficiency and increased risk of excessive runoff and erosion that lead to off-site pollution of water resources. Soil properties and processes affecting infiltration and water retention include surface sealing, soil structure, compaction, crop residue management, soil and water chemistry, salinity, and various aspects of soil biology. Innovative solutions to conserve soil resources through improved management strategies are needed to meet agricultural and societal demands for greater production and environmental quality protection. Efficient water storage and use in both dryland and irrigated systems are needed. Innovative and cost-effective soil management strategies, products, and technologies that directly or indirectly improve soil structure and infiltration are also needed to more efficiently use precipitation and reduce offsite impacts in urban, suburban, and rural areas. New technologies, assessment tools, and models are required to evaluate and predict soil properties, water availability, and effects of conservation practices at the landscape scale over time. ARS will fill gaps in knowledge of the effects of agricultural management practices on soil water status and processes and develop new management practices that promote desired soil characteristics.

Research Needs:

Improved techniques to quantify and understand soil water processes (e.g., infiltration, evaporation, and landscape soil-water redistribution) and the soil properties that influence them are required. Simulation models are needed to predict landscape infiltration, evaporation, and soil water redistribution. Improved soil management practices (e.g., conservation tillage and crop management practices) are also needed. Tools to help assess the effectiveness of conservation practices on soil, air, and water resources and crop productivity [e.g. the NRCS Soil Conditioning Index (SCI) and the Soil Management Assessment Framework (SMAF)] are required. Decision aids and strategies (e.g., management zones for site specific or precision agriculture) that are robust, reliable, and useful for guiding management decisions are needed.

Anticipated Products

- Guidelines and decision aids to improve management practices for better infiltration, water retention, aeration, and root proliferation for agriculture and urban land use applications.
- Tools and more sensitive instrumentation to measure management effects on temporal soil and hydraulic properties at field and landscape scales.
- Fact sheets, management guides, and synthesis publications that focus on conservation tillage technologies for cold, wet soils; irrigated soils; semi-arid dryland soils; and temperate non-irrigated soils.
- Fact sheets, management guides, and synthesis publications on conservation cropping systems (including cover crops and inter-cropping) and practices for integrated crop-livestock systems.
- Assessment tools to quantify soil quality benefits from conservation practices.
- Tools to delineate management zones for profitable adaptation of conservation practices and systems within fields.

Potential Benefits

- Improved productivity and efficient use of available water as well as reduced runoff, erosion, surface and subsurface water contamination.
- Measurable increase in implementation of conservation practices including improved crop sequences, rotations, and integrated crop-livestock systems
- Assessments of the effectiveness of various conservation practices.

Problem Statement 4D: Improving Nutrient Cycling and Use

Soil biological processes, application of animal manures, and use of inorganic fertilizer are the primary methods for meeting plant needs for essential nutrients. Basic and applied microbiological research focused on soil organisms and communities, as well as improved nutrient management practices, are needed to improve nutrient cycling and use efficiency. Inefficient nutrient use results in an economic loss to producers and creates an environmental risk to the public. Fertilizer use-efficiency is commonly less than 50% in many agricultural systems and application of excessive amounts of fertilizer and manure contributes to agriculture being the largest non-point source of pollution to surface and groundwater. Complex biological communities (including both beneficial and pathogenic organisms) reside and proliferate in the soil. Interactions among soil macro- and micro-organisms, plant roots, and root exudates influence many soil and ecosystem processes including nutrient cycling, soil structure and aggregation, and productivity. A small portion of the soil-borne community can also be plant and human pathogens. New technologies for assessment and control of microbial processes, improved understanding of nutrient fate and transport, and an improved understanding of how genetically modified organisms affect the soil and rhizosphere microflora are needed. ARS will address knowledge gaps of the states and processes involving soil organisms and communities affecting nutrient cycling and use. New strategies will be developed using this knowledge to improve nutrient management.

Research Needs

An improved understanding of nutrient fate and transport is needed upon which science-based guidelines for improved nutrient cycling and use can be developed. A variety of decision support tools for improved nutrient management are required. Basic and applied research must be conducted to understand the functional relationships among: (1) soil ecosystems and microbial communities; (2) biological, chemical, and physical processes; and (3) nutrient fate and transport in soil. Tools and technologies to better assess soil ecological status and rhizosphere ecology with regard to belowground food webs, soil stability, and nutrient cycling are required.

Anticipated Products

- Decision support tools (e.g., indices and models) for improved nutrient management.
- Synthesis publications and guidelines for management of nitrogen, phosphorus, and other nutrients.
- Site-specific best management practices for increased nutrient use efficiency within irrigated and rainfed agricultural systems.
- Improved methods and equipment for assessing soil biological and ecological communities.
- Synthesis papers and fact sheets quantifying relationships among above- and below-ground ecosystem processes and responses to soil and crop management decisions.
- An increased understanding of the functional relationships among soil microbial communities and the resultant soil physical and chemical characteristics.

Potential Benefits

- Decreased N and P loss to surface and groundwater resources.
- More efficient nutrient cycling and use within agricultural systems.
- Improved plant productivity and ecosystem function and health.

Component 4 Resources

Twenty (20) ARS CRIS projects that are coded to National Program 212 address the research problems identified under Component 4. ARS locations and lead scientists who are assigned to these projects include:

Akron, CO	Vigil, Merle
Ames, IA	Karlen, Douglas; Laird, David
Beaver, WV	Neill, Katherine
Beltsville, MD	Buyer, Jeffrey; Gish, Timothy
Brookings, SD	Osborne, Shannon
Columbia, MO	Suddeth, Kenneth
Florence, SC	Busscher, Warren
Ft. Collins, CO	Halvorson, Ardell
Lincoln, NE	Varvel, Gary
Lubbock, TX	Zobeck, Teddy
Mandan, ND	Liebig, Mark

Manhattan, KS	Wagner, Larry
Morris, MN	Papiernik, Sharon
Pullman, WA	Smith, Jeffrey
Stoneville, MS	Zablotowicz, Robert
Temple, TX	Potter, Kenneth
Urbana, IL	Sims, Gerald
Wyndmoor, PA	Douds, David

Program Data Management

There is increasing demand for quality scientific data from research addressed by NP212. This demand has fostered the creation of an ARS Natural Resources and Sustainable Agriculture Systems data base. Efficient assimilation of data into this data base using good data management technologies will enhance research opportunities by ARS scientists and the scientific community at-large.

Investment will be made to maximize the benefits that data bases and new information technologies bring to ARS research. Specifically, scientists addressing NP212 research needs will look for ways to:

- Improve the quality of available data and associated data technologies.
- Develop efficient practices for finding, obtaining, standardizing, and formatting research data.
- Increase visibility of research and collaborative opportunities by making research data available to other research efforts.

A data management team will be formed to provide leadership and guidelines to accomplish these goals. The team, co-led by Office of National Programs and a location scientist, will consist of scientists and information technology experts. Expected outcomes are program data management guidelines, increased staff proficiency in the use of relevant technologies, implementation of the research data system framework, and clear processes for ensuring ongoing success in using data management technology to increase scientific productivity. These activities will build upon the GRACEnet, REAP, the Conservation Effectiveness Assessment Project (CEAP), and Sustaining the Earth's Watersheds-Agricultural Research Data System (STEWARDS) data management efforts.

Synthesis and Integration of Research Findings

The complexity of air quality, climate change, and soils scientific issues creates a need to develop broad insight and conclusions from scientific literature and databases. An immediate demand by the scientific community, policymakers, and the public for integrated synthesis of scientific information justifies particular attention to this as an emphasis of NP212. Thus, ARS lead scientists contributing to NP212 will participate in synthesis and integration of information from all sources, including those outside their programs.