National Program 212 Soil and Air Action Plan 2021–2025

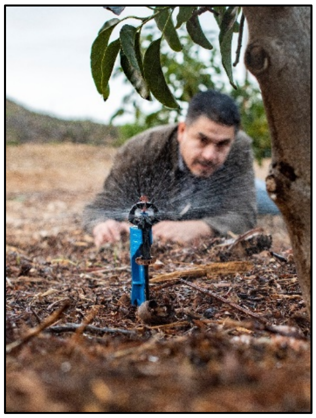
United States Department of Agriculture

Research, Education, and Economics Mission Area

Agricultural Research Service

Office of National Programs

September 2020



VISION

Productive and sustainable agricultural systems managed to optimize soil function and minimize impacts on air and water resources.

MISSION

Conduct scientific research that provides fundamental knowledge of soil-crop-air system dynamics and that leads to the development of technologies and practices producers can readily use to improve management of soil resources, reduce impact on air resources, efficiently use inputs, and contribute to ecosystems services.

Relationship of NP 212 to the USDA Strategic Plan

This NP 212 Action Plan outlines research that supports the following goals and objectives in the USDA Strategic Plan:

Strategic Goal 1: *Ensure USDA programs are delivered efficiently, effectively, and with integrity, and a focus on customer service*

- Objective 1.4: Improve stewardship of resources and utilize data-driven analyses to maximize the return on investment

Strategic Goal 5: *Strengthen the stewardship of private lands through technology and research*

- Objective 5.1: Enhance conservation planning with science-based tools and information
- Objective 5.2: Promote productive working lands
- Objective 5.3: Enhance productive agricultural landscapes

Relationship of NP 212 to the USDA Science Blueprint

NP 212 addresses the following themes from the USDA Science Blueprint:

Theme 2: *Ag Climate Adaptation*

- Subgoal 1A. Landscape-scale conservation and management
- Subgoal 1B. Climate research and resiliency

Relationship of NP 212 to the ARS Strategic Plan

NP 212 supports the following ARS Strategic Plan Goal areas and strategic goals:

Strategic Goal Area 2: *Natural Resources and Sustainable Agricultural Systems*

- *Goal 2.2.* Enhance and protect soil resources; manage nutrients and emissions from agricultural soils, livestock production systems, and byproducts; and improve production from agroecosystems to be resilient to changing climates.
    - *Performance Measure 2.2.* Improve quality of atmosphere and soil resources and understand the effects of climate change through development of knowledge and technologies.

Research conducted through NP 212 ties closely with other natural resources goals for water quality; management of pasture, range, and forage agroecosystems; and sustainable intensification of production. Additionally, managing soils and air for sustainable productivity directly relates to crop production (Strategic Goal Area 3); and through the influence on crop and forage productivity, outcomes of NP 212 research have indirect impacts for animal production (Strategic Goal Area 4). More directly, the impact of animal production effluents (e.g., animal wastes and manures) is directly related to the NP 212 goal.

NP 212 also supports two cross cutting priorities of the ARS Strategic Plan, climate change and the microbiome.

- *Climate Change.* NP 212 is within the natural resources research program area, and Components 1 and 2 of NP 212 are focused on research and development to determine how changing climate affects air quality, soil health, soil conservation (e.g., erosion), water infiltration and availability, and improving surface and subsurface water quality. These components also seek to develop better management practices of these resources to understand and then reduce agricultural impacts or drivers of climate change.
- *Microbiome.* NP 212 Component 1 is the primary focus for soil microbiome research, and that research will help us understand microbiomes and develop practices that promote the healthy functioning of diverse soil agroecosystems with a holistic approach that will integrate our understanding of crop and soil health with climate change. The research will also focus on management practices to increase biological diversity in soils that result in disease-suppressive soil communities and that can improve yields and the nutritional value of crops. On a larger scale, research on the soil microbiome and its effects on the complexity of the organic soil matrix will increase our understanding of how to manage these processes to lower nutrient losses to air and aquatic environments.

INTRODUCTION

U.S. agricultural production over the past several decades has undergone enormous progress due to myriad advances in scientific discovery, technology development, and efficient methods of agroecosystem management. Despite such gains and their resulting societal benefits, agricultural supply chains—and especially farms themselves—continue to be challenged to increase production for a growing global population and to do so through management approaches that maintain farm efficiency and profitability, preserve and enhance natural resources, are resilient to changing climate, and continue to instill public trust. This is clearly a daunting challenge that requires the support of research to help develop the next generation of management approaches and innovations to create a foundation of long-term agricultural sustainability.

Broadly, the goals of National Program 212 (Soil and Air) are to help farmers meet the challenges through research intended to develop practices and technologies that maintain and enhance soil health and quality essential for crop growth and production; reduce atmospheric emissions that degrade air quality and contribute to climate change; optimize management of fertilizers, manures, agrochemicals, and byproducts for crop production and environmental protection; and develop options for resilient farm production systems facing climate change and extremes.

Healthy soil has long been recognized as the foundation for sustainable production, and the focus on its importance continues to increase. For example, adoption of no-till and cover cropping were initially implemented due to rising costs of tillage operations and to improve erosion control. But observations from long-term research have additionally shown how these practices can improve other soil functions such as water infiltration and retention and increased organic matter content, which in turn contribute to increased crop production and economic returns. These observations have fueled public interest in research related to the full potential for developing healthy soils and that supports a variety of ecosystems services. Benefits of healthy soils include more efficient nutrient cycling and pest control, and associated cost reductions and environmental benefits of reduced reliance on anthropogenic inputs. Healthy soils are also associated with increased resilience to extreme weather, such as droughts and excessive precipitation, through increased soil moisture retention and increased rates of water infiltration. Healthy soils are also associated with reduced greenhouse gas emissions and climate change mitigation, both of which are driven by enhanced soil carbon sequestration. Ultimately, we need to improve our understanding of the phenomena and practices that can measurably improve what is broadly referred to as "soil health." We also need to develop methods to delineate where the greatest potential exists for those improvements, including how long it takes and to determine the magnitude of the potential. These needs are underpinned by science-based approaches to further develop the practices and technologies that improve soil health and the metrics for how much soil health is improving. This is a broad need for the entire agricultural community, but especially for burgeoning ecosystem services markets that are interested in establishing financial incentives for producers to adopt more sustainable management practices.

While interest grows in the potential for agricultural systems to help mitigate climate change through enhanced soil carbon sequestration, there is also growing focus on how agricultural production contributes to anthropogenic greenhouse gas emissions including nitrous oxide

(N_2O), carbon dioxide (CO_2), and methane (CH_4) from soils, animal facilities, and manure storage and processing. There is also growing interest in reducing agriculture's impact on air quality due to emissions of odors, particulate matter, and gases such as ammonia (NH_3) and volatile organic compounds from agrochemicals. A continuing need therefore exists for research to improve the ability to more accurately monitor and quantify the contributions of agriculture to atmospheric emissions, especially compared to other anthropogenic sources such as transportation or energy production. Practices and technologies that producers can use to reduce emissions are also needed.

Agricultural landscape management and production practices are also linked to environmental emissions. These include nutrient and other agrochemical loss to surface water and groundwater and their associated impacts on water quality. In addition to these chemical emissions, a need also exists to address emissions and the fate of high-priority biologicals, including pathogens of concern and genetic elements that confer resistance to antibiotics (broadly referred to as antimicrobial resistance), including antibiotic-resistant bacteria and antimicrobial resistance genes.

Agricultural production also represents an opportunity to implement the beneficial use of societal and agricultural byproducts to improve soils and/or to improve atmospheric conditions. One such example of this is the economical use of gypsum generated from municipal energy production as a soil amendment to improve water holding capacity, reduce erosion, and serve as a source of nutrients. Another opportunity derived from an agricultural byproduct is generating energy for the farming system via the use of methane produced from anaerobic manure digestion. More research is needed to further understand and develop efficient and environmentally benign uses of such inputs, such as enhanced efficiency fertilizers, or newly developed organics or biological materials as soil amendments. Similarly, a need exists for more research to understand and develop uses of outputs that can be generated from animal manures. Research is needed to assess the best use of inputs, outputs, practices, and technologies that producers can use to minimize their negative effects on the environment.

The preceding paragraphs compartmentalize agricultural production into the topics of soil, air, and inputs/outputs. However, agricultural production is a systems process in which, for example, soil management is a function of manure or fertilizer management, tillage, and/or cover crop practices. These in turn affect air and water quality and emissions. Because few if any farm enterprises operate in isolation, research that considers systems-level processes and develops systems-level practices and technologies (such as crop rotations that provide quality animal feed, improve soil health, and provide opportunities for efficient land application of manures) are often the most attractive and relevant options for producers to adopt to enable more sustainable practices on their farms. However, it can be challenging to conduct and assess scientific research at the systems level, and it often requires a combination of both physical experimentation and simulation modeling, which in turn requires a team-oriented, multidisciplinary approach to research.

This NP 212 Action Plan details the research priorities, strategies, and expected outcomes to address the topics outlined in this introduction. We developed these priorities in part through listening sessions and other engagements with customers and stakeholders including producers, nonprofit organizations, industry, academic institutions, and State and Federal agencies. The NP 212 research components described below consider stakeholder and partner needs along with program fiscal and personnel resources to ensure that the research can be translated into knowledge, practices, and technologies that can be adopted by customers. The plan is designed to be interconnected and to enable both focused efforts and team efforts. Figure 1 illustrates how the four components, although focused on priorities, also use a systems approach to enhance each other via flow of information, data, knowledge, and tools.

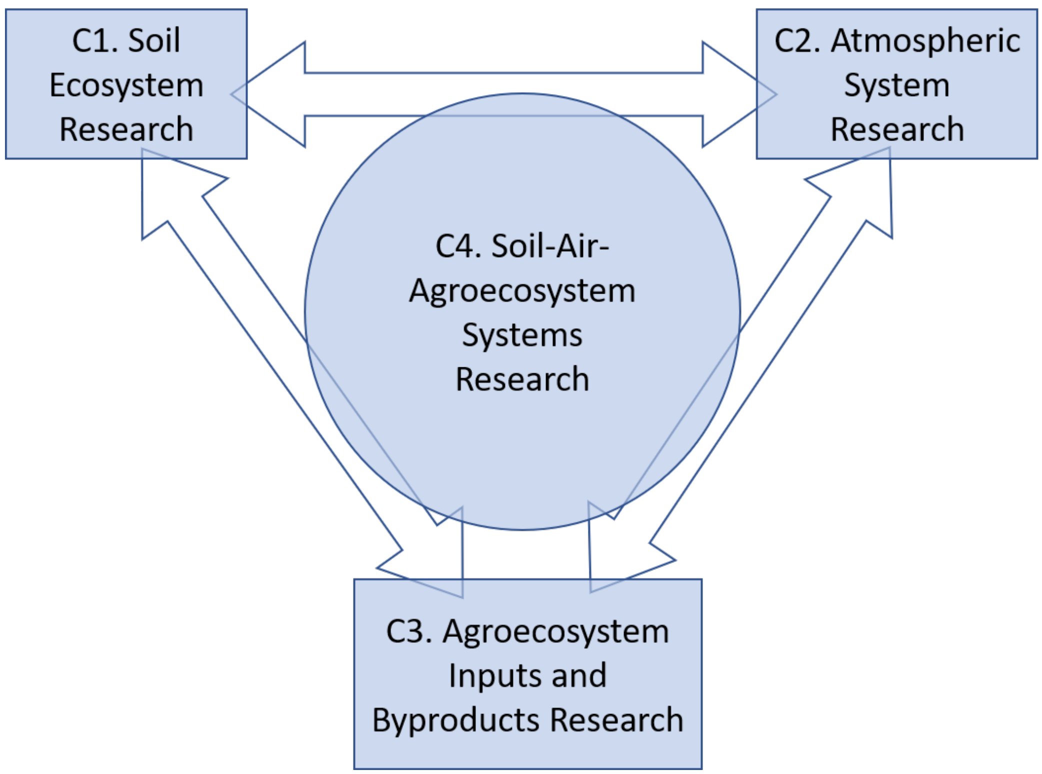


Figure 1. The interactive schema for the NP 212 research components (C1–C4).

COMPONENT 1

Develop fundamental knowledge of and practices for soil-based management that contribute to greater agricultural productivity, reduced reliance on inputs, resilience to disturbances, and ecosystem services.

"Soil health" is increasingly recognized as a foundation of sustainable agricultural production and food security. As agricultural production intensifies to extract greater performance from the landscape, there is a growing call to improve soil health. For example, soil biodiversity, when maintained at a high level, can improve productivity, prevent soil degradation, and reduce stresses from climate variability. However, holistic and even basic understanding and information about soil health and associated soil processes and functions is lacking. Many of the soil biological and chemical processes that influence and are influenced by agricultural productivity are not understood. Consequently, information is not fully available to optimize soil biological processes that promote nutrient availability to crops, provide pest and pathogen protection through development of disease-suppressive soils, and ensure sustainable production. Incorporating complicating factors such as cropping system and management practices (e.g., conventional and conservation tillage, organic practices), soil amendments (e.g., manures, biochar, compost, enhanced efficiency fertilizers, biostimulants), and weather makes this effort even more difficult. Furthermore, we must measure how soil biological species are affected by climate change and can contribute to climate change adaptation. Such measurements must also be flexible and applicable across cropping systems and geographic regions.

More information is also needed about how crops affect or are affected by microbial and other trophic-level communities and how these relationships can be managed to improve both soil health and crop productivity. Understanding the soil ecosystem in concert with evaluation of agroecosystem performance can enhance our understanding of soil-plant interactions; long-term changes in soil health; and agricultural production sustainability, resilience, and ecosystem services. Research on soil ecosystems will require applications of new techniques such as high-throughput sequencing, computational biology, artificial intelligence, and "omics" technologies to enable exploration of soil community composition, function, and activity. "Big Data" approaches and tools will be needed to assess the data-dense metagenomic and ecosystem process data in tandem with agricultural productivity.

NP 212 research will build on recent advancements in understanding the complexity, dynamics, and drivers of soil ecosystems and improve scientific assessments of how management affects these ecosystems and their processes. Research will also aim to develop practices to optimize soil health and crop and livestock productivity and sustainability, and reduce soil degradation. Improving soil health will also require more research on soil microbial and other trophic-level functions, and the influence of the surrounding abiotic matrix. These studies are critical for increasing our understanding of soil organisms and communities and their influence on agricultural production. NP 212 research will advance the emerging knowledge base of soil health and provide cutting-edge developments such as new soil health indices and databases for beneficial soil microorganisms (soil microbiome) and other taxa (soil macrobiome). This new knowledge of soil health will also be coupled to the performance and costs of production systems as a function of management practices.

NP 212 will strengthen the network of ARS scientists and partners who study the soil ecosystem (e.g., bacteria, archaea, fungi, viruses, nematodes, insects, plant roots, and others) and the plant-soil-microbial interface (the phytobiome and rhizosphere). Research through this national program will also strengthen networks with nontraditional partners seeking to understand how soil health affects their systems and outcomes. These partners include rangeland and pasture managers who may be interested in how soil ecosystems affect forage quality and the environment (e.g., erosion, greenhouse gases), producers interested in the use of "biostimulants" to improve productivity, and ecosystem services market groups interested in assigning aspects of soil health and productivity to socio-economic values.

Problem Statement 1A: *Quantify driving factors in soil carbon cycling, including organic matter dynamics, carbon sequestration, and CO_2 and CH_4 emissions.*

As agriculture is being intensified to meet expanding societal needs for food, feed, fiber, and fuel, there is a demand that management practices deliver improved productivity, greater resilience to variability in environmental and climate conditions, more efficient nutrient use by crops, mitigation of greenhouse gas emissions, and enhanced carbon sequestration from the atmosphere. There is increasing evidence that improved soil management can contribute to meeting this demand. From a technical perspective, better soil management often involves the soil carbon cycle, including agricultural management affecting carbon mass and energy fluxes between soil and air directly related to the physical, chemical, and biological properties that are critically important to soil functions.

Continuing research is needed on the soil carbon cycle and its ability to improve productivity, increase farming system resilience, and contribute to ecosystem services. Spatial, temporal, and mechanistic soil studies are needed to elucidate the underlying mechanisms that contribute to changes in soil organic matter structure and content, soil carbon sequestration, carbon-based greenhouse gas emission, and biogeochemical cycles. Research is also needed to understand and quantify how soil management practices such as choice of cropping systems, use of cover crops, and soil amendments affect these mechanisms. This research must also consider weather variability, local soil types, and longer-term climate changes.

The potential benefits of this research are powerful. For example, agriculture's pivotal role as both a source and sink for greenhouse gases is an opportunity for producers to reduce and mitigate greenhouse gas emissions. The research is also extremely challenging to carry out given the number of natural and anthropogenic variables that must be considered. The resulting research must also ensure that management practices truly promote good soil health, agricultural productivity, and related agroecosystem services; and it must be able to generate new tools, such as a comprehensive soil health index, that integrate information about the effects of management on soil carbon-related properties. Research must also provide long-term, holistic data on systems performance (soil properties, nutrient cycling, microbial communities, yield, and profitability) across agricultural landscapes.

Efforts are also needed to advance the science, expand the reach, and generally enrich national research efforts (and their integrated databases) such as GRACEnet (https://www.ars.usda.gov/anrds/gracenet/gracenet-home/) and REAP (https://www.ars.usda.gov/anrds/reap/reap-home/), and to facilitate the continuing process of refining, validating, and calibrating predictive and process models. New and improved methods, measurement techniques, and remote sensing technology are needed to facilitate sampling and mapping soil carbon properties for use in these efforts—tools that facilitate rapid, accurate, and cost-effective sampling and mapping of landscape properties and fluxes. Such data and knowledge are critical for improved agricultural landscape management and for producers to implement practices that improve their systems and lead to greater economic returns and environmental quality.

Anticipated Products

- Strategies and practices based on better understanding soil carbon cycling to enhance productivity and desired ecosystem services outcomes.
- Management practices that improve the carbon-based component of soil health and enable agricultural systems to be resilient to climate change.
- Databases that include holistic assessments for soil carbon dynamics.
- New or improved models and tools that assess short- and long-term changes in soil carbon and carbon-influenced functions and relate them to productivity and ecosystem services outcomes.

Potential Benefits

- Better soil carbon-based properties and functions that improve agricultural production, ecosystem services, soil health and resilience, and system sustainability.

Problem Statement 1B: *Advance the understanding of soil ecosystems that drive agricultural outcomes.*

The biological aspects of agricultural soils are gaining more attention owing to their observed effects on productivity, resilience, and sustainability. These include understanding the soil ecosystem in a similar manner as other ecosystems such as tropical rain forests or coral reefs. Microbiomes—defined as the complex microbial communities associated with soils, plant roots, livestock guts, and the human gut—have been the subjects of intense scrutiny to understand their complex influences on the well-being of their environments. Soil microbiome and ecosystem research is needed to better understand community members (e.g., a full census) and the functions they serve, and to develop metrics for how changes in these community profiles or functions relate to priority agricultural management and outcomes.

There are myriad ways to investigate such relationships; NP 212 will leverage team expertise in soil microbiome analysis, agronomic aspects of management and productivity, and environmental impacts such as runoff or nutrient loss.

Anticipated Products

- Better methods for assessing soil microbial communities that are tiered—where some can be applied in the field, some in basic laboratories, and some in advanced laboratories.
- Databases and associated metagenomic and phylogenetic analytical tools that improve analysis of any soil microbiome. The expected analytical tools will be of high value to agricultural and soil ecology communities nationally and internationally.
- Computational tools, data approaches, and models that couple information about the soil ecosystem to agricultural management and outcomes.
- Soil ecosystem databases that enable facile soil macrobiome and macrobiome data entry and analysis and sharing.
- Cost-effective technologies that translate soil microbial data into soil health management tools that producers and stakeholders can use to manage their systems to improve productivity and lower costs.

Potential Benefits

- Critical knowledge gained on the soil ecosystems, soil microbiomes, and soil health communities that will in turn drive agricultural productivity and sustainability outcomes.
- Enhanced understanding of soil ecosystems improves the ability to manage soils to enable the desired functions of microbiomes.

Problem Statement 1C: *Advance our understanding of innovative, nontraditional soil amendment research, including biostimulants and biochars.*

The number of novel soil amendments available and marketed that claim to improve productivity and crop nutritional value and/or to decrease environmental impacts is increasing. These amendments, or "biostimulants," fall outside the categories of traditional fertilizers and manures, and instead include 1) microbial inoculants, 2) complex organic materials (e.g., humic substances, biochars, composts, compost extract "teas"), or 3) combinations of living materials with complex organic materials as carriers. While some amendments have a long history (e.g., *terra preta* in ancient Amazonian agriculture), new formulations are being developed for different biological and complex organic amendments.

Producers are asking for research to understand the efficacy of these amendments. Although ARS is not a product testing organization, stakeholders need a framework for understanding the utility and value of these amendments. Such research fits well into the mission of NP 212 given the impact amendments have on soil ecosystem functioning and greenhouse gas emissions.

There is a need to understand the impacts of novel amendments on the soil ecosystem because some amendments are microbial in nature—and their manufacturers claim that these will improve the soil microbiome and agronomic productivity. However, more traditional inputs (organic fertilizers, cover crops) can result in exudates that stimulate the soil biomes that also impact productivity, nutritional value, and ecosystem services. For this reason, ARS biostimulant research will be formally coupled with research on these traditional amendments.

ARS has experience in assessing the effects of a variety of soil amendments, including humic substances, on agricultural commodities and biochar formulations (both traditional and hydrochars) on soil remediation and agricultural productivity. ARS also has experience developing microbial products for weed control in rangelands. ARS research will further our understanding of such amendments to determine their agricultural and environmental outcomes for a variety of regional and soil differences.

Anticipated Products

- A public-private partnership that establishes a tiered framework to evaluate soil amendments that is based on standard methods of material development, application, evaluation, and efficacy.
- Knowledge of how key "standard" amendments perform in a range of agricultural systems and environments, and especially in comparison to other relevant practices (e.g., cover crops, organic fertilizers).
- A centralized database that contains information on various classes of soil amendments and their efficacy in different agricultural systems.
- A standardized, science-based approach toolkit for assessing and reporting the efficacy of various classes of soil amendments for various systems and with baseline data for comparison to other practices (e.g., cover crops).
- A decision support tool that can help producers and stakeholders make informed decisions about possible amendment efficacy.

Potential Benefits

- Producers and stakeholders, including those who produce and use soil amendments, will have better and more standardized means to assess potential amendment performance.

Problem Statement 1D: *Establish metrics to reliably quantify the impact of management practices on soil health and function.*

As the importance of "soil health" increases, the chemical, biological, or physical properties that make a soil more productive or resilient must be identified, and metrics for those properties and tools to quantify how those metrics change with management practices must be developed. Because the need for such soil metrics is global, they must be robust and reliable no matter where they are used. They must also work in coordination with other national and global partners (e.g., the NRCS and/or the Food and Agriculture Organization's Global Soil Partnership soil assessment tools, respectively). Soil metrics must be appropriate for particular soils and regions (e.g., sodic vs. spodic soil), able to assess the impact of a variety of management practices and the trajectory of a soils' state (i.e., improving, degrading, or remaining stable), and useful to those interested in the economic value of management practices. These metrics should be useful for scientists to understand basic soil function, for producers and stakeholders to assess the value of their soil health for productivity and the impact of their management decision on that value, and for informing emerging ecosystem services markets or consumer sustainability indexes.

ARS has been a leader in soil health research with the aim of understanding the fundamentals of soil functions and their changes over different time scales and as a function of management. With extensive research investigations, NP 212 teams have contributed topical syntheses in-house and via co-efforts with NRCS and NIFA, nongovernmental organizations, university partners, and industry. ARS will continue to advance the science of soil health, and NP 212 teams will advance these soil metrics with existing and innovative assessment of soil features under different management regimes—features that range from physical (e.g., aggregate stability, water infiltration) to chemical (nature of the soil organic matter, available or labile nitrogen, phosphorous, and potassium), to biological (key features of the soil microbiome and macrobiome). Such knowledge development will occur in conjunction with other assessments coupled to the productivity and sustainability outcomes of the associated agroecosystem. Taking this holistic approach, ARS will advance soil health metrics that are grounded in relevance to productivity and desired outcomes. Research will also focus on strategies to incorporate soil metrics into more commonly used assessments. The strategies may likely consist of standard correlation determinations and resulting correction factors, but could assess the ability of artificial intelligence approaches to "translate" the highest quality and sophisticated metrics to more standard or feasibly collected metrics and allow weighting of the most important measures for a desired outcome.

Anticipated Products

- Metrics that are rigorously evaluated and refined for assessing key indicators of soil state and performance based on several outcomes.
- Database tools of soil metrics that have been evaluated in different systems and allow a user to select the most informative metric for a particular need (e.g., cropping system, soil type, climate).
- Advanced analytical methods that better assess soil state and processes and reduce uncertainty in implementation of optimal management practices.
- Innovative new tools for assessing the near-real-time benefits of soil carbon storing practices, such as instruments or approaches that estimate changes in soil organic carbon.

Potential Benefits

- Scientists, stakeholders, and producers will have coherent and rigorous soil metric standards and approaches from which to select to guide agricultural or conservation management practices and decisions.
- Ecosystem service stakeholders will have new soil metric toolkits to more accurately assess soils to guide management practices and improve agricultural outcomes.

Component 1 Resources

- Ames, IA
- Auburn, AL
- Beltsville, MD (3)
- Bowling Green, KY
- Brookings, SD
- Bushland, TX
- Clay Center, NE
- Fayetteville, AR
- Florence, SC
- Fort Collins, CO
- Kimberly, ID
- Lincoln, NE
- Morris, MN
- Pendleton, OR
- Pullman, WA
- Riverside, CA
- St. Paul, MN
- Wyndmoor, PA

COMPONENT 2

Advance the understanding and monitoring of atmospheric emission, transport, and deposition processes, and develop management strategies and support tools to reduce the release or mitigate the effects of gases, chemical emissions, particulate matter, and odorants while ensuring productivity and ecosystem health.

Common agricultural operations can lead to unintended emissions of substances to the atmosphere that affect air quality and surrounding ecosystem health. These can include gas emissions from animal housing and manure storage and processing facilities, gas emissions from soil after land applications of manures and fertilizers, volatile organic emissions from use of pesticides and other chemicals, particulate emissions from soils and farm mechanical operations, and odor emissions from animal and manure facilities and after land application of manure. Research on these topics is complex and focuses on understanding the biophysiochemical processes that control emissions, the atmospheric transport and deposition processes, and how these processes affect off-site ecosystem health. Research also includes developing methods and sensors to monitor and reliably quantify the magnitude of emissions, models to simulate emissions and options for reducing them, and management practices and technologies to reduce emissions. ARS has made substantial contributions to understanding emission processes at a variety of scales and developing management support tools to reduce emissions. The problem statements listed below outline ongoing knowledge gaps and research needs that the NP 212 program will address.

Problem Statement 2A: *Quantify and reduce atmospheric gas emissions from animal production facilities.*

The implementation of air quality regulations in livestock-producing states have increased the need for accurate estimates of gas emissions from the wide range of animal production facilities, management practices, and climatic conditions that exist across the United States. Although ARS has made substantial contributions to these efforts, we need better monitoring techniques and sensors, and to build databases that document the magnitude of gas emissions from animal facilities and operations associated with animal production. These include animal housing for beef, dairy, swine, and poultry, facilities (open lot vs. confinement), manure storage (lagoons, pits, piles), manure processing (solids separation, digestion), and the different climatic conditions that exist in major animal producing regions. We also need better ways to monitor, understand, and document the transport and deposition processes of these gas emissions, and the extent of their impact on ecosystem health after deposition. Finally, we need to compile and use monitoring data to develop and improve simulation models and decision support tools that can be used to reliably estimate the contribution of animal production to regional and national gas emissions and to assess the ability of alternative management practices to reduce emissions and improve ecosystem health.

ARS has also made substantial contributions to developing management options for reducing gas emissions from animal facilities. These options include air scrubber systems to remove ammonia from swine and poultry houses, vegetated tree buffers, and confinement housing and open-lot surface treatments such as alum in poultry facilities. These management options have often proved quite effective at reducing emissions, but often at costs too high for producers to be able to implement effectively. Research is needed to continue to develop these technologies to make them more cost-effective and easier to combine with conventional management practices.

Anticipated Products

- Improved methods and sensors, and technical guidelines for their use, to quantify atmospheric emissions from animal production.
- More complete livestock gas databases for emissions factors and model development, improvement, and verification.
- Improved mathematical, process-based simulation models for gas emissions, transport, and deposition from animal production that are used for farm, regional, and national assessments; and user-friendly decision support tools for on-farm use.
- Cost-effective farm technologies and management practices to reduce gas emissions and capture nutrients for on-farm use.

Potential Benefits

- Advanced monitoring techniques and sensors will allow for more reliable and effective quantification of livestock gas emissions.
- Improved emission factors for farm, regional, and national inventories (USDA Agriculture Greenhouse Gas Inventory, EPA National Emissions Inventory, and Intergovernmental Panel on Climate Change) to more accurately assess animal operations for mitigation policies or regulations.
- Better and more cost-effective reduction technologies and decision support tools that consider livestock systems, climate, and management practices, which will allow livestock producers to meet gas emissions standards.

Problem Statement 2B: *Quantify and reduce atmospheric gas emissions from soils.*

Like livestock gas emissions, there is also concern surrounding gas emissions from soils, including their impact on air quality, how they contribute to climate change, and the extent to which they cause a reduction in nutrient use efficiency. These concerns have increased the need for accurate estimates of gas emissions from the wide range of soil types, soil management and amendment practices, and climates across the United States. ARS has made significant contributions to soil gas monitoring efforts and understanding the processes that control them, but many of these measurements have been made at small-plot scales within limited time frames. There remains a need to improve monitoring techniques, especially at broader physical and continuous time scales to determine how these data relate to existing plot-scale data. Improved monitoring will contribute to databases that document the magnitude of soil gas emissions from a variety of cropping systems, field management practices (tilled vs. no-till), and fertility sources (commercial fertilizers and manures) and practices (surface application, injection, incorporation). We also need a better understanding of gas transport and deposition processes, especially for NH_3, and their impact on ecosystem health. Finally, we need better simulation models and decision support tools in order to reliably estimate the contribution of soils to regional and national gas emissions and to assess the ability of alternative management practices to reduce emissions.

Anticipated Products

- Improved monitoring of soil gas emissions, especially N_2O and NH_3, at field to farm scales and increasing continuous time frames, for existing plot-scale data.
- More complete soil gas databases that can be used for developing emission factors for farm, regional, and national inventories (USDA Agriculture Greenhouse Gas Inventory, EPA National Emissions Inventory, and Intergovernmental Panel on Climate Change); and for model development, improvement, and verification.
- Improved mathematical, process-based simulation models for gas emissions, transport, and deposition for farm, regional, and national assessments; and user-friendly decision support tools for on-farm use.
- Cost-effective farm technologies and management practices to reduce gas emissions and improve nutrient use efficiency.

Potential Benefits

- Improved soil gas emission inventories, factors, and standards more to accurately assess agricultural operations for mitigation policies or regulations.
- Reduced gas emissions, improved nutrient use efficiency, and decision support tools that will all result from a better understanding of the relationship between soil management and soil gas emissions.

Problem Statement 2C: *Quantify and reduce atmospheric emissions of agricultural chemicals, particulate matter, and odorants.*

The loss of contaminants such as volatile organic compounds, other agrochemicals, odorants, and particulates of varying sizes to the atmosphere from agricultural operations can pose potential risks to plant, animal, and human health. The generation, transport, and loss of these constituents may be exacerbated by changing weather patterns attributed to climate change. Research is needed to understand the sources and processes that control the generation and transport of these agricultural emissions. Research is also needed to create or enhance existing methods for monitoring and predicting contaminant losses; and to develop cost-effective management practices, tools, and systems to ameliorate these losses and their negative impacts on human and ecosystem health.

Anticipated Products

- Improved monitoring of atmospheric emissions and more complete databases that can be used to develop emission factors for farm, regional, and national levels; and for model development, improvement, and verification.
- Improved mathematical, process-based simulation models for atmospheric emissions, transport, and deposition for farm, regional, and national assessments; and user-friendly decision support tools for on-farm use.
- Cost-effective farm technologies and management practices to reduce atmospheric emissions.

Potential Benefits

- Improved monitoring techniques that will allow for better understanding of atmospheric emissions at the enterprise operation and farm scales.
- Improved emission inventories, factors, and standards to more accurately assess agricultural operations for mitigation policies or regulations.

- Reduced atmospheric emissions resulting from improved producer understanding of how to use decision support tools that consider source characteristics, management practices, and weather variations.

Component 2 Resources

- Ames, IA
- Auburn, AL
- Beltsville, MD (3 projects)
- Bowling Green, KY
- Bushland, TX
- Fayetteville, AR
- Florence, SC
- Fort Collins, CO
- Kimberly, ID
- Morris, MN
- Pendleton, OR
- Pullman, WA
- St. Paul, MN

COMPONENT 3

Develop management practices and technologies to enhance the efficient use of manure, byproducts, and agricultural chemicals such as pesticides and fertilizers, and minimize their losses to the environment.

Animal production systems can generate substantial quantities of manure that when properly applied on farm fields can be a valuable source of nutrients and organic matter for crop production and soil health. Processed manures can also have valuable uses such as for animal bedding and energy production in anaerobic digesters. However, manures can have negative environmental impacts. These include off-site nutrient transport and reductions in surface water and groundwater quality, especially when manure nutrients are repeatedly applied in excess of crop needs; off-site pathogen transport; and an increased risk of antimicrobial resistance in the environment due to veterinary antibiotics used in animal production. ARS has a history of research in developing beneficial uses of manures on farms, treatment systems to reduce pollution potential, and proper land application practices for crop production. The problem statements listed below outline ongoing knowledge gaps and research needs that the NP 212 program will address for on-farm manure use.

Municipal and industrial byproducts are used on farms in plant and animal production systems, often as soil amendments or as bedding material in animal housing. Research continues to be needed to provide critical information to regulatory agencies about constituent phytoavailability and bioavailability in byproduct amendments, and guidance on how to use these data to conduct risk assessments to support use decisions.

Agricultural chemicals such as inorganic fertilizers and pesticides are commonly and necessarily used to achieve successful crop production and farm profitability. However, their use can also contribute to water quality impairment if the chemicals are lost from fields via water movement. ARS is actively investigating alternative formulations of these chemicals, such as enhanced efficiency fertilizers, to reduce their loss and ultimately to reduce the need for their use. ARS is also studying how legumes can be integrated into cropping systems to reduce the off-site transport of such chemicals.

In agricultural systems, soil-borne and manure-borne pathogens can cause economically important diseases, especially when they are transported off site in air or water emissions. Research is needed to survey and measure pathogen occurrence and persistence in soils and manures and the potential for off-farm loss. Soil is a natural reservoir of antibiotic-resistant bacteria and antibiotic resistance genes, and these can be commonly detected. However, there is increasing concern that use of antibiotics in animal production and the subsequent land application of their manures can increase drug resistance in soil organisms and have related negative consequences to public health. Furthermore, agricultural antibiotics are most likely transported off site via the movement of manure-impacted soils in water runoff and air, and little information exists on how long antibiotics, other pharmaceuticals, resistant bacteria, and their genes persist in the environment or how they might affect soil functions. Research is needed to determine the specific impacts of agricultural management practices on all these topics.

Problem Statement 3A: *Improve use of manure as a soil amendment; develop manure processing, treatment, and value-added technologies; and reduce manure constituent loss to the environment.*

Research has clearly established that application of animal manure to farm fields can be a valuable source of nitrogen and phosphorus for soil fertility and organic matter. Applications that are well planned and managed can minimize off-site transport of manure. This can be achieved by integrating applications into soil through tillage or injection; scheduling applications appropriately; and applying them in places where the risk of water runoff is low. Yet it is challenging to achieve this ideal in manure management given how difficult it can be to cost-effectively integrate management with the priority demands in commodity production. For economic reasons, most farms also manage manure with conventional collection, storage, and land application practices that offer few alternatives for change. Research is needed to translate existing data and information into simulation models so that producers can decide when and where to apply manure to maximize their nutrient benefits and minimize nutrient loss to the environment. Research is also needed to develop new and innovative strategies, practices, and technologies that give producers alternatives in manure resources to minimize their environmental impacts. These alternatives may include better land application machinery that can place manure below the soil surface without concomitant soil disturbance that increases erosion; manure treatment technologies such as solids separation, nutrient extraction, or energy production through anaerobic digestion; and regional strategies to distribute manure from areas of excess to areas of need.

Anticipated Products

- Improved guidelines and technologies, including better farm machinery for applying manure in ways that maximize the use of nutrients and organic matter and minimize its environmental impact.
- Improved simulation models for assessing application of manure that maximizes the use of nutrients and minimizes their loss to the environment.
- New and better manure treatment technologies such as solids separation or nutrient extraction that help alleviate the occurrence of excess on-farm nutrients.
- New and better manure treatment technologies such as animal bedding or anaerobic digestion for value-added farm use.

Potential Benefits

- Improved crop production through more efficient use of manure nutrients and organic matter.
- Improved air quality and water quality due to fewer excess nutrients remaining after improved land application practices.
- Innovations in manure land application practices that will help producers meet manure use regulations and allow manure to remain a valuable source of soil fertility on farms.
- Cost-effective innovations and technologies for on-farm manure processing and treatment that will improve nutrient management and generate value-added uses.
- Coordinated strategies for manure distribution that will reduce local and regional nutrient excesses from animal production.

Problem Statement 3B: *Effectively use nonagricultural and agricultural byproducts in agricultural settings.*

Technologically feasible and cost-effective methods are needed to use agricultural, industrial, and municipal byproducts in agriculture or to reclaim degraded soils. This includes blending, composting, and amending byproducts; and developing land application and management techniques that will improve soil quality and crop production and/or water and air quality. Priorities include identifying beneficial byproduct properties, developing innovative byproduct processes, and applying real-time cost-benefit evaluations to the findings. Regulators also need information on transport and fate of byproduct components in the environment, and how byproducts impact soil function and plant growth if they are to approve the use of these byproducts in agriculture and horticulture. The development of methods to examine and approve byproducts based on sound science will help protect or improve soil, water, and air quality, and increase profits for byproduct generators and the agricultural community.

Anticipated Products

- A model process for evaluating different types of agricultural, industrial, and municipal byproducts for agricultural and horticultural use, including sampling, analysis, and assessment protocols that provide accurate and reliable data for risk assessments.
- Guidelines and practices for using agricultural, industrial, and municipal byproducts to improve soils, remediate degraded or contaminated soils, or for use as components of manufactured soils such as potting material in the horticulture industry.
- Guidelines for using byproducts to stabilize or sequester nutrients in manures and soils.
- Byproduct-use decision trees for State, city, and local agencies.

Potential Benefits

- More safe, efficient, and economical use of byproducts in agriculture operations.
- Improvements in the ability to reclaim degraded soils.

Problem Statement 3C: *Efficiently use chemical inputs, such as fertilizers and pesticides, for crop production and reduce their environmental losses.*

Inorganic fertilizers have been considered essential for soil fertility and may be required for optimal crop production, but they need to be used with practices that minimize their loss from fields and their negative effects on air and water quality. The fundamental processes driving fertilizer nitrogen and phosphorus availability and loss are well understood and documented, but research is needed to translate this information into algorithms to improve nutrient transport and fate models for assessing use efficiency and environmental impact. Research is also needed to develop and evaluate fertilizer formulations such as enhanced efficiency fertilizers that can increase plant uptake and reduce loss to the environment.

Although agrochemicals for pest and disease control are currently designed to be less persistent and less toxic, they remain a risk to wildlife, sensitive plants, and humans. These chemicals can be transported to the environment via atmospheric and water pathways, including release from the soil surface to groundwater systems. Research has historically focused on minimizing pesticide emissions. Quantifying agrochemical dynamics and the factors that influence the various fate pathways remains difficult, and research is needed to enable more accurate estimates of agrochemical availability for release and transport. Research is also needed to use information, knowledge, and data obtained from previous research to develop accurate pesticide transport and fate models to facilitate risk assessments.

Anticipated Products

- A better understanding of the efficacy and benefit of enhanced efficiency fertilizer formulations for crop production.
- Better models of soil nutrient cycling, availability, and transport for making fertilizer use management decisions and assessing loss risk.
- A better understanding of agrochemical availability and the potential for off-site transport.
- Better models of agrochemical transport and fate for use decisions and risk assessments.

Potential Benefits

- More efficient use of fertilizer nutrients for crop production.
- Better air and water quality due to less nutrient loss.
- More efficient use of agrochemicals to control pests and disease, and fewer chemicals lost to the environment.

Problem Statement 3D: *Assess and reduce the risk of off-farm transport of agricultural pathogens and pharmaceuticals and develop methods for measuring antimicrobial resistance and potential impact of these on public health.*

Research is needed to assess the occurrence, persistence, and transport of soil-borne and manure-borne pathogenic organisms and pharmaceutical chemicals, and to develop management systems and conservation practices that control and contain them. Information is needed for a range of transport pathways, including air and water emissions, on a range of landscapes from field-scale to regional groundwater resources. Research is also needed on how these substances are affected by management practices, tillage, soil type, and fluctuating climate conditions, and how they might be remediated via interactions with soil constituents and amendments such as biochars and/or other agricultural byproducts. It is essential that ARS develop methods for measuring antibiotic-resistant bacteria and resistance genes in complex agricultural samples; describe relationships between pharmaceutical chemicals, bacteria, and genes; incorporate baseline and control measurements; identify environmental “hot spots” of resistance; and collect data on how resistance changes over time at different locations.

Anticipated Products

- Validated methods and procedures for measuring pathogens and antibiotic resistance in agroecosystems, and data that measures these parameters through time and space.
- New databases that contain information on the types, amounts, and persistence of pathogens and pharmaceuticals and levels of antibiotic resistance on farms and in the environment.
- Manure, soil, and waste treatment practices that mitigate pathogens and antibiotic resistance in agricultural, livestock, industrial, and municipal waste streams.

- Agricultural management practices that reduce the off-site transport of pathogens and antibiotic-resistant bacteria.
- Improved pathogen and antimicrobial risk assessment methodologies, and transport and fate models.

Potential Benefits

- A reduction in the number of pathogens, pharmaceuticals, antibiotic-resistant bacteria, and antibiotic resistance genes transported within and outside of agroecosystems.
- Improved plant, animal, human, and environmental health.

Component 3 Resources

- Ames, IA
- Auburn, AL
- Beltsville, MD (3 projects)
- Bowling Green, KY
- Bushland, TX
- Clay Center, NE
- Fayetteville, AR
- Florence, SC
- Fort Collins, CO
- Kimberly, ID
- Lincoln, NE
- Madison, WI
- Pullman, WA
- Riverside, CA (2 Projects)
- St. Paul, MN
- Wyndmoor, PA

COMPONENT 4

At a systems level, develop soil-crop-air strategies, technologies, and practices that ensure producers can adapt to climate change and extremes, remain resilient and profitable, and provide abundant food, feed, fiber, renewable energy, and ecosystems services.

On farms, soil and air processes and dynamics are highly intertwined with many management variables such as crop choice, fertilizer or manure inputs, tillage, and harvest and crop residue management, and with non-management variables such as weather and soil type. Research is needed that considers and explores this systems perspective to understand these interactions and dynamics and to optimize production and ecosystem services.

NP 212 priorities focus on several systems-related topics, including cropping system management and cover crops, conservation tillage, and crop residue management. Cropping systems that prevent soil degradation are the key to maintaining soil quality and productivity. Systems such as perennial living mulches that can take advantage of a shorter growing season hold promise through their resiliency and decreased environmental footprint because erosion and nutrient inputs and losses are both reduced. Cover crops have multiple potential benefits because they improve nutrient-use efficiency and reduce the potential for surface or ground water contamination through runoff or leaching. As cropping systems and approaches are intensified to optimize profit, crop residues are often removed from fields after harvest to serve, for example, as animal feed or bedding, or for bioenergy feedstock. However, because these residues help protect soils from erosion and maintain soil organic matter, structure, and hydrologic properties, their removal can contribute to soil degradation. Production practices that consist of intensive tillage and minimal crop diversity can negatively impact soil carbon and other beneficial soil properties, especially through soil erosion that arises from tillage and lack of crop diversity.

Another aspect of a systems approach to agriculture is the use of precision agriculture and modeling strategies for crop production and soil management. Use of remote sensing, unmanned vehicles, and other imaging technologies can help rapidly process data and information so that producers can make systems management decisions, such as using riparian buffers to prevent soil erosion. Finally, conducting physical research at the systems level can be challenging, long, and expensive. Therefore, simulation models play a valuable role in assessing the impact of changing management practices and weather on production systems to help understand and identify tradeoffs in potential outcomes. This component integrates well with the ARS LTAR network, and some of the NP 212 teams participate in this network because of their systems-level approach to meeting the needs of producers and stakeholders.

Problem Statement 4A: *Develop cropping systems that enhance agroecosystems and promote resilience to climate change.*

Producers are seeking sustainable cropping systems that provide consistent returns on investment and build soil health. Additionally, with the recent interest in global climate change as it relates to soil resilience, producers are also seeking ways to improve the ways they build soil organic matter, reduce soil erosion and compaction, control weeds, and provide nutrients for plant growth. Agricultural practices such as no-till soil management, diversified crop rotations, and cover crop use can directly and significantly affect the sustainability of soil resources. Research is needed to assess how the impact of agricultural practices varies within and between geographic areas depending on crop, soil, water, climate, and other variables. Long-term systems research is also needed given the time required to observe changes in soil properties resulting from changes in management practices.

Research is needed on cropping system design and function. One example is finding the right combination of tillage and water management practices to ensure acceptable production throughout a crop rotation while simultaneously assessing inputs, soil function, and greenhouse gas exchange and associated carbon balance. For cover crops, research is needed to assess management variables such as crop choice, timing and method of crop establishment relative to winter conditions, and spring termination timing and methods. Research is also needed to assess the long-term ecological and economic benefits of cover crops, especially in their ability to reduce erosion, sequester carbon in soil, provide nutrients to following crops, improve soil health, and increase yields of cash crops.

Research is also needed to understand how conservation tillage and crop residue management, especially over the long term, directly and indirectly influence soil, water, and air and to determine whether the integration of multiple practices can produce more than additive benefits. This requires being able to assess multiple ecosystems such as soil health, conservation of natural resources, crop yield and quality, and insect and wildlife habitats while maintaining or improving economic sustainability for producers.

Finally, research is needed to understand how both soils and crops will adapt to a changing climate. For example, although much is known about plant responses to rising atmospheric CO_2 levels, how soil and crop systems, including pastures and rangeland, may respond to rising CO_2 remains largely unstudied. A need also exists to assess how management practices such as soil fertilizer nitrogen inputs interact with rising CO_2 levels and how that impacts crop production.

Anticipated Products

- Alternative cropping systems that target multiple beneficial outcomes related to production, farm profitability, and ecosystems services.
- Improved knowledge on the near- and long-term effects of cover crops and conservation tillage on soil health, crop productivity, and the environmental impacts of their use.
- Improved guidelines and practices to help overcome the hesitation by producers to integrate cover crops and conservation tillage into their conventional row crop systems.

Potential Benefits

- Improvements in soil health, crop productivity, and ecosystem services through greater implementation of diversified cropping systems.
- More resilient farm production systems to extreme weather such as floods and droughts, making them more sustainable and profitable.

Problem Statement 4B: *Use innovative precision agriculture, remote sensing, and/or modeling strategies for farming systems development and assessment.*

Precision farming promises to vastly improve production efficiency, reduce input use, and reduce the environmental footprint of operations. For example, precision farming can use soil, topography, and crop productivity variations within a field to determine application rates of fertilizers, agrochemicals, and irrigation water and thus reduce waste. These systems are predicated on data availability and systems to process the data and translate them into decision-making tools. This in turn requires remote sensing data from satellites and unmanned vehicles, and drones that are customized to detect agricultural problems early during a growing season, which in turn allows the targeted use of agrochemicals to increase nutrient use efficiency. Research is also needed to associate these data with physical variables such as landscape position that producers can use to target alternative management practices or conservation systems.

Agricultural systems models are becoming more widely used to develop management and policy recommendations. For example, watershed-scale models are used to set Total Maximum Daily Load (TMDL) restrictions for nonpoint nutrient and sediment pollution, including assessing nutrient dynamics in crop production. However, many commonly used models may not be consistently updated to reflect current scientific findings; or they may not include algorithms to represent the effects of emerging conservation practices such as the effect of cover crops on soil properties like water infiltration or nutrient availability. Research is needed to update these models and to develop new techniques and methods to improve these algorithms derived from conservation practices at field to watershed scales.

Anticipated Products

- New methods for agricultural remote sensing, including drones and unmanned aerial vehicles.
- Improved data processing and decision-making tools that allow producers to readily use remote sensing or other data to target management practices to improve efficiency and reduce the environmental footprint of agricultural production.
- Improved field- to watershed-scale simulation models that represent the current state of the science in both coding and biophysiochemical processes for evaluating agricultural production systems and their environmental impact.

Potential Benefits

- More efficient agricultural production through reduced input use, improved profitability, and reduced environmental impacts.
- Improved simulation models will lead to more reliable and efficient decision making and policy processes.

Component 4 Resources

- Auburn, AL
- Beltsville, MD (2 projects)
- Bowling Green, KY
- Brookings, SD
- Fayetteville, AR
- Fort Collins, CO
- Kimberly, ID
- Pendleton, OR
- Pullman, WA
- St Paul, MN