National Program 215
Grass, Forage, and Rangeland Agroecosystems

Action Plan 2023-2027

USDA Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

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Vision

Forage, fiber, and turfgrass enterprises and production systems that have state-of-the-art, science-based tools needed to use an agroecological approach to optimize productivity, resilience, economic viability, and environmental enhancement.

Mission

Through comprehensive, stakeholder-motivated, basic and applied research, develop and promote use of improved plant germplasm, novel crops and production approaches, decision support tools, and ecological land management practices in enterprises and production systems that use turfgrass and forages.

Relationship of NP215 to the **USDA Strategic Plan for FY 2022-2026**:

- This Action Plan outlines research that supports primarily the following goals and objectives in the USDA Strategic Plan: Goal 1: Combat Climate Change to Support America's Working Lands, Natural Resources and Communities
    - 1.1. Use Climate-Smart Management and Sound Science to Enhance the Health and Productivity of Agricultural Lands
    - 1.2. Lead Efforts to Adapt to the Consequences of Climate Change in Agriculture and Forestry
    - 1.4. Increase Carbon Sequestration, Reduce Greenhouse Gas Emissions, and Create Economic Opportunities (and Develop Low-Carbon Energy Solutions)
- Goal 2: Ensure America's Agricultural System is Equitable, Resilient, and Prosperous
    - 2.1. Protect Agricultural Health by Minimizing Major Diseases, Pests, and Wildlife Conflicts
    - 2.2. Build Resilient Food Systems, Infrastructure, and Supply Chains
    - 2.3. Foster Agricultural Innovation
- Goal 3: Foster an Equitable and Competitive Marketplace for All Agricultural Producers
    - 3.1. Foster Sustainable Economic Growth by Promoting Innovation, Building Resilience to Climate Change, and Expanding Renewable Energy

Relationship of NP215 to the USDA Science Blueprint:
This Action Plan outlines research that supports the following themes of the 2020-2025 USDA Science Blueprint

- Theme 1. Sustainable Ag Intensification
- Theme 2. Ag Climate Adaptation

- Theme 4. Value-Added Innovations

Relationship of NP215 to the ARS Strategic Plan:
This Action Plan outlines NP215 research that supports several strategic goals listed in the 2018-2020 ARS Strategic Plan:
NP215 primarily supports Goal Area 2, Natural Resource and Sustainable Agricultural Systems, which includes Goal 2.3, Improve Management Decisions and Enhance the Function and Performance of Rangelands, Pastures, Forage, and Turf Agroecosystems While Enhancing Ecosystem Service.

Other strategic goals that NP215 research supports include:

- Goal Area 1. Nutrition, Food Safety and Quality:
    - Goal 1.3. Improve Postharvest Quality and Develop New Uses of Agricultural Products
- Goal Area 2. Natural Resource and Sustainable Agricultural Systems
    - Goal 2.1. Effectively and Safely Manage Water Resources to Sustain and Increase Agricultural Production and Water Use Efficiency while Protecting the Environment and Human and Animal Health
    - 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
    - Goal 2.4. Integrated Solutions for Agriculture Enabling Greater Productivity, Profitability, and Natural Resource Enhancement
- Goal Area 3. Crop Production and Protection
    - Goal 3.1. Harness the Genetic Potential of Plants to Transform U.S. Agriculture
    - Goal 3.3. Improve and Expand our Knowledge of Existing and Emerging Plant Diseases and Develop Effective and Sustainable Disease Management Strategies that are Safe to Humans and the Environment
    - Goal 3.4. Provide Technology to Manage Pest Populations Below Economic Damage Thresholds by the Integration of Environmentally Compatible Strategies that are Based on the Biology and Ecology of Insect, Mite, and Weed Pests
- Goal Area 4. Animal Production and Protection
    - 4.1 Improve Food Animal Production Efficiency, Industry Sustainability, Animal Welfare, Product Quality, and Nutritional Value while Safeguarding Animal Genetic Resources

Performance measures for Goal 2.3. Develop and transfer economically viable and environmentally sustainable production and conservation practices, technologies, plant materials, and integrated management strategies based on fundamental knowledge of ecological processes that conserve and enhance the Nation's diverse natural resources found on its range, pasture, hay, and turf lands.

Relationship of NP215 to the ARS Grand Challenge-Synergy Initiative
NP215 will be a key contributor to ARS Grand Challenge projects “Dairy Agriculture for People and the Planet” and “Beef Systems.”

Introduction

Grasslands, lands for forage production, and rangelands—which include turfgrass, herbaceous biomass harvested as bioenergy feedstocks, forages harvested for animal feed, and pastures and native ecosystems for grazing—cover about 38 percent of the total land area in the United States and vast areas of the earth. Livestock productions systems are a major user of forages, both harvested and grazed. Ruminant animals derive nutrients and metabolites from forages, and there is a wide range of forage types and management systems for livestock across the United States. Millions of acres are not suited to human food crop production due to unsuitable environmental characteristics such as topography, rainfall or other water sources, soil type, and climate. Using these lands for forage enables them to contribute to producing meat, milk, and fiber for humans. These land areas also benefit humans and animals in a variety of non-food ways, including contributing to nutrient cycling (e.g., carbon, nitrogen), maintaining water quality, providing vital habitats that support plant and animal species diversity, and generating biomass for biofuels. Turfgrass-covered areas contribute many of the same ecological services and also provide aesthetic value and utility for recreational or other purposes.

These lands are subject to a number of environmental and anthropogenic dynamics that threaten their productivity, sustainability, and utility. These dynamics include conversion to other land uses for cropland or urban development and current and projected changes in climate such as shifting seasonal temperatures, precipitation, and pest pressures. However, there are also opportunities related to different dynamics that can improve utility of these land areas. For example, higher temperatures may be optimal for growth of current forages, depending on location and species; and higher atmospheric CO_2 concentrations can promote increased growth and water use efficiency. Increased demand for agricultural lands to produce energy and fiber and contribute to ecosystems services can also spur producers to expand grass and forage land uses.

Grass, forage, and rangeland areas require proper management to balance productivity and ecological benefits, and scientific information is often lacking to optimize this process. Major topics of scientific investigation include improving the types and quality of forages for livestock production; exploring alternative forage crops for food, feed, fiber, and fuel uses; managing soil for improved forage growth and quality, water availability, and nutrient cycling; reducing inputs required for forage production; reducing negative environmental impacts related to soil erosion and greenhouse gas emissions; increasing potential for soil carbon sequestration and other ecosystem services.

To address these topics, NP215 will perform research broadly classified into four components, listed below, that are organized around the physical scale of research. Component 1 is designed to provide basic information at the plant and soil-based scale to expand genetic and genomic resources, enhance soil and plant interactions and function, and advance the understanding of plant metabolites and metabolic pathways. Components 2 and 3 address field-scale research to improve harvested and pasture-based forage productions systems, respectively. Component 4 addresses ecologically-based and landscape-scale research related to rangeland management. All four components address the agronomic productivity of grassland, forage, and rangelands; innovative uses of technology and production alternatives; systems-level analysis; and climate resiliency and provisioning of ecosystem services.

NP215 Research Components

Component 1: Provide basic and applied research at the plant and soil scale to improve utility of crops for turfgrass; harvested forage, fiber, and bioenergy; pasture; and rangeland systems.

- 1A: Enhance plant genetic resources with improved traits and uses.
- 1B: Enhance beneficial microbial and plant interactions and reduce impact of pests, pathogens, and microbial toxicity to crops and livestock.
- 1C: Advance the understanding of plant metabolites and metabolic pathways to improve quality and value of plants used for harvested forage, fiber, bioenergy, pasture, and rangeland.
- 1D: Enhance genetic selection efficiency and quantify ecosystem services of turfgrass systems.

Component 2: Improve field-scale management strategies and production tools for harvested forage and fiber systems for livestock, bioenergy, and bioproducts.

- 2A: Develop harvested forage systems that optimize productivity, resilience to climate change, and environmental benefits.
- 2B: Develop cover crop systems that provide agroecosystem services and forage resources.
- 2C: Promote novel crops and value-added end uses for harvested forage and fiber systems.

Component 3: Improve pasture and grazing management systems and technologies for agricultural productivity and ecosystem services.

- 3A: Grazing system management to improve soil, forage, and animal health and productivity.
- 3B: Technologies for precision management and diversification of forage-livestock systems.
- 3C: Grazing systems for improved environmental outcomes and ecosystem services.

Component 4: Develop systems-based approaches for rangeland management to enhance forage and livestock productivity, land restoration, and ecological services.

- 4A: Fuels management to mitigate wildfire.
- 4B: Ecological management strategies for forage and livestock productivity, invasive species mitigation, and land restoration.
- 4C: Rangeland systems management for multiple ecosystem services and socioeconomic outcomes.
- 4D: Rangeland and animal management strategies that reduce the negative impacts of poisonous plants in the landscape.

Component 1: Provide basic and applied research at the plant and soil scale to improve utility of crops for turfgrass; harvested forage, fiber, and bioenergy; pasture; and rangeland systems.

Better plant materials are a cornerstone for improving crop production and are often the cheapest and most efficient way for growers to address their production challenges. For crops used as forage, in rangeland and pasture, and for bioenergy and cover cropping, plant materials include native and introduced grass and forb species; germplasm collections held in the USDA National Plant Germplasm System; and genetically selected, improved germplasm and cultivars. Collectively, these crops represent a diverse range of plant species with equally diverse breeding methods aimed at creating improved plant materials.

Breeding improved plants is a long-term endeavor, and plant breeders must consider several factors when deciding which traits to prioritize, such as changes in crop production and use, climate change and environmental stresses, new market opportunities, and the crop itself. Priorities for improvement include forage biomass and seed yields; resistance to disease and insect pests; tolerance to drought, salinity, cold and winterkill, and other environmental stresses; competitive ability with weeds; nutritive value and digestibility; and specialized metabolites that improve animal productivity and health. Improving these traits results in plants that are more resilient to stress and adverse climate conditions, and have better yield, quality, and market opportunities.

The Problem Statements for Component 1 are designed to emphasize four areas of plant and soil scale research: 1) Enhanced plant genetic resources, 2) microbial and plant interactions, 3) plant metabolites and metabolic pathways, and 4) genetic selection efficiency and ecosystem services of turfgrass.

Problem Statement 1A: Enhance plant genetic resources with improved traits and uses.

Advancements in plant breeding methods can shorten the time needed to release a new cultivar, allowing plant breeders to respond more quickly to new challenges or opportunities. Many new or advanced breeding methods draw on research that associates phenotypic data with crop genome sequences, molecular marker data, gene transcripts, proteins, or metabolites. Crops used for forage and biomass feedstocks commonly have complicated polyploid or duplicated genomes and significant genetic variability. These factors have slowed improvement of these crops. Research is needed to develop genomic and genetic resources in these crops to advance breeding methods. Gene editing enables changes to be made directly in crop DNA, leading to changes in plant traits. The technique needs to be developed or improved in many grasses and legumes. Genomic resources and gene editing are also useful for studying crop physiology and determining the genetic basis for important plant characteristics. Techniques to measure plant traits have also advanced using high-throughput sensing technologies, and these approaches need to be extended to more crop species, production environments, and plant developmental stages to capture the breadth of plant performance.

Research Focus

ARS will develop genomic and genetic resources in forage and biomass feedstock crops to advance breeding methods, improve gene editing techniques for grasses and legumes to enable changes to plant DNA and traits, and extend plant trait measurement techniques to more crop species and production environments.

Anticipated Products

- Better knowledge of plant trait genetics, including quantitative trait loci, trait functions and their biological impacts, and new methods for genetic analysis.
- Improved breeding methods, such as selectable molecular markers, genomic approaches, and gene editing, that accelerate cultivar development in perennial forage grasses and biomass feedstocks.
- Genomic resources such as reference sequences, transcriptomes, and other databases.
- New populations useful for genetic analysis of priority traits.
- Accurate measurement of plant traits using phenomics and high-throughput phenotyping.
- New plant germplasm and cultivars with improved performance for priority traits that are accessible to end users.

Potential Benefits

- Forage, rangeland, pasture, and bioenergy scientific communities use reference genomes to advance their own research in multiple disciplines.
- New methods for genetic analysis increase the pace of scientific discovery.
- Improved crop breeding methods increase the rate of cultivar development and the number of new cultivars available to growers, improving the ability of crop breeders to rapidly respond to unforeseen challenges to crop production.
- Accurate molecular markers allow more efficient trait selection for improved performance.
- Use of phenomics and high-throughput phenotyping reduce the time and monetary resources dedicated to measuring traits and increase the accuracy of measurement.
- Functional transcriptomic resources advance understanding of the resistance to diseases, insect pests, and environmental factors.
- New cultivars increase crop yields, decrease losses due to stresses, and broaden market opportunities.

Problem Statement 1B: Enhance beneficial microbial, plant interactions, and reduce impact of pests, pathogens, and microbial toxicity to crops and livestock.

Soil microbial communities are foundational to healthy soils that sustain plants, animals, and humans, but their roles in plant and ecosystem health dynamics and their response to agricultural practices are poorly understood. A better understanding of how plant and soil microbiomes respond to agricultural management, such as manure amendment, crop rotation, and harvest schedules, can help guide management practices and identify key microbial populations for future study. Research is also needed to identify microbiome functions, the mechanisms they use to interact with each other and plants, and subsequent outcomes for plant stress tolerance. For example, tall fescue with the fungal symbiont *Epichloë coenophiala* have better resilience to stress, but the physiological mechanisms are still unknown. Further, the most common symbiont produces alkaloids that are toxic to animals grazing the fescue. Although symbionts are available that lack animal toxins, their effect on tall fescue resilience has not been demonstrated.

Crop losses due to disease and pests continue to be a dynamic challenge, especially as climate change introduces unknown impacts on pest and pathogen distribution and damage. Better methods are needed to detect and characterize pests and pathogens, and better crop chemicals and biocontrol agents are needed to minimize damage. With development of high-throughput sequencing, the "one microbe - one disease" concept is being replaced with the "pathobiome" principle, which is the comprehensive biotic environment that includes a diverse community of all disease-causing organisms within the plant, their interactions, and the effect on plant health. While numerous individual pathogens and diseases they cause are well known, the concept and understanding of the "pathobiome" remains limited.

Finally, the preservation of stored forages can be compromised by bacterial contamination. Very damp silage or haylage will undergo a "secondary fermentation" that is characterized by the conversion of protein to ammonia and increased pH. However, plant antimicrobial compounds can inhibit secondary fermentation. Identification of plant antimicrobials is needed to decrease production losses during storage.

Research Focus

ARS will identify key microbial populations, their roles in plant and ecosystem health dynamics, and their response to agricultural practices. ARS will also develop methods to detect and characterize pests and pathogens, develop better crop chemicals and biocontrol agents needed to minimize damage, and identify plant antimicrobials to decrease forage loss during storage.

Anticipated Products

- Identification and characterization of soil microbial communities associated with healthy soils and healthy plants used for rangeland, pastures, forage, and bioenergy.
- Identification and characterization of microbial communities associated with diseased plants to minimize their effect on plant health.
- Biomarkers for soil health and microbial community function.
- Better methods of pest and pathogen detection, identification, and characterization for prevention of disease outbreaks.
- Fungicides and biocontrol agents that reduce disease in plants used for rangeland, pastures, harvested forage, and bioenergy.
- Persistent forage endophytes that are non-toxic to animals.
- Antimicrobial plant compounds that inhibit secondary fermentation of silage or haylage.

Potential Benefits

- Better understanding of the dynamics and function of soil microbial communities allows land managers to cultivate the beneficial soil communities that improve soil function and productivity.
- Producers can use biocontrol agents to promote greater plant productivity with reduced inputs.
- Identification of emerging pathogens and pests helps researchers develop resistant plants and management strategies to reduce damage.
- New detection methods enable indexing of plants and soils for potential pathogens so producers can implement appropriate management methods to reduce damage.
- Tall fescue varieties that contain non-toxic, persistent endophytes improve pasture productivity and animal performance.
- Inclusion of safe, narrow-spectrum antimicrobials reduces forage quality loss during storage and has beneficial effects on rumen function when fed.

Problem Statement 1C: Advance the understanding of plant metabolites and metabolic pathways to improve quality and value of plants used for harvested forage, fiber, bioenergy, pasture, and rangeland.

Metabolites are intermediate or end products of chemical reactions that occur in organisms. Primary plant metabolites such as amino acids, nucleotides, and acyl lipids, are directly involved in growth, development, and reproduction. Secondary, or specialized, metabolites such as phenolics and alkaloids are involved in non-essential plant functions and can influence interactions between a plant and its environment. Plants can accumulate a variety of metabolites that have negative impacts, such as toxins to grazing animals, but other metabolites have health benefits that could add value to forage crops. Understanding metabolite production and bioactivity is critical for choosing and breeding forage crops, particularly cover crops that could be fed as forage.

Condensed tannins are metabolites that accumulate in many forage species and can positively impact agricultural production systems, such as helping to improve forage protein use efficiency by ruminant animals. They have many useful activities, including antimicrobial and antiparasitic effects, and can also prevent pasture bloat. Tannins can have a vast array of chemical structures, and a better understanding of the relationship of tannin structure with biological function can help breeders and producers select tannin-containing forages or supplements that can increase animal production efficiency. Realization of the potential tannins can provide will require translation of lab-scale research to animal and farm-scale assessment.

Lignin is a fundamental component of plant cell walls, and the role of lignin in the digestibility of forages by ruminant animals has been thoroughly explored, especially in alfalfa. Synthesis of other cell wall components, how they influence cell wall assembly and composition, and impacts on forage digestibility, are less understood. A better understanding of the cell wall assembly and biosynthetic pathways could lead to new targets for plant breeders to increase forage digestibility, allow animals to use feeds more efficiently, and lower production costs and resources required to produce feeds.

Proteins available in forages such as alfalfa tissues can degrade after harvest and decrease their value as livestock and aquatic feeds. A better understanding of the plant activities that degrade proteins offer plant improvement targets for breeders and improve crop processing strategies to maintain forage quality. For example, in forages such as red clover, perennial peanut, and some grasses, postharvest oxidation of *o*-diphenol compounds by polyphenol oxidase (PPO) prevents degradation of plant protein. Reconstructing such a PPO system in alfalfa could greatly increase its forage value. Powerful new research approaches such as transcriptomics and proteomics can provide critical information in this area. Furthermore, although alfalfa and other forage crops are good animal protein sources, they may not contain some amino acids that are critical to animal nutrition, especially for high producing dairy cattle. Little work has been done to see whether amino acid profiles of alfalfa or other forages could be improved through breeding or genetic modification approaches for animal production systems.

Research Focus

ARS will advance understanding of select plant metabolites, how they are synthesized, and their impact in forage production systems. Research will focus on plant phenolics, alkaloids, and tannins. ARS will also conduct basic research to understand the structure and fate of the plant cell wall in ruminant production systems and ways to improve forage protein preservation and profiles.

Anticipated Products

- Improved methods (less labor intensive, higher throughput) to identify and quantify specific metabolites of forage and bioenergy crops.
- Better understanding of the roles of specific metabolites of forage and bioenergy crops.
- Knowledge of the impact of metabolites on nutritive value, postharvest storage, production efficiency and health of livestock.
- Methods for preserving protein in harvested forages.

Potential Benefits

- Understanding of prominent metabolites, including when and how they are made and their bioactivities, will aid in choosing and breeding forage crops.

- Selection of metabolites increases nutritive value, postharvest storage, production efficiency, and health of livestock.
- Better understanding of postharvest physiology, including protease activities, improves the use of forage crops.

Problem Statement 1D: Enhance genetic selection efficiency and quantify ecosystem services of turfgrass systems.

Turfgrasses are short grasses that tolerate mowing and provide a continuous ground cover. In the continental United States, approximately 163,800 km^2 of land is managed as turfgrass on lawns, parks, golf courses, sports fields, and roadsides. Turfgrasses provide soil erosion control, carbon sequestration, water filtration, and heat dissipation, and they enhance the beauty and attractiveness of an area while also providing a recreational surface. However, turfgrasses often require irrigation and other inputs that can negatively impact systems where they are grown. There is a need to better quantify turfgrass benefits and input requirements to identify if turf is the best option in a landscape and which turf varieties are best for a given land use.

Breeding better turfgrasses can be challenging due to their genetic complexity and difficult reproductive systems. Breeding objectives include seed yield, turf quality and color, drought tolerance, and resistance to disease. Unlike other agronomic crops, molecular markers linked to these traits have not been used to create turf cultivars, and a relatively small amount of genomic and phenotype information is available for turfgrass species. ARS recently initiated an effort to sequence the genomes of core turfgrass species. Reference sequences need to be completed for major warm- and cool-season turfgrasses, and molecular markers, along with high-throughput phenotyping, need to be used to identify marker-trait associations that can improve selection for traits of economic and ecological importance.

Research Focus

ARS will advance research on turfgrass genomic resources to improve breeding programs. ARS will document resource inputs required for turf production and develop management practices to reduce inputs. Finally, research will improve quantification of turfgrass ecosystems services to help identify systems where turfgrass is ideally suited and identify which varieties of turfgrass to use in those systems.

Anticipated Products

- Turfgrass reference genome sequences that can be placed in a publicly available database.
- Improved bioinformatic methods for turfgrass genome data analysis.
- SNPs, RNA expression data, and metabolites associated with traits of economic and ecological interest, such as water use efficiency, drought, disease, and seed yield.
- Established breeding populations for evaluation and development of improved germplasm for warm- and cool-season species.
- Knowledge of the genes controlling important traits of turfgrass.
- Cultivar identification using DNA based markers.
- Phenomics/high-throughput phenotyping platforms to enhance breeding practices.
- Better documentation and quantification of ecosystem services provided by turfgrasses.
- Innovative management techniques to reduce water and fertilizer use.

Potential Benefits

- Research and development institutions use turfgrass reference genomes to improve tolerance to biotic and abiotic stresses.
- Accurate molecular markers allow turf breeders to efficiently select for climate resilience traits.

- The turfgrass industry will have improved germplasm for drought tolerance, disease resistance, seed yield, and quality for intended land uses.
- Sod companies, seed companies, and researchers use cultivar identification for patent protection and to maintain genetic purity.
- Use of phenomics and high-throughput phenotyping increases the accuracy of trait measurement and reduces time and money spent on measuring traits.
- A greater understanding of turfgrass ecosystem services allows land managers to better decide where to use turfgrass and which varieties to use.
- Better water and fertilizer management practices allow land users to improve resource efficiency.

Component 1 Resources

Beltsville, Maryland	Corvallis, Oregon	El Reno, Oklahoma
Lexington, Kentucky	Lincoln, Nebraska	Logan, Utah
Madison, Wisconsin	Maricopa, Arizona	Pullman, Washington
St. Paul, Minnesota	Tifton, Georgia	Woodward, Oklahoma

Component 2: Improve field-scale management strategies and production tools for harvested forage and fiber systems for livestock, bioenergy, and bioproducts

Forages that are harvested by machine play important roles in animal and crop-based agriculture for food production and in non-food enterprises, such as feedstocks for bioenergy (e.g., cellulosic ethanol) and other bioproducts. Forage-based systems differ from grazed systems in that forages are grown, harvested, and typically stored before being delivered for their intended use. Because production, harvest, and storage represent major enterprise costs, there are constant needs to improve productivity and efficiency of forage supply. Due to climate and ecological variation across the United States, improvements in harvested forages need to be customized for different agroecosystems. These improvements also need to be adaptable to the current and projected impacts of climate change, including both gradual changes such as increasing seasonal temperatures, shifting precipitation patterns, and short-term weather extremes such as intense droughts and floods. Furthermore, there is growing demand for agricultural enterprises to reduce their impacts on the environment, quantify their contribution to ecosystems services, and contribute to mitigating climate change. Scientific research is needed to improve the potential for harvested forage systems to address these challenges. The three problem statements for Component 2 are designed to address the topics presented above by emphasizing three areas for harvested forage systems: 1) increased productivity, resilience, and ecological sustainability; 2) use of cover crops in forage systems; and 3) novel forage crops and value-added uses.

Problem Statement 2A: Develop harvested forage systems that optimize productivity, resilience to climate change, and environmental benefits.

Efficient and cost-effective production of high-quality harvested forages is the cornerstone of both animal production and biomass enterprises, and there is a consistent demand to improve productivity to maintain enterprise viability and rural prosperity. Research areas include improving chemical and physical conditions of soils and soil fertility for better forage establishment and growth; developing more diverse forage systems; reducing the need for fertilizer or pesticide inputs; developing field-scale methods for pest control; improving existing forage yield and quality and methods to analyze forage quality; improving harvest practices to maintain forage and soil quality; and improving storage efficiency and preservation of forage quality. Improvements in these areas would make forages more attractive to growers and allow them to adapt more readily to changing market conditions. These production improvements would also make forages more resilient to climate change; for instance, improved establishment of forage stands can protect soil from more intense rains.

There is a growing demand for agriculture enterprises to provide more ecosystem services such as clean air and water, and especially to help mitigate the effects of climate change. Harvested forages, especially perennials, have a high potential to address these needs through functions such as pollinator habitat, reduced soil erosion from vegetative cover, lower emissions of greenhouse gases due to lower fertilizer needs (especially for legumes), carbon storage in soils and vegetation, and generation of feedstocks for bioenergy. Research is needed to understand and document the ability of harvested forages to contribute to these ecosystem services, and to provide quantification tools for use in markets for ecosystem services or carbon trading.

Research Focus

ARS will develop harvested forage management practices that optimize productivity by promoting beneficial soil and plant interactions and soil health. Research will identify and develop regionally adapted management strategies that address forage productivity and nutritive value and increase resilience and adaptability to climate-related challenges. Research will also focus on improving practices related to soil conservation, reducing off-farm inputs, improving nutrient cycling, and reducing air and water quality impacts.

Anticipated Products

- Management practices to improve forage and biomass crop establishment and resilience to climate, weather extremes, pests, and diseases.
- Forage management practices that reduce the need for fertilizer inputs, improve crop nutrient use efficiency, and reduce sediment and nutrient loss from fields.
- Methods to increase the rate of hay dry down between cutting and harvest in dry bale systems
- Harvest and storage strategies, such as use of preservatives and inoculants, that optimize forage quality, such as protein for livestock and energy density for biomass feedstocks.
- Strategies of forage management that minimize emissions of greenhouse gasses and consistently build soil carbon.
- Protocols and models for quantifying ecosystem services in forage systems.

Potential Benefits

- Forage producers have better strategies for crop establishment, reduced inputs, and pest and disease management that improve in-field forage productivity and resiliency and reduce risk associated with climate change and weather extremes.
- Producers have forage harvest, handling, and storage management systems that maintain forage quality beneficial for animal feed, biofuels, and bio-based products.
- More U.S. producers integrate perennial forage and bioenergy crops into cropping systems, with a positive effect on climate change, soil health, and water quality.
- Producers have forage management strategies to reduce greenhouse gas emissions and store soil carbon.
- Ecosystem market managers and participants have better data and tools to reduce the uncertainty around quantifying the impacts and benefits of forage production systems.

Problem Statement 2B: Develop cover crop systems that provide agroecosystem services and forage resources.

Replacing fallow periods in crop rotations with cover crops is growing in popularity as a tool to provide a variety of services, such as reducing soil erosion, improving soil aggregation and infiltration, suppressing weeds, reducing nutrient losses in leaching and runoff, increasing soil organic matter, acting as green sources of nitrogen to reduce costs of fertilizer inputs, and producing forage for livestock to reduce feed costs. Integrating cover crops within main crop rotations may enhance these benefits by protecting bare soil and increasing the amount of biomass produced per unit of land area. However, any potential cover crop must be resource efficient, perform within the systems used to produce cash crops, and not deplete soil fertility or moisture important to establishment and growth of cash crops. While there is growing adoption of cover crops, there is still little scientific information in many regions on their establishment, management, and performance to address a range of on-farm issues.

Research Focus

ARS will develop management practices for improved cover crop selection, establishment, management, and utility in existing and alternative crop production systems. Research will identify and develop regionally adapted strategies that address cover crop function, resilience, and adaptability to challenges of climate change. Research will also focus on minimizing the agronomic barriers related to cover crop use and documenting the benefits to ecosystem services.

Anticipated Products

- Methods for improved establishment and termination of cover crops, including choosing the best cover crop for a system and recommended planting logistics, such as preparation of seed beds, planting method, seeding rates, stand management, and planting dates.
- Information on diversified cover crops and methods to integrate cover crops as living mulches or companion crops within the main production crop.
- Information on tradeoffs between use of complex vs simple mixes of cover crops for a variety of outcomes, including forage quality and productivity, or soil erosion.
- Regionally adapted options for cover crops such as summer-based systems, and problem-oriented options, such as minimizing nitrates in forages for animal health.
- Data and information on the effects of nitrogen-containing cover crops on soil fertility, nutrient supply to subsequent crops, and contributions to nutrient losses from fields.
- Recommendations for managing cover crops as forage sources for livestock.
- Enhanced tools and information to evaluate the effects of cover crops on soil health and soil carbon.

Potential Benefits

- Producers have regional recommendations for management of cover crops that meet the needs of their production system and climate while providing climate resilience and ecosystem services.
- Cover crop adoption increases nationwide, with parallel improvements in ecosystems services such as reduced soil erosion and nutrient losses

Problem Statement 2C: Promote novel crops and value-added end uses for harvested forage and fiber systems.

Worldwide, roughly 7,000 plant species are cultivated as crops for human food and animal feeds. However, just 20 percent of these species meet 90 percent of total food requirements. The remaining species are underutilized, or their use is restricted to limited geographic areas. This group includes well-known crops that are uncommon in a particular region, have not been developed for use at commercial scales, or have uses that are currently unknown or underdeveloped. This means there is a diverse range of underutilized crops, many with potential to use as forage or biomass crops, to enhance the sustainability of forage and livestock production, and to increase agroecosystem diversity. While novel crops such as hemp have potential to enhance existing crop and forage production systems, there are critical knowledge gaps and issues to be addressed. Any crop being introduced to a new region must perform within the environment and existing production systems without unduly reducing important resources such as soil fertility or water availability. There is limited information available on the performance of many novel crops in areas outside their traditional home range, or their function as parts of different cropping systems.

Research Focus

ARS will provide basic information on the agronomic production of novel crops, including establishment, performance, and molecular and genetic improvement. Focus will be placed on hemp and kernza, which is a perennial grain crop targeted for several human food and animal feed uses. Research will focus on novel crop characterization to determine potential for a variety of end uses, such as human foods, animal feeds, and bioproducts. Research will also investigate integration of novel crops at a farm-systems level to determine their feasibility in existing production and their potential to improve farm economic diversity, climate adaptability, and ecosystem services.

Anticipated Products

- Data and information on the establishment, agronomics, and performance of novel crops, especially hemp and kernza. Topics will include assessments of seed quality, dormancy, and production; and recommendations for optimizing planting, establishment, growth, and production under a range of environmental and management conditions.
- Characterization of novel crops for targeted end uses, including animal feed, human food, or bioenergy feedstocks.
- Management practices that allow producers to effectively use novel crops in existing production systems and weather and climate conditions, including recommendations for managing novel crops for livestock grazing and harvested production to increase options for end uses, and strategies for enhancing biomass or forage production under diverse environmental and management conditions.
- Data evaluating the impact of novel crops on soil health and cropping system carbon balances.

Potential Benefits

- Improved knowledge base allows producers to grow novel crops as sources of grain, forage, or bioenergy and increases the resilience of their production systems to weather variability and climate change.
- New flexible and adaptable crop rotations enhance on-farm economic performance in the face of climate and market variability

Component 2 Resources

Booneville, Arkansas	Corvallis, Oregon	El Reno, Oklahoma
Lexington, Kentucky	Lincoln, Nebraska	Logan, Utah
Madison, Wisconsin	Parlier, California	St. Paul, Minnesota
Tifton, Georgia	University Park, Pennsylvania	Woodward, Oklahoma

Component 3: Improve pasture and grazing management systems and technologies for agricultural productivity and ecosystem services.

Meeting the multifaceted challenge of profitable and efficient food production with reduced environmental impact and sustained ecosystem services requires a systems approach to crop and animal production that has a clear understanding of the tradeoffs inherent in biological systems. While agricultural production has increasingly tended toward enterprise specialization and intensification, there is renewed interest in how greater integration of crop, pasture, and livestock enterprises can improve the stability and resilience of agricultural landscapes. Benefits of integration include more effective use of complex topography and soils; reduced soil and nutrient losses; greater animal, pasture, and crop productivity; improved ecosystem services and reduced disservices; improved soil health and productivity; adaptation to longer growing seasons and changing weather patterns; and improved farm profitability through productivity, efficiency, income diversity, and decreased input costs. Opportunities to integrate livestock in pasture landscapes are emerging as interest in renewable energy (solar and wind) in agricultural landscapes expands. However, increasingly extreme weather associated with climate change requires management that explicitly incorporates greenhouse gas mitigation and identifies pathways of adaptation. Strategies suited to different farm systems and climates are needed to improve production efficiency and environmental outcomes of alternative approaches.

Integrated crop-pasture-livestock (CPL) systems that use science-based, ecological principles can improve sustainable agroecosystem functions. For example, CPL systems can integrate annual crops, perennial forages, and livestock and manage them to improve on-farm nutrient and carbon recycling, thereby increasing ecosystem services. However, CPL systems require more complex management strategies to achieve their potential, and information on system components and their interactions is limited. CPL systems are particularly applicable to small farms and underserved populations and have potential to help improve farm diversity and rural economies, but specialized decision support tools are required for these systems to succeed. Component 3 focuses on pasture and livestock grazing systems, and the problem statements focus on: 1) farm productivity, 2) ways to promote innovation, and 3) ways to provide societal benefits beyond food production.

Problem Statement 3A: Grazing system management to improve soil, forage, and animal health and productivity.

Pasture productivity, through contributions to grazing animal production and positive effects on the environment, contributes to a secure and sustainable food supply, especially by using marginal lands not suitable for crop production. Increasing both pasture and grazing animal productivity and utility requires a greater understanding of the complex soil-forage-animal interactions in grazing systems. Management strategies must be developed that consider pasture function within an ecosystem context, fit regional climate and soil differences, and can increase operational flexibility and economic viability. These strategies must include ways to deal with grazing animal health challenges, such as fescue toxicosis, parasites, and foot ailments. Furthermore, both gradual climate changes, such as seasonal temperature shifts and increasing atmospheric CO_2, and weather extremes, such as drought or floods, affect pasture species composition, forage yield and quality, and weed encroachment. Animal health and productivity are directly affected by these climate changes and indirectly by factors such as secondary compounds in grazed plants that change in response to environmental stress and increased intensity of disease or pathogens in longer, hotter summers. Research is needed to document climate-driven shifts in pasture resources, grazing animal behavior, and grazing animal status, and to develop resilient grazing systems.

Research Focus

ARS will develop pasture and grazing management practices that optimize productivity through soil, plant, and animal interactions and health. Research will identify and develop regionally adapted management strategies that address forage productivity and nutritive value while supporting the use of genetic selection to identify animal populations that are resilient and adaptable to challenges of climate change, such as parasites, disease, and limited resources. Research will also focus on improving practices related to soil conservation, reducing off-farm inputs, and improving pasture nutrient cycling.

Anticipated Products

- Pasture and alternative forage management strategies that improve forage species mixtures for stand resilience, enhanced productivity, and extended grazing seasons.
- Management strategies that optimize animal grazing in space and time to capitalize on forage quality and longevity and improve animal productivity and health.
- Forage and animal management strategies to improve grazing livestock health.
- Forage and grazing management practices for reducing off-farm inputs such as commercial fertilizer, feed supplements, fossil fuels, and herbicides.
- Improved methods and on-farm tools to assess soil health parameters, such as organic matter, aggregates, and biological communities and function.

Potential Benefits

- Producers have management approaches for mixed forage grazing and enhanced feed resource quality and availability that improve animal performance and reduce disease challenges.
- Animal breeders have value and selection indices that incorporate genetic resistance to parasites and address genetic by environmental (grazing) interactions.
- Ruminant farm producers rely less on medicinal applications for control of parasitic worms, with concomitant improvements in animal growth and reproduction.
- Producers rely less on off-farm inputs, including fertilizers, fossil fuels, and feed supplements, to improve farm profitability.
- An improved understanding of soil health allows producers to increase pasture and grazed forage productivity and quality.
- Producers have more management and forage selection options to extend the grazing season during times when traditional perennial forages do not produce well, such as drought, summer slump, early spring, and late fall/overwinter.

Problem Statement 3B: Technologies for precision management and diversification of forage-livestock systems

Understanding the complex interactions between land, plants, grazing, and animal components of forage-livestock systems is essential for sustainable and profitable management. Precision management technologies that improve measurement capability and expand data integration and analysis can help improve this understanding. For example, the ability to monitor pasture forage state and dynamics, including stand density, species composition, nutritive value, and forage accumulation, will allow more effective timing and implementation of management decisions (grazing, fertilization, animal density and rotation, prescribed fire) that influence input and output efficiency. Improved individual and group animal measurement capabilities (remote assessment of physiological measures, tracking technology to assess grazing behavior and plant choice, and use of GPS to control animal grazing) will help improve animal productivity, health, and well-being. Technologies that can generate and analyze these data will provide new means to address gaps that influence profitability in grazed systems in the presence of environmental changes and extremes. Optimizing resources and economic opportunities in grazed livestock systems requires strategic placement and use of forage crops and pasture in the landscape and integration of alternative land uses, such as silvopasture or renewable energy enterprises (solar and wind). Research is needed to help document the physical and economic benefits and limitations of land use placement and alternatives.

Research Focus

ARS will address complex CPL systems through innovative, transdisciplinary research focused on integrating automation and remote monitoring technologies (e.g., aerial drones, enhanced imagery, animal physiological assessment tools) that enhance grazing management and animal productivity. Research will address concurrent integration of data streams from the pasture and animal interfaces, identifying key elements that influence system productivity and efficiency. Efforts will help develop cost-effective, precision management strategies for diverse farming systems that include forage-animal production, specialty crops, and alternative land use approaches.

Anticipated Products

- Technology applications that support precision pasture management through accurate remote assessment of forage and soil characteristics.
- Improved methods to collect animal behavior and physiology measures and enable greater control of animal grazing in response to forage, soil, and land use characteristics.
- Grazing and animal management decision support tools that use precision animal, plant, and soil data to improve system-wide function across environmental settings.
- Guidelines for placement of pastures, forage crops, and alternative enterprises on landscapes, using data derived from research to develop simulated land-use scenarios.

Potential Benefits

- Integration of innovative technologies and precision data collection and analyses for pasture and grazing management enhances yield, reduces costs, and increases returns per acre.
- Integrated crop-livestock systems expand producer income opportunities through enterprises that more efficiently use resources.
- Grazing and forage management strategies that focus on early identification of challenges to animal nutrition and health improve animal productivity.
- Producers can capitalize on the efficiency of animal grazing in support of renewable energy initiatives in agricultural landscapes.

Problem Statement 3C: Grazing systems for improved environmental outcomes and ecosystem services.

Livestock grazing systems provide well-documented and field- to watershed-scale ecosystem services, such as minimal soil erosion and improved water quality. Configuring land uses to optimize grazing can improve the provision of such services. Research is needed to assess ways to optimize use of grazed landscapes and determine if strategies such as spatial diversification, grazing intensification, better use of marginal land, or reducing competing land-use strategies through crop-livestock integration, can increase the delivery of ecosystem services and reduce land-use competition between food and fiber/fuel. Tools such as simulation models or lifecycle analysis can help assess farm systems or supply chains, and research is needed to reduce the uncertainty associated with such tools. While grazed systems have distinct ecosystem benefits, they also have environmental impact challenges that research can address. Compared with confinement operations, grazing-based livestock systems can have greater greenhouse gas emissions per unit of output (milk and meat) due to greater use of forage in diets and poorer feed conversion efficiency. While grazing systems have less control over forage quality and fewer options for supplementation than confinement operations, particularly when targeting grass-fed, organic, or other specialty markets, there are opportunities to reduce gas emissions through forage selection, grazing management, and strategic supplementation. Research is needed to develop effective strategies that include ways to manage both pastures and animals. For example, adding legumes and novel forages in pasture mixtures can improve digestibility and reduce purchased fertilizer needs; long term maintenance of perennial pastures can improve soil carbon sequestration; and lifecycle assessments can facilitate a more consistent and thorough evaluation of inputs and outputs in grazing operations.

Research Focus

ARS will generate data and develop tools to assess the ecosystem services of grazing systems and will develop management practices that can increase those services, including water and air quality, soil health and productivity, pollinators, and systems-level carbon and greenhouse gas footprints. Tools and practices will be able to incorporate information about changing climate and diverse topography and soils for customized and more scientifically informed decision making.

Anticipated Products

- Spatial and temporal quantification of how ecosystem services support managed grazing systems.
- Landscape use planning tools, such as simulation models and lifecycle assessment, to investigate impacts of novel forages and grazing management strategies on economic and environmental sustainability of grazing-based livestock systems.
- Knowledge about options for and benefits of regenerative agricultural practices in pasture systems.

Potential Benefits

- Producers have greater knowledge about how to redistribute land use between forage and pasture to improve ecological balance while maintaining farm income.
- Producers have strategic grazing and supplementation strategies to reduce greenhouse gas emissions from grazing-based livestock systems.
- Improved information on carbon sequestration potential and net carbon exchange under different grazing management strategies can inform simulation models to support ecosystem services markets.

Component 3 Resources

Booneville, Arkansas	El Reno, Oklahoma	Lexington, Kentucky
Logan, Utah	Madison, Wisconsin	University Park, Pennsylvania
Woodward, Oklahoma		

Component 4: Develop systems-based approaches for rangeland management to enhance forage and livestock productivity, land restoration, and ecological services.

Rangeland managers, especially in the western United States, face several daunting challenges. First, rangelands are vast, complex landscapes that differ logistically and operationally from smaller, more uniform land uses such as cropland or pastures. Therefore, rangeland managers may not have intensive interventions available to achieve desired outcomes and must rely more on long-term, ecologically based management that considers highly variable climate, plant, soil, and animal drivers that interact at different spatial and temporal scales. Second, climate drivers are exhibiting both directional trends and increasing variability, including more extreme events, that make management more difficult and increase the risk of land degradation. For example, invasive plants continue to expand, droughts and floods are more extreme, wildfire extent is increasing, and growing season start dates and associated plant development have been altered. Woody plant encroachment, often by native species expanding their range, is increasing as a problem in western rangelands, reducing available forage and degrading ecosystems. Poisonous plants also continue to cause large losses to the livestock industry through death, reduced production efficiency, reproductive dysfunction, and compromised harvesting of rangeland and pasture forages. Finally, in the face of these changes, rangeland managers are increasingly expected to achieve both production and conservation outcomes and sustainably provide ecosystem services to society, such as wildlife habitat, biodiversity, and water supply and quality. Achieving these multiple outcomes makes management highly complex and requires enhanced cooperation and collaboration among private, state, non-governmental, and federal land managers.

Given these challenges, research related to rangeland management must address issues in a cross-disciplinary manner that takes a long-term (e.g., decadal) focus. Research should be ecologically based with a systems approach that can reliably assess biophysical and socioeconomic tradeoffs, take advantage of merging technologies such as virtual fencing and remote sensing tools, and explicitly include partners in all aspects of the process. Research topics and goals in Component 4 are itemized by problem statements that represent major topics of: 1) vegetative fuels management to mitigate wildfires, 2) management strategies to optimize agricultural productivity and land restoration, and 3) systems management approaches for multiple ecosystem services and socioeconomic outcomes. While these problem statements are separated for clarity in this document, rangelands research using a systems approach combines several topics and assesses multiple interrelated outcomes.

Problem Statement 4A: Fuels management to mitigate wildfire.

Western U.S. rangeland ecosystems evolved with wildfire as a natural disturbance, but in many regions frequency of large and intense wildfires is increasing; estimates suggest there has been a 179 percent increase in area burned and 83 percent increase in fire size in the past 30 years. Over that time, the federal fire suppression budget has increased 600 percent to $2.4 billion per year. Impacts such as altered vegetation composition and lost forage resources for livestock, reduced wildlife habitat, and threats to human safety and property are making land management more difficult. Wildfire frequency and intensity are driven by environmental factors such hot and dry weather and the quantity, composition, and connectivity of vegetation that acts as wildfire fuel. This includes herbaceous fuels such as grasses and woody fuels such as shrubs and small trees. Compared to herbaceous fuels, woody fuels drive hotter, more severe wildfires that cause greater damage to desired plant species and soil quality and make land restoration after fire more difficult. While herbaceous fuels are associated with less severe fires, their presence in high amounts, especially in landscapes dominated by invasive annuals such as cheatgrass, increases probability of fire ignition and the continuity of fuels across large landscapes, which increases the rate and extent of fire spread and in turn the risk of fires encountering more dangerous woody fuels.

A key intervention for impacting wildfire dynamics is intentional alteration of herbaceous and woody fuels. Research is needed to determine how management can influence the ratio of woody:herbaceous fuels in the landscape and possibly reduce wildfire impact. Information is needed about improved cutting, mowing, and herbicide management practices to reduce woody fuel abundance, as well as how livestock grazing can be used to alter herbaceous fuel abundance and connectivity. For example, grazing can be used to create linear fuel breaks that disrupt fire spread and provide fire-free areas for safety of suppression crews. Grazing can also be used for generalized fuel reduction in between fuel breaks. Given how vast rangelands can be, land managers need tools to strategically decide where using limited grazing can most effectively reduce wildfire risk. Research is needed on precision agriculture and geospatial technologies that allow managers to determine fuel amounts in time and space and use grazing more strategically, even when areas to be grazed do not match permanent fence boundaries. The ability to manage vegetation is influenced by both short-term weather variability and longer-term climate dynamics. Research is needed to understand how these complex feedback loops between environmental and management factors can be incorporated into decision making.

Research Focus

ARS research will focus on vegetative fuels management as a key intervention strategy to reduce wildfire frequency and severity. Topics will include development of tools to quantify fuel loads and connectivity and grazing and non-grazing management strategies that reduce fuels for fire and create fuel breaks. Research will also prioritize assessing the impact of fire on soil health and erosion, and post-fire vegetation recovery and appropriate grazing.

Anticipated Products

- Description of climate-modulated vegetative fuel dynamics and woody plant encroachment effects on regional wildfire incidence and intensity.
- Guidelines to determine when, where, and how to use targeted grazing to decrease exotic annual grasses and implement fuel breaks.
- Geospatial and precision livestock technologies to identify fuel accumulations in the landscape and target fuel reduction interventions.
- Fuels-reduction management practices that are adapted for short-term weather extremes and long-term climate changes.

Potential benefits

- Fuel breaks reduce wildfire impact and increase firefighter safety.
- Greater initiation of actions to manage rangeland fuel loading and levels prior to the fire season reduces potential for large, intense wildfires.
- Altered plant community composition (e.g., reduced annual grass or shrub fuels) helps reduce wildfire ignition, size, and severity.
- Land management agencies have science-based guidelines for grazing-based fuel reduction for public lands grazing permits.
- Less frequent and intense wildfires reduce loss of livestock forage resources, wildlife habitats, and human property.

Problem Statement 4B: Ecological management strategies for forage and livestock productivity, invasive species mitigation, and land restoration.

A major focus for rangeland management is to optimize both primary (e.g., forage) and secondary (e.g., animal) productivity to support agricultural enterprises whose goals are to convert forage consumption effectively and profitably by ruminant livestock into animal weight gains and high-quality protein for humans. Because rangeland agroecosystems are vast and diverse due to natural differences in soils, plant communities, elevation, and climate, both private and public rangeland managers must rely heavily on basic ecological principles rather than intensive interventions to achieve productivity goals. This includes considering the landscape as an array of ecological sites and using principles of state-and-transition models to maintain an ecological state or induce a transition to a more desirable state. Research is needed to continually update these ecological principles, especially how they are impacted by emerging and intensifying challenges such as climate change, invasive weeds, woody plant encroachment, and wildfire that can rapidly degrade land resources and productivity potential. Research is also needed to understand how experimental and experiential knowledge of land managers can be combined with basic ecological principles and monitoring datasets and translated into specific management practices such as prescribed and targeted grazing, prescribed fire, brush and woodland management, rangeland seeding and planting, upland wildlife habitat management, and herbaceous weed and invasive plant control. Research is also needed on the application of emerging technologies, such as unmanned aerial vehicles, to monitor and assess rangeland conditions. The goal is ultimately to provide producers with management and conservation practices and technologies they can readily implement to promote desired ecological states and associated productivity.

Research Focus

ARS research will use an ecological systems approach to conduct the science that supports producer efforts across space and time to optimize vegetative community structure, forage productivity, and cattle grazing for efficient, profitable, and socially sustainable agricultural enterprises. Specific research topics will be diverse, including invasive weed management, woody plant management, optimized grazing times and stocking rates, land restoration after disturbance, and minimizing impact of soil erosion.

Anticipated Products

- Science-informed and data-driven state and transition models for ecological sites.
- Improved rangeland system simulation models for soil erosion and health, forage availability and quality, grazing management, disturbance evaluation, and climate impact and resilience.
- Guidelines for prescribed fire and grazing to control invasive plants.
- Determination of sustainable cattle stocking rates to determine the economics of incorporating flexible stocking rates across grazing seasons.
- Guidelines to minimize livestock grazing-related degradation of soil and forage resources following fire.
- Guidelines on woody plant management and effects on ecohydrology and restoration.
- Methods and products for herbicide use and seeding that improves efficiency and effectiveness of land restoration.
- Near real-time precision technologies for rangeland monitoring and adapting cattle management decisions to changing conditions for optimized forage use and plant community health.

Potential benefits

- Enhanced understanding of the temporal aspects of transitions and thresholds associated with vegetation state changes increases effectiveness of land management practices.
- Livestock producers have management practices that are buffered against severe weather events and long-term climate change.
- Land managers better understand how to use targeted grazing in space and time to control invasive plants and minimize negative impacts on native plant communities.
- Land managers use adaptive grazing management principles to better use flexible stocking rates across grazing seasons to match animal demand more effectively with forage availability and quality.
- Improved seeding practices improve the establishment of diverse plant communities in disturbed rangelands.

Problem Statement 4C: Rangeland systems management for multiple ecosystem services and socioeconomic outcomes.

Public and private rangelands are complex social-ecological systems managed by disparate groups that have multiple, highly dynamic, and sometimes conflicting land-use goals. Rangeland management focuses predominately on sustainable food animal production and agricultural livelihoods. But rangeland stakeholders and managers have other goals, such as stewarding multiple ecosystem services that include conserving biodiversity, promoting carbon sequestration and climate neutrality, provisioning of wildlife habitat, and sustaining cultural systems and communities. Additionally, rangelands are vast and physically diverse ecosystems subject to highly dynamic natural forces that impact resource states. These socioecological complexities create significant challenges for making land management decisions. Rangeland research can serve an important role in supporting science-informed and data-driven decision making by providing rigorous evaluations of the synergies and trade-offs among multiple land use goals and outcomes. To do that most effectively, scientists need to include diverse rangeland user groups and types of knowledge directly in the research process. Integrating professional, local, traditional, and experimental knowledge increases the likelihood that research can help diverse rangeland mangers collectively achieve goals.

Research Focus

ARS research will focus on understanding and quantifying how rangelands contribute to a variety of ecosystems services, from soil and water quality to wildlife habitat and climate neutrality. This research will aim to develop tools such as simulation models for systems assessment and management practices that rangeland managers can readily implement and monitor progress. ARS will also focus on integrating socioeconomic research into traditional biophysical research and will develop methods to integrate diverse stakeholder groups directly into research projects and promote coproduction of knowledge that improves the ability of rangelands to meet a diversity of needs and goals.

Anticipated Products

- Tools for rangeland and watershed management to optimize water availability, use, and quality.
- Baseline greenhouse gas emissions from cattle grazing rangelands, including enteric methane, and management interventions that can reduce emissions.
- Information on how rangeland management practices affect soil organic carbon stocks and that supports science-based tools for reliably projecting carbon sequestration.
- Tools for setting benchmarks related to the benefits that rangeland ecosystems provide to society and evaluating the ability of management interventions to achieve production, conservation, and social outcomes.
- Quantification of the synergies and tradeoffs among management tools and their outcomes, especially via process models and empirical experiments, for systems management.
- Development and evaluation of effective methods of collaboration and knowledge co-production in complex natural resource systems.

Potential benefits

- At the watershed scale, water availability and use are optimized, and water quality is improved.
- Land managers have better tools for monitoring and adaptive management to build soil health and reduce soil erosion.
- Multiple stakeholders have increased understanding of the role of rangeland ecosystems in climate neutrality for livestock production.
- Public and private rangeland managers have greater capacity to achieve goals for multiple ecosystem services that range from biodiversity conservation to profitable ranching operations and rural communities.

- Stakeholder participation in the research process creates action-oriented knowledge, promotes social learning, builds trust, mitigates conflict, increases the impact of research findings, and builds capacity for problem solving in complex natural resource systems where diverse users otherwise have conflicting or misaligned goals.

Problem Statement 4D: Rangeland and animal management strategies that reduce the negative impacts of poisonous plants in the landscape.

Certain plant species are inherently poisonous to livestock and can interfere with the optimum use of rangelands and contribute to livestock losses. These losses can be reproductive (abortions), structural (anatomical deformities), and production related (reduced growth and efficiency and direct mortality). These losses are estimated to account for more than $300 million in damages for livestock producers annually. Management strategies are needed to minimize the impact of poisonous plants, and improved diagnostic tools are needed that veterinarians and land managers can use to identify livestock poisoned by plants, determine effective decisions for treatment, and assess risk to feed and food contamination. Enhancing the ability of livestock to graze rangelands containing poisonous plants should lead to more productive and economical land use.

Research Focus

ARS research will develop science-based guidelines for grazing livestock on rangelands infested with poisonous plants and evaluate the potential for establishing improved forage species on infested sites to improve livestock productivity, reduce the risk of livestock loss, and improve other rangeland ecosystem services. Research will also focus on enhancing feed and food safety by improving risk assessment and diagnosis of plant-induced poisoning of livestock and improving procedures and guidelines for diagnostic and prognostic evaluation to reduce negative impacts of poisonous plants on livestock.

Anticipated Products

- Diagnostic tools to identify livestock poisoned by plants, determine effective decisions for treatment, and assess risk to feed and food contamination.
- Recommendations, plant materials, and grazing strategies for producers to reduce livestock losses from poisonous plants.
- Methods and products for herbicide control of poisonous plants to create rangeland ecosystems that are more sustainable for desired uses.

Potential benefits

- Restored landscapes with improved plant species increase productivity of rangelands and pastures.
- Impacts of poisonous plants on grazing livestock are reduced.

Component 4 Resources

Boise, Idaho
Burns, Oregon
Cheyenne, Wyoming
Dubois, Idaho
El Reno, Oklahoma
Fort Collins, Colorado
Logan, Utah
Miles City, Montana
Reno, Nevada
Woodward, Oklahoma