USDA Agricultural Research Service

Action Plan 2019-2023

# National Program 215: Grass, Forage, and Rangeland Agroecosystems

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The Agricultural Research Service (ARS) is the intramural research agency for the U.S. Department of Agriculture (USDA) and is one of four agencies that make up the Research, Education, and Economics mission area of the Department. The ARS budget is allocated to research conducted in 17 national program areas through 750 projects located at 90 laboratories across the United States and abroad. The ARS national program addressing grass, forage, and rangeland agroecosystems involves research conducted at 20 U.S. locations by 91 full-time scientists and has an appropriated budget of approximately $42 million per annum.

**Vision**

Healthy, productive rangelands, pastures, forage cropping systems, and green spaces that support rural prosperity, food security, and earth's ecology.

**Mission**

The mission of the National Program is to provide research results that can be used to improve management decision making and enhance the utility, function, and performance of rangelands, pastures, forage, and turf agroecosystems while enhancing environmental and ecosystem services.

**Strategic Objectives**

The Grass, Forage, and Rangeland Agroecosystems National Program has three strategic objectives.

1. Enhance the utility and ecology of grass, forage, and rangeland agroecosystems.
2. Develop and characterize plant materials that optimize the utility, stress tolerance, resilience, and productivity of grasses and forages for uses such as animal nutrition and productivity, ecosystem services, bioenergy, and recreation.
3. Provide tools and decision support to managers to enable more resilient grass, forage, and rangeland agroecosystems.

**Relationship to the USDA Strategic Plan**

This National Program addresses the following Strategic Goals 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.

Research within component 3 of this plan specifically addresses data collection and model building that will be relevant to rangelands and pastures in the United States. These efforts will facilitate evaluation of land management efforts as well as decision making designed to affect improvements. Coordination of research efforts with other government agencies, as well as strategic engagement with land-grant universities and other external partners can help USDA develop new and innovative methods to improve environmental and production outcomes across the country.

Strategic Goal 2: Maximize the ability of American agricultural producers to prosper by feeding and clothing the world; Objective 2.3: Protect agricultural health by preventing and mitigating the spread of agricultural pests and disease.

Research within components 1, 2, and 4 of this action plan address toxic plants, invasive species, and forage and legume diseases that broadly effect the agricultural health of rangelands and pastures in the United States. A specific subcomponent of component 1 addresses the microbiome, which will include

exploration of detrimental as well as beneficial microorganisms associated with forage plants and soil in rangelands and pastures.

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; and Objective 5.3: Enhance productive agricultural landscapes.

Research within Component 3 of this action plan specifically addresses environmental measures and model building. Research on environmental measures will provide needed information to assess where interventions are needed, as well as the success of interventions once deployed. Model-building research is designed to provide decision support using available data and to maximize the effectiveness of interventions before they are deployed. Scientists within this program will continue to develop and streamline technical tools and assistance by partnering with scientific research institutions and private industry experts to enhance the conservation planning process and results. The short-term outcome will be measurable increases in qualifications and capacity for conservation planners that directly interact with customers. The long-term outcome, after customers implement science-based rangeland and pasture management tools, will be simultaneous improvement in production from the land along with reductions in soil erosion, improvements in air and water quality on the farm and downstream, and enhanced wildlife habitat as measured by programmatic trends and State, regional, and national conservation statistics.

**Relationship to the USDA Research, Education, and Economics (REE) Action Plan**

This National Program addresses the following Goals from the REE Action Plan:

Goal 1. Sustainable Intensification of Agricultural Production; Subgoal 1A. Crop and Animal Production; Subgoal 1B. Crop and Animal Health; and Subgoal 1C. Crop and Animal Genetics, Genomics, Genetic Resources, and Biotechnology.

Research within this National Program addresses pasture and rangeland vegetative biomass production, with the ultimate goal of providing nutritious feedstocks for the efficient production of livestock. Strategies within the program include genetic selection of plants (grass and legumes) to thrive in pasture and rangeland conditions. A portion of the program focuses on genetic selection of animals for efficient production in range and pasture settings.

Goal 2. Responding to Climate and Energy Needs; Subgoal 2A. Responding to Climate Variability; and Subgoal 2B. Bioenergy/Biofuels and Biobased Products.

Components of this National Program focus on management and genetic selection strategies to improve the resilience of rangelands and pastures to climate variability, primarily temperature extremes and drought. Other portions of the research focus on the applicability of biomass for biobased products.

Goal 3. Sustainable Use of Natural Resources; Subgoal 3A. Water Availability: Quality and Quantity; and Subgoal 3B. Landscape-Scale Conservation and Management.

A significant portion of the research within this National Program is focused on the sustainable use and management of rangelands and pastures. Research focuses on nutrient cycling within the environment, to be able to better ensure that use of rangelands and pastures do not contaminate nearby streams and waterways. Management and genetic selection strategies focused on the sustainable use and management of rangelands and pastures will also be developed.

**Relationship to the ARS Strategic Plan**

This National Program supports the following ARS Strategic Plan Goal areas and Strategic goals:

Strategic Goal Area 2: Natural Resources and Sustainable Agricultural Systems; Goal 2.5. 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.

Performance Measure 2.2.5. 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.

This National Program will perform research to improve agricultural production from U.S. grass, forage, and rangeland agroecosystems while simultaneously improving the ecological services that these areas provide. To accomplish this, research is focused on understanding the interacting ecological and production components of these areas. Improving the physiology and genetics of plant materials will enhance health, vitality, and utility of production systems for pasture, biomass for feed and fuel, rangeland, and turf. Development of integrated science-based tools will foster improved management of grass, forage, and rangeland agroecosystems. Generating strategies to manage grass, forage, and rangeland agroecosystems that simultaneously contribute to environmental conservation will benefit human and animal use of these areas.

**Relationship to ARS Grand Challenge**

In FY 2015, ARS set an aspirational goal for itself—to Transform Agriculture to Deliver a 20 Percent Increase in Quality Food Availability at 20 Percent Lower Environmental Impact by 2025. This Grand Challenge recognizes not only the many pressing issues facing U.S. agriculture, but that these issues are intertwined. In the minds of farmers, consumers, and citizens, having sufficient food to meet a growing population, ensuring that food is wholesome, and addressing the substantial environmental footprint of agriculture are inextricably linked. Recognizing that these issues need to be addressed holistically and synergistically, ARS research leadership developed this Grand Challenge to encourage and facilitate collaboration across projects, locations, and programs within the Office of National Programs (ONP) in utilizing a systems approach to address the agricultural research needs of the nation and the world.

This National Program is at the core of one of the three flagship Grand Challenge projects started in 2017, the Dairy Agriculture for People and the Planet project. The overarching objective of this project is to compare genetic differences in dairy cattle across a range of forage management systems to deliver nutritionally superior products that positively impact public health with a lower environmental impact. ARS scientists in this National Program are developing scientific knowledge to improve the production capacity of rangelands, pastures, and turf systems, while at the same time reducing the environmental impact of these production practices on the environment. Production capacity includes ecological services, livestock, and biomass production for energy and other biobased products. Environmental impacts include fire incidence, invasive species, pathogen and nutrient contamination, and detrimental effects of wildlife and plant species diversity.

**Introduction**

Grass, forages, and rangelands — which include turfgrass, herbaceous biomass harvested for fuel, forages harvested for feed, and pastures and native ecosystems for grazing — cover vast areas of the earth. Although these areas support a variety of native and non-native plant and animal life, some grasslands and most rangelands are typically unsuitable for growing annual crops due to characteristics of the environment such as topography, rainfall or other water sources, soil type, and climate. However, these areas benefit humans and animals in a variety of ways, including contributing significantly to nutrient cycling (e.g., carbon, nitrogen), maintaining water quality, providing vital habitats that support plant and animal species diversity, generating biomass for feed and fuel, and contributing to human food security through grazing of ruminant and non-ruminant animals. Turfgrass-covered areas contribute many of the same ecological services, while at the same time providing either aesthetic value or utility for recreational or other purposes. Although grass, forage, and rangeland areas contribute a great deal to human existence and to species biodiversity, proper management to balance productivity and ecological benefits is very complex. Often, information is lacking that enables optimal use and productivity of these areas, in terms of animal, biofuel, or other uses, with ecological services such as nutrient cycling, recreation, and wildlife habitat. Improper management also contributes to dangerous or detrimental conditions such as wildfire, dust storms, and excessive erosion.

To address these issues, this National Program will perform research broadly classified into four components. Component 1 is designed to provide basic information on the physics, biology, ecology, and microbiology of grass, forage, and rangeland systems. This information will inform the remaining components. Component 2 will specifically address selection of plants for a variety of characteristics to improve the function of grass, forage, and rangeland systems. The basic information from component 1 will provide information on phenotypes for effective selective strategies. The goals of selection will include the development of plants with traits important to the optimal function of pastures, rangelands, and turf covered areas, such as nutrient and toxic chemical absorption, seed production, germination, resilience (both environmental and grazing), persistence, and nutrient and/or chemical content (livestock, biofuels, and other production uses). Component 3 will specifically address measures and models for grass, forage, and rangeland systems. Information from Component 1 will help to inform what measures would provide the most beneficial information to assess agroecosystem function. Novel methods to measure these parameters will also be a part of the research within this component. Models will be developed using this information to both help determine when intervention is needed and what type of intervention may be most effective. The same measurement methods can then be used to assess the effectiveness of interventions. Finally, research in component 4 integrates the information from the previous components to determine management strategies that balance and optimize production and conservation on grass, forage, and rangeland agroecosystems. Research within this component focuses on four broad challenges that are current priorities: fire management; balancing livestock and ecology management; optimizing harvested forage production and ecological management; and strategies to mitigate invasive or toxic plant species. It is expected that research within this program will contribute to increased agricultural production from these regions, with simultaneous improvement in the ecological services provided by the same regions.

The integration of grass, forage, and rangeland research into broader production systems is a priority of a number of ARS national projects. Indeed, major national initiatives, including the Long-Term Agroecosystem Research (LTAR) Network, Dairy Agro-ecosystem Working Group, and the Conservation Effects Assessment Project, all include objectives to better integrate pasture, forage, and rangeland management strategies as part of a broader vision to enhance local nutrient cycling and improve the environmental sustainability of animal production systems. Climate change, bioenergy development,

increasing recreational activities, preserving natural resources, social interests, and a growing population all make management of grass, forage, and rangelands challenging and complex. Meeting competing demands for increasing food production while maintaining ecosystem services on these areas requires a combination of fundamental knowledge, science-based tools, and management strategies to renew, maintain, and enhance productive sustainable systems.

## Research Components

**Component 1: Provide fundamental knowledge and understanding of interacting ecological components of grass, forage, and rangeland agroecosystems.**

1A. Fundamental characteristics and interactions of the atmosphere, plant, soil, animal, and nutrient interface (includes climate, environment, plant biology, wildlife and livestock dynamics, and water and nutrient management).

1B. Role of microbes in promoting healthy soils, plants, animals, and related ecosystems.

**Component 2: Improve the physiology and genetics of plant materials to enhance health, vitality, and utility of pasture, biomass for feed and fuel, rangeland, and turf systems.**

2A. Plant resilience and resistance to stressors.

2B. Environmental remediation and restoration.

2C. Genetic manipulation of the nutritional value of forages for livestock and other uses.

2D. Aesthetics and utility of turf.

**Component 3: Develop integrated science-based tools to foster improved management of grass, forage, and rangeland agroecosystems.**

3A. Measuring and monitoring system status and function at various scales.

3B. Tools that support management decisions and aid implementation.

**Component 4: Generate strategies to manage grass, forage, and rangeland agroecosystems that simultaneously contribute to environmental conservation and are beneficial to human and animal use.**

4A. Fire assessment, management, and remediation.

4B. Livestock management and grazed or harvested forage utilization strategies.

4C. Improved growth, handling, and storage of harvested biomass for optimized quality and utilization as feed or feedstocks and positive environmental benefits.

4D. Land and animal management strategies that control or mitigate invasive species and reduce the negative impacts of poisonous plants in the landscape.

**COMPONENT 1: Provide fundamental knowledge and understanding of interacting ecological components of grass, forage, and rangeland agroecosystems.**

ARS has conducted foundational research on various ecological processes, but progress in rangeland production, conservation, and restoration is hindered by limited basic science explaining process interactions and changes over time and space. In addition to these interactions, new sequencing technologies and methods will enable better assessment of the role of microbes in rangelands and pastures. Significant gaps exist in the understanding of processes within the soil and their effects on the vegetation above. Improved understanding of fundamental relationships among management practices, ecological processes, and climate variability will facilitate development of management practices, prediction tools, and risk assessment. Fundamental, science-based understanding of soils, plants, animals, microbes, and their interactions is necessary to support sustainable livestock production and other uses of plant biomass. Research is needed to understand how stockpiled forages maintain forage yield and nutritional quality in the dormant season. Simultaneously, research is needed to aid conservation and restoration of rangeland natural resources. ARS has made substantial contributions to understanding fundamental processes at plot-to-landscape scales. However, adjusting to climate variability, changing land use patterns, and altered fire regimes will require increased understanding of how interactions among these elements vary across rangeland landscapes. This information will be necessary to support development of improved forage plants (Component 2), management decision aids (Component 3), and innovative management strategies (Component 4) necessary to adapt to changing conditions and management objectives.

**Problem Statement 1A: Fundamental characteristics and interactions of the atmosphere, plant, soil, animal, and nutrient interface (includes climate, environment, plant biology, wildlife and livestock dynamics, and water and nutrient management)**

Extreme or prolonged weather events can be caused by a variety of complex atmospheric and hydrologic factors, which when altered by climate change, often make these events more severe or more prolonged. Scientific evidence indicates that climate change is a result of increased concentration of carbon dioxide ($CO_2$) and other greenhouse gases in the atmosphere globally. These gases trap heat radiating from earth to space, resulting in a gradual and general warming trend of the oceans and atmosphere. This trend is not uniform around the globe, but generally leads to more evaporation, which can result in locally extreme precipitation. Some plants seem to respond positively to increased atmospheric $CO_2$, changing the nature of competition among plant species. Often the plants that show the strongest response to elevated $CO_2$ are invasive and undesirable species. The changing temperature and precipitation patterns will also likely cause a shift in where crops are optimally grown. For turfgrasses and forages, climate change within the United States will likely result in the expansion of warm-season and cool-season species further north, more heat stress, more variability in rainfall, longer growing seasons, increased humidity that may cause more disease, and the potential of more severe pest outbreaks as many pest species will be able survive winter temperatures.

Pastures span the nation's precipitation gradients, from the humid eastern and southern regions to the arid west, and may or may not be irrigated. Today, there remains a tendency for pastures to be underutilized and undermanaged, ignoring their potential as a profitable forage resource and productive foundation for high-value animal husbandry. Frequently, pastures are found in areas that are not well suited to row crop production and are vulnerable to the adverse consequences of intensive management. When properly managed, pastures serve as important components of landscape management strategies that support an array of ecosystem services. However, profitable, sustainable management of pastures can be complex, requiring a basic understanding of animal behavior and

physiology, plant phenology, nutrition, response to management, and site potential. Understanding the potential for profitable pasture management must be grounded in an understanding of the response of pasture forages to changing weather patterns. Many of ARS' pasture sites are also home to long-term precipitation and watershed monitoring. This long-term research has improved forecasting of weather pattern changes that would affect the availability of water to pasture species as well as the potential for pasture runoff to adversely impact water quality. Fundamental information is needed to model the complex conditions affecting differences in pasture forage yield, quality, and timing.

The U.S. Census of Agriculture and the annual USDA Agricultural Yield Survey show that forage yields across the country have made minimal gains since the 1980s. University field trials and some farms in both the eastern and western U.S. agroecosystems report yields significantly above the regional averages. However, the potential yield, quality, and persistence of forages is not being attained on many farms. Most U.S. cropland currently relies on chemical fertilizer applications and limited crop rotations, often resulting in soil degradation, erosion, and nutrient losses to the environment. Incorporation of perennial forages in cropping systems can mitigate many of these issues, but costs and labor needed in forage production, coupled with low national yields, have resulted in declining use of forages across the United States. There is a need to identify the environmental factors that prevent the full realization of yield potential and affect seedling establishment, stand persistence, and quality of forage grasses, legumes, and mixtures. There is a lack of understanding of how amendments to improve soil fertility, such as biochar, green manures, annual cover crops, and animal manures, affect soil, water, and plant processes and how these amendments can be incorporated into cropping systems. There is a need to understand how environmental factors, water, microbes, and plants contribute to soil fertility and improve soil health. Likewise, knowledge of effects of soil health on crop yield, resiliency, and nutrient cycling, use efficiency, and loss is also needed.

**Research Focus**

1A.1 Determine relationships between climate variability and change, plant production and nutrient value, and livestock gains.

1A.2 Better understanding of how changes in climate patterns interact with other ecological processes to cause changes in rangeland and pasture system status, health, and function.

1A.3 Determine what influences livestock movement and feeding behavior in range and pasture settings.

1A.4 Better understanding of variables affecting forage establishment, yield, quality, and stand persistence within the landscape.

1A.5 Evaluate the effect of strategic incorporation of perennial forages in cropping systems on soil and water resources.

1A.6 Evaluate the factors affecting nutrient use efficiency of plants.

1A.7 Determine effects of soil amendments, green manures, cover crops, and animal manures on soil, water, and plant processes.

1A.8 Measure the effects of soil health on crop yield, resiliency, nutrient cycling, and nutrient use efficiency and loss.

1A.9 Improve characterization of the physics of erosion by wind and water and develop strategies to conserve soil.

1A.10 Better understanding of how climate and site factors interact to constrain potential species composition and diversity, and consequent effects on ecosystem services.

1A.11 Measure the effects of different management strategies on pests of forage crops

1A.12 Quantify carbon and nitrogen fluxes and evapotranspiration dynamics, their controlling factors, and underlying mechanisms for different pastures under different grazing and management practices
1A.13 Improve our understanding of water use efficiency to optimize water usages.
1A.14 Identification of plant traits that improve soil quality.
1A.15 Improved understanding of the compounds, mechanisms, and characteristics of plant toxicities to livestock.
1A.16 Improve understanding of beneficial plant secondary metabolites to enhance livestock health and performance.

**Anticipated Products**

- Best management practices for livestock producers and rangeland managers experiencing the effects of weather variability and climate change (Focus 1A.1 and 1A.2).
- Data and information on the effects of nitrogen fertilizer application timing on biomass and soil carbon (1A.1).
- Recommendations for managing livestock behavior in range and pasture settings (1A.3).
- Enhanced tools and information for evaluating perennial and annual forage production systems based on soil organic matter (soil carbon), nutrient use or removal, and greenhouse gas emissions (1A.5, 1A.7, and 1A.8).
- Enhanced tools for determining weather and microclimatic requirements for establishment and maintenance of rangeland plant species. (1A.2 and 1A.4).
- Strategies for enhancing plant resiliency and forage dry matter production under diverse environmental and management conditions (1A.2 and 1A.4).
- Knowledge of the effects of soil amendments, green manures, cover crops, and animal manures on soil, water, and plant processes (1A.6, 1A.7, and 1A. 8).
- Strategies that optimize legume/grass mixtures to enhance nitrogen use efficiency in pastures (1A.6).
- Strategies and plant traits for improving soil health (1A.7, 1A.8, and 1A.14).
- Identification of conditions resulting in enhanced vulnerability to accelerated erosion (1A.9).
- Strategies for optimizing forage species selection to improve production and health under changing climates. (1A.2, 1A.6, and 1A.10)
- Basic information on water, carbon, and nitrogen cycling in range and pasture systems (1A.12 and 1A.13).
- Influence of various environmental factors on pests of forage crops (1A.11).
- Improved diagnostic techniques for laboratories and veterinarians for toxic plants (1A.15).
- Information on plant components that enhance health and performance of grazing animals. (1A.16)

**Potential Benefits**

Improved knowledge of how the climate, soil, plants, animals, water, and nutrients interact will inform research in Components 2-4 of the action plan. Basic information on climate effects on plants and animals will inform genetic selection and management strategies for reducing the impact of climate on production systems. Basic information on physical interactions between soil, water, and nutrients will inform measuring and modeling research in Component 3 and management systems research in Component 4. Information on nutrient interactions with plants and animals will allow genetic selection

for improved plant varieties that reduce nutrient losses into runoff (Component 2), more nutritious forages for animals, and animals adapted to the forages available in different production systems.

**Problem Statement 1B. Role of microbes in promoting healthy soils, plants, animals, and related ecosystems**

Microbiomes, the communities of microorganisms that live in soil and in and on plants are increasingly recognized for their critical role in the function of diverse ecosystems. Plant host, tillage, nutrient and pesticide inputs, and irrigation can impact microbial communities. However, the impacts of cropping systems and manure amendments on soil microbial community dynamics and microbial functions remain poorly understood. Both beneficial and pathogenic microbes are associated with forage crops. Understanding the dynamics of these microbes, their genetic diversity, and their roles in the environment is critical to developing sustainable management systems and improved plant germplasm. There is a need to understand the dynamics of soil and rhizosphere microbial community interaction with forage crop management systems and crop rotation to increase nitrogen and phosphorus utilization in dairy and other crop production systems. In particular, greater knowledge of the contribution of microbes to nitrogen cycling is needed.

Losses due to plant pathogens continue to challenge production and yields. A greater understanding of pathogen populations, their interactions within microbial communities, and their dynamics with management systems is needed. In addition, microorganisms can have a large influence on ecosystem function by impacting critical processes such as plant water uptake, nutrient availability, soil stability, and greenhouse gas production. The role of microorganisms on productivity and sustainability of rangeland ecosystems is poorly understood. Turfgrasses are commonly subject to frequent fertilization, mowing, irrigation, and application of herbicides and pesticides. The microbial community that exists in this environment and its response to the various management practices is just starting to be characterized and understood. There is a strong need to connect the complex processes of soil ecosystems with tangible production and environmental outcomes that have relevance to rangelands, pasture, and turf management. For instance, very little is understood regarding feedback in pasture management and soil health, particularly with regard to the quantity, quality, and timing of forage availability. Opportunities exist to leverage ARS' LTAR network, which is seeking to investigate appropriate metrics of soil health and to connect those metrics to agronomic and environmental responses. Fundamental work is needed to describe endophyte and microbial populations that exist in different pasture, rangeland, and turf plant communities and how they affect plant salt tolerance, drought resistance, and forage quality.

**Research Focus**

1B.1 Improve the understanding of the endophytic and soil microbial mechanisms associated with salt and drought tolerance, winter injury, seed shattering, herbicide resistance, and forage quality in forage and turfgrass.
1B.2 Toxic endophyte control in pasture management systems.
1B.3 Identify novel endophytes that provide biotic and abiotic stress tolerance without detrimental effects to livestock.
1B.4 Improved methods for identifying pathogens of legumes and grasses used forage and biomass.
1B.5 Characterization and impact of beneficial and pathogenic microbes associated with forage legumes and grasses.
1B.6 Effect of endophyte and soil microbe influences on rangeland structure and function.

1B.7 Identify soil microbial functions and systems that promote and/or improve nutrient procurement and utility.
1B.8 Understand the microbial communities that exist in the turfgrass, pastures, forages, and rangeland environments and the effects of management practices on these communities.
1B.9 Measure the impact of microbes on forage, pasture, and turf systems and determine the effects of management on soil microbial carbon sequestration.
1B.10 An increased understanding of how soil microbes interact with water, nutrients, climate, plant, and animal processes and how those interactions affect pasture or rangeland status and soil health.
1B.11 Improve the understanding on how beneficial symbiotic organisms, such as endophytes, epiphytes, and those found in the rhizosphere associated with forage and turf grass species that improve growth, persistence, and stress tolerance.
1B.12 Understanding the role of endophytes and their contributions to toxicity of forages.
1B.13 Develop web-based tools linking soil microbial profiles to vegetation, ecological site, and land condition.

**Anticipated Products**

- Information on endophyte biology that enhances plant biotic and abiotic stress resistance without detrimental effects to livestock (Focus 1B.1, 1B.2, 1B.3, 1B.11, and 1B.12).
- Improved use of endophytes and genetic approaches to enhance disease resistance in forage legumes and grasses and increasing seed yield in forage grasses (1B.1 and 1B.3).
- Strategies to enhance soil microbial function and promote or improve carbon sequestration and nutrient availability and use (1B.7 and 1B.9).
- Improved methods for identifying pathogens of forage and biomass legumes and grasses. (1B.4).
- Diagnostic tools, tests, assays, and/or phylogenies to aid in the identification, classification, and control of pathogens affecting forage cropping systems, biomass legumes, and grasses (1B.4 and 1B.5).
- Improved understanding of the turfgrass microbiome and management to improve health, vitality, and resilience of turf systems (1B.8).
- Management approaches that enhance the productivity, resilience, and sustainability of pastures and forage cropping systems (1B.5, 1B.7, and 1B.9).
- Information on the role of microbes on soil health in range and pasture settings (1B.6 and 1B.10).
- Web-based tools linking soil microbial profiles to vegetation, ecological site, and land condition (1B.13).

**Potential Benefits**

Because microbes provide the chemistry that makes soils function, information on the microbes present in the soil and how they are affected by cropping systems and manure amendments will allow improvements in soil function and productivity. In range, pasture, and forage systems, improvements include the ability to process animal waste (both chemically and microbially), enhanced retention of nitrogen and other nutrients by soil and plant components, and decreased release of nutrients and detrimental microbes into the watershed. Because soil microbes also include parasitic organisms for livestock and other microbes that may be detrimental to soil health or contribute to greenhouse gas emissions, understanding soil microbial dynamics will allow development strategies that reduce these detrimental effects.

**Component 1 Resources**

- Beltsville, Maryland
- Boise, Idaho
- Burns, Oregon
- Corvallis, Oregon
- El Reno, Oklahoma
- Fort Collins, Colorado
- Lexington, Kentucky
- Lincoln, Nebraska
- Madison, Wisconsin
- Miles City, Montana
- Reno, Nevada
- Tifton, Georgia
- University Park, Pennsylvania
- Woodward, Oklahoma

**COMPONENT 2: Improve the physiology and genetics of plant materials to enhance health, vitality, and utility of pasture, biomass for feed and fuel, rangeland, and turf systems.**

Improved plant materials are a cornerstone for improving the ecological and production potential of pasture, biomass, rangeland, and turf systems. These plant materials include native and introduced grass and forb species, germplasm collections held in the USDA National Plant Germplasm System, and improved selected germplasm and cultivars. A better understanding of phenotypes from the cell to whole plant level, physiological traits and processes, as well as the genomes, proteomes, and metabolomes of plants used in these systems will accelerate their genetic improvement and utilization for various purposes.

Plant breeding aims to create plants that have better characteristics than the plants currently present in the ecosystem or grown in production systems. For range, pasture, turf or harvested forage grasses, and legumes, these characteristics range from increasing germination and persistence in harsh environments (biotic and abiotic stress tolerance) to improving nutrient uptake and/or content of the plant so that it is more digestible by livestock or wildlife. For turfgrasses, plants are also selected that have increased plant density, green color, quality, durability, and a spreading growth habit.

**Problem Statement 2A. Plant resilience and resistance to stressors**

Rangeland, pasture, forage, and turf systems are sensitive to many environmental biotic and abiotic stressors, changing climatic conditions, and the pressures imposed by their utilization and management (e.g., mowing). Developing plant materials that have enhanced resilience to climatic extremes, adaptability to widely variable environmental conditions, as well as tolerance to biotic and abiotic stresses, is critical to maintaining productivity and ecology of forage, pasture, biomass, rangeland, and turf-based systems. The fundamental information gained from Component 1 regarding climate-plant interactions will be used to select for heartier plants. Selection will be focused on the plant metabolic systems that will allow greater plant resilience. This will include systems affecting germination in various harsh environments (dry or wet soils, high salt or toxic chemicals, high or low nutrient density) as well as the plants ability to persist in those environments. Assessment methods for desired traits using phenotypic and/or genotypic methods are needed that are robust and reproducible.

**Research Focus**

2A.1 Knowledge and improved manipulation of the metabolic and physiological capacity of legumes and grasses used for forage and biomass.

2A.2 Knowledge of the environmental stressors and identification of the genetic basis of biotic and abiotic stress tolerance in forages and turf.

2A.3 Develop technologies and materials to facilitate improved germination and persistence in harsh environments (dry, high salt, heavy metal).

**Anticipated Products**

- Identification of metabolites that improve the resilience of forage and biomass plants to stressors (Focus 2A.1).
- Databases useful to identify and characterize genetic and physiological pathways as a means to more efficiently improve plant materials (2A.1).
- Data describing temperature tolerances of native wheatgrasses (2A.1).
- DNA markers for identifying genetic stocks with biotic and abiotic stress tolerance (2A.2).
- New genomic, transcriptomic, proteomic, and metabolomics tools and other molecular resources to support cultivar development of forage grasses, turfgrasses, and legumes, and to

determine implications for plant production, fitness, and forage and turf utilization under differing environmental conditions (2A.2).

- New genomic and physiological tools and markers to identify genes and quantify genetic variation for drought and salt tolerance in forage and turf grasses and legumes (2A.2).
- Germplasm of grasses, cover crops, or forages with improved tolerance to abiotic and biotic stress, as well as to extreme climatic conditions (2A.1, 2A.2, and 2A.3).
- Alfalfa and forage grass cultivars/germplasms with improved salt tolerance, grazing tolerance, and persistence on semi-arid rangelands (2A.3).
- Identification of new and emerging stress challenges in the changing environment (2A.2 and 2A.3).

**Potential Benefits**

Benefits include improved germplasm suitable for forage and turf production in dry, high salt, or naturally or endogenously contaminated soils. Improved germplasm would expand the areas where forages can be produced and improve the amounts of forages currently produced in inhospitable landscapes. As climates change and produce new areas inhospitable to forage and turf production, ARS will have developed varieties that can be deployed into these compromised areas.

**Problem Statement 2B. Environmental remediation and restoration**

The interactions of climate changes resulting in drought, wildfire, and invasive species are degrading rangelands and threatening the sustainability of agriculture and the economic viability of rural communities across the west. Past land management practices, climate variability, and changing fire regimes are driving invasions of exotic annual weeds and woody plants that have resulted in degraded rangeland health and wildlife habitat and reduced ecosystem biodiversity and forage availability. ARS has made valuable contributions to linking a science-based knowledge of ecosystem dynamics with strategies and practices for impacting plant community structure and composition in these systems. However, the increasing rate of degradation coupled with increased emphasis on maintaining biologically diverse ecosystems under a dynamic management environment are driving a need for additional research to modify existing strategies and practices to maximize effectiveness and to explore new approaches for addressing management of these important landscapes. Future research challenges will involve both preventative actions to contain or limit the impacts of invading plants, as well as remedial strategies to restore ecosystem function and productivity.

Nutrient or other chemical retention by forages is a valid landscape treatment option to maintain or restore impacted lands. To optimize nutrient retention, plants are needed that retain more nutrients from the soil instead of allowing the nutrients to escape and run off into surrounding watersheds. Remediation of toxic metals and other pollutants from industrial and mining activities often rely on engineering-based technologies. Phytoremediation, or remediation of pollutants by using green plants, often involves plants that can absorb heavy metals from the soil and move them to the harvestable plant parts.

There is a strong preference to remediate disturbed or degraded rangelands with native plant species. However, restoration of these degraded ecosystems remains difficult due to a lack of improved native grasses and legumes that perform better than non-native forage species. More work is needed on the breeding, selection, and improvement of native grasses and native, nitrogen-fixing legumes to address these challenges. Native and introduced plant materials need to be developed that are easy to establish,

competitive, and persistent in local environments experiencing increased wildfires, drought, and heat associated with climate change. Improved methods are needed that optimize seed preparation; that allow plantings to be more harmonious with the landscape, and that time plantings to increase the probability of plant establishment success.

**Research Focus**

2B.1 Identify regions of the plant genome that allow the uptake of toxic metals or other compounds for plant remediation.
2B.2 Improvement of plant varieties for environmental remediation that optimize accumulation of various compounds from the soil or ground water.
2B.3 Develop strategies and technologies to improve the success of rangeland and pasture seeding.
2B.4 Develop sound methods to select appropriate plant materials for revegetation.
2B.5 Develop improved plant material that enhances productivity, conservation, and restoration of rangelands and/or pastures.

**Anticipated Products**

- Plant materials that can be utilized for soil and groundwater remediation (Focus 2B.1 and 2B.5).
- Identification of genes and genetic markers associated with uptake of heavy metals and other toxic compounds in perennial grasses or forages (2B.2).
- Technologies that can be used to improve the establishment of desirable plants at sites in need of restoration (2B.3).
- Methods to critically evaluate rangeland management and restoration practices (2B.3).
- Strategies and technologies (such as seed mixtures, planting timing, planting density, seed coating, and dispersion) that improve restoration or revegetation efforts (such as establishment of desirable plants in rangeland seeding projects) (2B.3).
- Environmentally adapted perennial grass cultivars and hybrids with superior persistence, seasonal forage accumulation, height, forage quality, and salt-tolerance (2B.4 and 2B.5).
- Native and introduced plant materials that are competitive, easy to establish, and persistent in harsh environments (2B.4 and 2B.5).
- Adapted native grass and legume germplasm for restoration of degraded rangelands and habitat for wildlife (2B.5)
- Competitive, easy to establish forb and grass germplasm for use in green strips to suppress cheatgrass and wildfires (2B.5).

**Potential Benefits**

Research results will be used to reduce the amount of rangeland infested with cheatgrass and other invasive species. Technologies will be developed that help restore sagebrush range to improve and increase habitat for sage grouse and other species dependent on these regions for mating and survival. Simultaneously, plant materials will be developed that can improve the productivity of grasslands and rangelands for livestock and other uses. Development of native grasses that can compete with cheatgrass will reduce the annual rate and extent of wildfires on the western range. Soils with toxic compounds will be remediated to become more productive and reduce potential movement of toxins to water resources. Excess nutrients can be recovered by plants from soils to reduce environmental contamination and reclaim these nutrients for use in agriculture.

**Problem Statement 2C. Genetic manipulation of the nutritional value of forages for livestock and other uses**

Pastures generally occur in landscapes where other agricultural and non-agricultural land uses are found. Given the array of ecosystem services pastures may promote, from wildlife and pollinator habitat to riparian soil stabilization, opportunities exist to expand or shift the location of pastures to achieve broader objectives, as well as to take advantage of sites with improved potential for productive pasture. Improved grass and legume germplasm is needed that can be efficiently utilized by livestock or for production of bioenergy and bioproducts. The composition of forage grasses and legumes has a major impact on the digestibility of the forage and nutrients obtained by ruminant animals and also influences the use of biomass for secondary products such as fuels. Improving the digestibility of roughage cell walls and preserving protein content will improve animal performance and reduce loss of nutrients to the environment. In parallel, dry matter yields and other production related characteristics need to be increased to provide sufficient feedstocks for animal nutrition and industrial uses.

Rangelands provide an extensive diversity of forage types that support livestock production and a diversity of wildlife species. Forage production and quality largely depend on the amount of precipitation received, which can be highly variable. Drought and fire can aid invasive plants such as exotic annual grasses that dramatically degrade the availability of nutritional forage. Annual grasses have higher inter-annual variations in production, shorter growing seasons, and less nutritional value when compared to native perennial vegetation.

Challenges associated with sustainable rangeland production systems include rising costs associated with feed grains and uncertain environmental conditions, which increase the need to produce livestock more efficiently on forage-based diets. This can be accomplished by improving forage use efficiency by livestock, extending the grazing season, and improving plant materials genetically to maintain forage yield and nutritional quality. Identification of animals that are more efficient at using nutrients from forage-based diets and strategies that improve forage utilization and resultant livestock production through strategic protein supplementation would increase sustainability of livestock production systems. Improved grass and legume germplasm is needed for diverse environments that can be efficiently utilized by livestock or the production of bioenergy and bioproducts

**Research Focus**

2C.1 Develop new genomic, proteomic, and metabolomics tools for grass and legume species to support cultivar development.
2C.2 Develop new methods for identifying, evaluating, and incorporating desired bioenergy and forage traits into improved germplasm.
2C.3 Increase the nutritional value of forages by management or development of improved grasses or forages.
2C.4 Improve understanding of and selection for forage nonstructural carbohydrates and cell wall structure and function to increase and optimize utilization by livestock.

**Anticipated Products**

- Improved analytical tools for rapidly determining cell wall composition, physiology, and development as they affect conversion efficiency (Focus 2C.1 and 2C.4).
- Genomic tools that support and enhance selection for improved forage and seed traits in forage grasses and legumes (2C.1).

- Genetic tools, plant breeding methods, and management practices for improving performance and conversion efficiency of grasses and legumes (2C.1, 2C.3, and 2C.4).
- Identification of annual winter crops for feedstocks within current row crop production systems (2C.2 and 2C.3).
- A selection methodology that enhances breeding for improved forage traits, including seed production and forage mass in grass-legume mixtures (2C.2, 2C.3, and 2C.4).
- New grass germplasm and cultivars with later flowering time (longer vegetative phase), greater digestibility and metabolizable energy, and broader adaptation to fluctuating and extreme climatic conditions (2C.2, 2C.3, and 2C.4).
- Forage grass and shrub germplasm adapted to semiarid rangelands with improved nutritional value (digestibility, protein, and metabolizable energy) when stockpiled for fall and winter forage (2C.2, 2C.3, and 2C.4).

**Potential Benefits**

Development of more nutritious or easily digestible forages will improve livestock production on pastures and rangelands. More digestible and nutritious forages will improve dairy production and reduce losses of nutrients to the environment. Development of forages that maintain their digestibility longer will reduce the need for supplemental feeds during the winter. Finally, successful development of improved forage varieties for biofuel and bioproduct generation will reduce our reliance on unsustainable fossil fuels.

**Problem Statement 2D. Aesthetics and utility of turf**

Turfgrasses are planted on 40 million acres in the United States and serve many benefits, such as soil erosion control, soil improvement, heat dissipation, noise abatement, and a decrease in noxious pests, allergy-related pollens, and human disease exposure when compared to areas with less management. Turfgrass also provides a recreational surface for outdoor sports and serves to improve the physical and mental health derived from recreational and leisure activities. Properly maintained turfgrass provides beauty and attractiveness that enhances the quality of life for the people around it. At the same time, turfgrasses must be easy to care for and maintain, with minimum inputs (water, pesticides, herbicides, and fertilizers).

Reference genomes provide a multitude of tools for genetic analysis, such as the ability to identify candidate genes for map-based cloning, link the genetic and physical maps of the genome, identify genes, understand the genetic structure of the species (including population tracking of gene families that are evolving by duplication or elimination), and obtain references for proteomic work. In addition, analysis of microbes associated with plants would be enhanced if the sequence of the host plant could be easily separated from commensal or symbiotic organisms. Sequenced genomes for most of the grasses are not currently available. Research is needed to begin to define the genomes for the grass species that are relevant to turf.

**Research Focus**

2D.1 Identify the genetic mechanisms that control traits contributing to the aesthetic value and reduced maintenance of turfgrass.

2D.2 Sequence the genomes of major turfgrass species.

2D.3 Develop genomic, proteomic, and metabolomics tools for grass species to support cultivar development.

2D.4 Improved understanding of the genetics by environment by management (GxExM) interactions of turf systems.

**Anticipated Products**

- Turf germplasm with improved seed germination and enhanced turf quality (Focus 2D.1).
- Turfgrass germplasm or varieties with increased water use efficiency and nitrogen use efficiency (2D.1).
- Data on genetic mechanisms associated with drought tolerance in Kentucky bluegrass and perennial ryegrass (2D.1).
- Identification of genes that control turf aesthetics (2D.1, 2D.2, and 2D.3).
- Genomes of Kentucky bluegrass, hard fescue, and crested wheatgrass (2D.2).
- Genomes for major turfgrass species (2D.2 and 2D.3).
- Documented GxExM interactions on turf color and quality for cool- and warm-season turfgrasses in cool temperature, reduced irrigation environments (2D.4).
- Management strategies to reduce turf maintenance (2D.4).

**Potential Benefits**

Obtaining reference genomes will facilitate genetic selection for turfgrass species, allowing for genomic technologies to be used for selection and identification of genes responsible for controlling desirable traits. Improved turfgrasses will increase the ability to maintain green spaces while reducing the cost and effort required to maintain those spaces. This will result in improved quality of life for homeowners and anyone utilizing green spaces for which turf represents some portion of the ground cover. Simultaneously, use of water and fertilizers by homeowners/landscapers for maintenance of lawns and other turfgrass covered areas will decrease, allowing the diversion of water for other uses and better management of nutrient runoff into waterways.

**Component 2 Resources**

- Beltsville, Maryland
- Boise, Idaho
- Burns, Oregon
- College Station, Texas
- Corvallis, Oregon
- El Reno, Oklahoma
- Lexington, Kentucky
- Lincoln, Nebraska
- Logan, Utah
- Madison, Wisconsin
- Miles City, Montana
- Pullman, Washington
- Reno, Nevada
- Tifton, Georgia
- Woodward, Oklahoma

## COMPONENT 3: Develop integrated science-based tools to foster improved management of grass, forage, and rangeland agroecosystems.

Changing land use patterns, climate variability, and altered fire regimes pose significant challenges for managing grass, forage, and rangeland ecosystems. Management strategies must evolve and adapt to these changes to improve productivity and sustain environmental resources. Measuring and monitoring system status and function to understand how these ecosystems are responding to change is the basis for identifying opportunities for innovations in management and enabling land managers to make decisions that maintain or improve landscape outcomes. Development and improvement in models based on these measurements will facilitate decision making. Integrated science-based tools that allow managers to evaluate multiple management strategies and compare outcomes will help take the guesswork out of making decisions.

### Problem Statement 3A. Measuring and monitoring system status and function at various scales

Altered seasonal extremes in temperature and rainfall are affecting forage composition and yield, forage quality, and persistence relationships in both rangeland and pasture settings. Many forages are producing yields below their genetic potential; however, the factors for this yield gap have not been identified. Rangelands are comprised of complex, heterogeneous lands that are sensitive to, and often slow to recover from, disturbances. The complexity of these landscapes can be separated into distinct ecological sites based on vegetation composition and productivity that also provide insight into how each will respond to management actions and natural disturbances. The soils and ecosystem processes that determine the distinctiveness of a particular ecological site vary across temporal and spatial scales. This complexity requires science-based support tools to inventory, assess, and classify ecosystem status, function, and temporal transition or trend. In cases where rangelands may not be functioning at their full potential, such tools can suggest the need to implement conservation and restoration practices specific to a particular site, taking into account the underlying conditions and historical land-use. Understanding how abiotic and biotic thresholds dictate and limit the application of conservation and restoration practices is a critical step towards increasing the effectiveness of rangeland management.

Turning to pastures, environmental extremes such as high temperature and drought also reduce dry matter productivity in pasture systems due to heat and water stress on forages, causing annual economic losses of $900 million to $1.5 billion in the dairy industry. Grazing systems provide fewer options to ameliorate the effects of environmental extremes compared with confinement operations, which can result in shifts in grazing behavior. Remote sensing or other useful methods to assess and predict pasture productivity, including both dry matter and nutrient availability, are needed to help producers make management decisions. In addition, a greater understanding is needed of the complex animal-forage interactions in grazing systems, specifically how shifts in forage quality, yield, and species composition affect grazing behavior and dry matter intake of grazing ruminants as well as how environmentally induced shifts in grazing behavior affect these sward parameters. Improved methodologies and behavior-monitoring tools are needed to more accurately assess grazing behavior, forage intake, and diet selection. This research would result in improved management strategies for grazing herds to optimize both forage and animal productivity with increasing environmental changes and extremes.

#### Research Focus

3.A.1 Develop techniques for evaluation and monitoring of rangeland and pastures that leverage remote imaging, GIS, and/or Big Data technologies.

3.A.2 Improve methods to classify state and transition or ecological site potential of rangelands and/or pastures.
3.A.3 Develop methods, assessments, and/or tools to evaluate the ability of landscapes to supply production demands, as well as quantifiable ecosystem goods and services.
3.A.4 Assess changes in soil carbon, carbon and nitrogen emissions, and water dynamics from plot to landscape scales and upscale to regional scales using remote sensing approaches.

**Anticipated Products**

- Ecologically based pasture assessment, concepts, and monitoring tools for forage suitability groups and for regional scale assessment of forage and pastures (Focus 3A.1 and 3A.2).
- Improved remotely sensed techniques for rangeland evaluation and monitoring (3A.1).
- Improved ecological site descriptions, state and transition models, and/or habitat suitability assessments (3A.2).
- Measurements of economic and environmental benefits of perennial legumes and grasses in cropping systems (3A.3 and 3A.4).
- Web-based tools to assess management effectiveness using monitoring information by ecological site for western rangelands (3A.1, 3A.2, 3A.3, and 3A.4).
- Soil health measures and metrics for use in pasture, rangeland, and forage systems (3A.3 and 3A.4).

**Potential Benefits**

Methods will be developed that provide routine and/or real-time measures of aspects of rangeland and pasture function, including forage productivity, nutrient cycling, and ecological functions like plant species and erosion. These monitoring methods will feed into Problem Statement 3B, where they will be used to develop predictive models and other decision-support tools to enable land managers to make decisions that maintain or improve landscape outcomes.

**Problem Statement 3B. Tools that support management decisions and aid implementation**

Given the complex array of factors affecting the outcomes of pasture, rangeland, and turf management systems, science-based tools are needed for implementing and monitoring grazing, conservation, and restoration practices at various management scales. A variety of tools are needed to support decisions, from those that predict particular outcomes of management to those that seek to prioritize and better focus management in space and time. At their best, decision-support tools serve to educate end users and target audiences, which may range from producers to regulators to the general public. However, the utility of a decision-support tool is closely tied to its availability, ease-of-use, and inferences. ARS' history of advancing useful tools for nutrients, pests, grazinglands, and turf is well established.

Predictive models to evaluate and maximize production and environmental benefits of perennial cropping systems are needed. Effective models integrating various measurements made on range and pastures with proposed modifications to that environment are needed to help inform decisions on the best modifications to undertake for a desired outcome. Ideally, models that integrate predicted temperatures and rainfall, current status of the environment, and the influence of various proposed modifications (plant species, livestock, biomass harvest, nutrient deposition, irrigation) would be extremely useful in deciding the optimum strategy to reach a desired outcome. Fundamental characteristics of the environment and plant materials obtained from Components 1 and 2 would also potentially be incorporated into these models to improve their effectiveness. Outcomes might include

restoration of rangelands to a desired state; balancing restoration with utility for livestock or other uses; maximizing land output; prediction of land carrying capacity under adverse conditions; and contribution of various management practices to detrimental outcomes, such as the spread of invasive species, fire danger, release of greenhouse gasses, or nutrient runoff into watersheds.

**Research Focus**

3B.1 Develop tools to integrate climate and weather patterns into restoration and land management decisions.
3B.2 Develop decision-support tools to assist land-use planning in the placement of pastures, forages, and bioenergy crops.
3B.3 Develop predictive models to evaluate, quantify, and maximize productivity and environmental benefits of annual/perennial cropping systems.
3B.4 Develop indicators and guidelines for evaluating restoration and management practice success based on ecological site landscape position and climatic variation.
3B.5 Develop ecological site classifications that managers can use to improve current management and adaptation to climate change.
3B.6 Determine site specific recommendations for soil water availability combined with nutrient requirements to optimize forage production for economic sustainability.
3B.7 Develop tools to identify environmental factors affecting forage production to maximize productivity and environmental and ecosystem benefits in diverse environments.
3B.8 Develop or improve models to assess rangeland and pasture ecosystems, soils, hydrology, restoration, and productivity to support improved management decision-making.

**Anticipated Products**

- Weather and climate application technology and a strategy toolbox for both restoration and education purposes (Focus 3B.1, 3B.4, and 3B.5).
- Bioclimatic models of forage species distributions under climate variability, and grassland management guidelines to optimize environmental benefits in forage production systems (3B.1, 3B.2, and 3B.3).
- Site specific recommendations for forage species, nutrient requirements, and economic inputs for improved farm management (3B.1 and 3B.2).
- Decision support systems for using improved native and introduced plant materials to enhance or restore rangelands that fundamentally differ in disturbance and land-use history (3B.1, 3B.2, 3B.3, 3B.4, and 3B.5).
- Guidelines for placement of pastures, forages, and bioenergy crops on landscapes derived from assessment of simulated land-use scenarios (3B.2).
- Decision support tools to determine where on the landscape specific conservation practices will be most effective (3B.2 and 3B.4).
- Decision support information on the economic and environmental impacts of cropping systems, including perennial forages that can be used by producers, conservation services, and policy makers (3B.2 and 3B.3).
- Models and databases of the capacity for different landscapes to provide for a variety of ecosystem services, including livestock production for the development of best management practices (3B.2, 3B.3, and 3B.4).
- Improved rangeland hydrology and erosion models applicable for optimizing the enhancement of disturbed rangelands following fire, juniper encroachment, and annual grass invasion,

allowing assessment of hydrologic impacts, management alternatives, and conservation benefits (3B.7 and 3B.8).

- Improved cropland hydrology, water quality, and erosion models for optimizing crop productivity under various tillage and grazing practices while reducing environmental footprints (3B.7 and 3B.8).
- Decision support information on native forage species beneficial to native pollinators that can be incorporated into livestock pastures (3B.7).
- Data and decision-support tools for improved forage systems that maximize productivity and environmental and ecosystem benefits (3B.6, 3B.7, and 3B.8).
- Improved ecohydrological models for rangelands and pastures (3B.8).

**Potential Benefits**

Benefits of the results from this research will help take the guesswork out of making decisions regarding various environmental modifications. Effective models will reduce the trial and error, and the wasted resources, that are currently a part of management of rangeland and pastures. Various strategies can be tested *in silico*, and the possible results assessed, before an intervention or management strategy is undertaken. Effective models, by providing valid decision support, will thus improve our confidence and ability to direct changes to the environment for a given targeted outcome.

**Component 3 Resources**

- Boise, Idaho
- Booneville, Arkansas
- Burns, Oregon
- El Reno, Oklahoma
- Fort Collins, Colorado
- Lincoln, Nebraska
- Madison, Wisconsin
- Miles City, Montana
- Reno, Nevada
- University Park, Pennsylvania
- Woodward, Oklahoma

## COMPONENT 4: Generate strategies to manage grass, forage, and rangeland agroecosystems that simultaneously contribute to environmental conservation and are beneficial to human and animal use.

Traditionally, rangelands and pastures have been managed to provide food, feed, and fiber through management practices that achieve sustainable forage and livestock production. Today, these lands are increasingly expected to simultaneously provide for multiple competing ecosystem goods and services. Determining tradeoffs associated with changing management from principally forage and livestock production to a blend of production and conservation goals is a significant research and management challenge. Changing goals and land use patterns require increased understanding of systems-level interactions among climate, plants, soils, animals (including livestock and wildlife), and land management practices. Compounding the uncertainty of determining the most appropriate tradeoffs associated with provisioning multiple ecosystem services from rangelands involves adequate scientific understanding and application of management practices over long periods of time and across vast complex landscapes. The potential for using livestock as a tool for managing plant communities, rather than simply as products from rangelands, offers an opportunity to enhance ecosystem services within a wide spectrum of ecological and climatic conditions and for varying management objectives. Component 1 will provide basic information on the fundamentals of the environment affecting rangeland, pastures, forages, and turf. Component 2 will provide plant materials with improved characteristics for applications to these land-use areas. Component 3 will provide measures and predictive models that will allow assessment of the current and putative future states of various landscapes, to provide decision support for possible interventions. In this component, information from the three previous components will be integrated and validated, testing whether the fundamental information, plant materials, and models are sufficient. Validated strategies will feed forward to producers as useful strategies for range, pasture, and forage management. Simultaneously, unsuccessful validation will feed back to the other components, revealing gaps in fundamental information, availability of appropriately selected plant materials, and measures and models for decision support.

### Problem Statement 4A. Fire assessment, management and remediation

Wildfires are an increasing problem in dry western areas of the U.S. At the same time, the controlled use of fire to manage rangelands and pastures is a successful management scheme to improve productivity. When a wildfire occurs, questions remain regarding what remediation efforts will be effective, and when it is appropriate to return the land to grazing and other uses. Much of the increase in fire frequency is due to various invasive annual grass species and fire can either encourage or discourage the prevalence of these species depending on the environment. However, many of the environmental influences on the effective use of fire to control these species is still unclear.

#### Research Focus

4A.1 Develop fuel management and post-fire grazing strategies.
4A.2 Develop grazing management strategies that reduce fuel for fires to reduce wildfire disturbance on the landscape.
4A.3 Optimize the role of prescribed fire in maintaining ecosystem function and productivity.
4A.4 Develop techniques for using pyrolysis to manage woody encroachment and enhance soil health and rangeland productivity.

**Anticipated Products**

- Data and information on post-fire recovery and appropriate grazing management (Focus 4A.1).
- Grazing management strategies to influence fuel management to reduce fire frequency (4A.2).
- Data and information on interactions between annual prescribed burns and livestock grazing on species composition and biomass production/fuel loads of native prairie (4A.2 and 4A.3).
- Management strategies for improved use and management of prescribed burning (4A.2 and 4A.3).
- Data and information on the applicability and feasibility of using biochar to manage woody encroachment and land restoration (4A.4).

**Potential Benefits**

The most significant benefit of this research will be the reduced incidence of uncontrolled rangeland and pasture fires in the United States. These fires are responsible for the loss of property, livestock, vital wildlife habitat, and contribute to poor air quality and safety concerns over large regions of the United States depending on their extent. Improved management of fuel and effective use of fire as a management strategy will improve the beneficial use of rangelands and pastures, because grass and other plant material that contribute to fuel load are nutrient poor and unsuitable for livestock or other wildlife. A secondary benefit will be improved management strategies for the beneficial use of fire to improve rangeland and pasture health and productivity.

**Problem Statement 4B. Livestock management and grazed or harvested forage utilization strategies**

It is well established that differences exist in grazing animal behavior within pastures and in response to different pasture forages. These differences extend across species, such as sheep, goats, and cattle, and also occur between breeds within a species. Although a majority of the nation's beef herd originates from pastures and rangeland, there has been relatively little research to select for breeds, or combinations of breeds, that are best suited for grazing. Selection for behavioral traits that could improve their access and use of pasture forages would reduce the degradation of natural resources. There is a similar dearth of research on the physiological response of beef cattle to pasture forages. Certainly, even less research has focused on grazing dairy cattle, even though grazing remains common in many Midwestern and northern dairies, albeit for heifers and dry cows. Several efforts within ARS have the potential to elucidate breed-related differences in grazing animals. This includes research on Criollo cattle in southwestern rangelands and the Dairy Grand Challenge that seeks to evaluate differences in the response of Holstein and Jersey dairy breeds to different diets and to better understand the optimization of performance and efficiencies in integrated production systems.

In addition to breed differences, behavioral adaptation, within and across breeds, is another important component to developing optimal grazing systems to serve greater ecosystem services. Grazing behavior is a combination of genetic and learned behaviors, the latter of which is frequently influenced by pre-weaning exposure with the dam as well as individual experience that allows animals to adapt to changing forage conditions, nutritional needs, and climate. Research efforts within ARS are evaluating feeding, grazing, and pasture management strategies to develop best management practices for grazing livestock systems to optimize animal and plant production while minimizing environmental impacts. Managers need integrated land and livestock management strategies that enhance both livestock production and conserve rangeland ecosystems to provide multiple ecosystem services, including soil and water conservation, control of invasive species, recreation, and wildlife habitat conservation, all

under changing environmental conditions. This Problem Statement focuses specifically on strategies that can simultaneously provide forages suitable for livestock grazing along with the full spectrum of other ecosystem services essential to ecosystem health and rural communities, including water resources, soil conservation, wildlife habitat, biodiversity, recreational opportunities, and cultural heritage values.

Pasture-based systems are challenged with not only meeting nutrient requirements, animal health, and production goals of the grazing herd, but also providing for other ecosystem services, such as wildlife habitat, reduced soil erosion, improved water quality, nutrient utilization, and reduced negative environmental impacts. For example, high-forage diets (such as pasture-based diets) have been shown to result in increased methanogenesis and related greenhouse gas emissions, and represents a loss of productive energy and reduced nutrient efficiency for the grazing ruminant. In addition, overgrazing pastures not only reduces animal health and productivity, but can result in decreased forage yield, increased weed invasion, decreased water-holding capacity, and increased erosion. Improved feeding and management strategies are needed that better manage nutrient and animal supplementation for increased production, improved nutrient utilization efficiency, reduced methane production, and improved adaptability to environmental and climatic change.

**Research Focus**

4B.1 Develop pasture- and forage-based livestock management systems that enhance soil health and feed efficiency.
4B.2 Improve management strategies for multi-animal species grazing systems (either simultaneously or sequentially).
4B.3 Develop pasture- and forage-based livestock management practices that improve resilience to climate change, conserve soil or protect water quality, and optimize production, conservation, and environmental goals.
4B.4 Determine cattle and wildlife interaction effects on livestock and wildlife distribution and performance and vegetation dynamics.
4B.5 Determine animal genotypes and phenotypes that do well on low-input forage systems.
4B.6 Develop efficient strategies for producing livestock on forage-based diets, targeting optimal productivity, and feed conversion efficiencies.
4B.7 Develop management strategies for the use of stockpiled grasses, legumes, forbs, and shrubs to extend the grazing season in the fall, winter, and early spring to enhance environmental sustainability and economic profitability.
4B.8 Develop grazing management strategies for maintenance of a diverse native plant pasture that serves livestock and wildlife including native pollinators.

**Anticipated Products**

- Improved forage and livestock management practices and technologies (Focus 4B.1, 4B.2, 4B.3, 4B.6, 4B.7, and 4B.8).
- Information on intensive grazing of livestock to improve forage and microbial diversity (4B.1 and 4B.3).
- Best management practices for multi-animal species grazing to increase pasture utilization and efficiency (4B.2).
- Botanical products that influence carbohydrate utilization (4B.2 and 4B.3).
- Small ruminant pasture systems to control internal parasites (4B.2 and 4B.6).
- Documentation of the effect of grass-legume mixtures on livestock performance and economic and environmental sustainability within pasture-based dairy systems (4B.3).

- Demonstrated increase in productivity of grass-monoculture dominated grazinglands through incorporation of improved legume-interseeding strategies (4B.3 and 4B.6).
- Management practices that reduce manure, sediment, and nutrient movement off-farm and retain plant productivity under variable environmental conditions (4B.3 and 4B.7).
- Data, indicators, and/or metrics of cattle and wildlife interaction effects on animal distribution and performance and vegetation dynamics (4B.4).
- Identification and selection of animal genotypes and phenotypes that are productive and thrive on low-input pasture systems to minimize management inputs (4B.5).
- Identification of animals that are more metabolically efficient at utilizing nutrients from rangeland, pasture, and harvested forages (4B.5 and 4B.6).
- Strategic supplementation strategies that more efficiently utilize pasture and rangeland forage (4B.6 and 4B.7).
- Strategies to improve forage utilization and livestock production through protein and post-rumen amino acid supplementation (4B.6 and 4B.7).
- Guidelines and management options for optimized use of forage crops for livestock (4B.6 and 4B.7)
- Data identifying grass and legume species and mixtures that optimize forage production and nutritional value for fall and winter grazing on semiarid rangelands (4B.6 and 4B.7).
- Decision support information on grazing native forage species that will provide benefits to native pollinators and wildlife (4B.8).

**Potential Benefits**

A primary beneficial use of rangelands and pastures is livestock production. Results of the research in this subcomponent will optimize livestock production through the appropriate use of animals and forages from range and pasture resources. Research results will increase the contribution of forage-fed livestock to U.S. food security, by improving our ability to generate food from resources that are mostly unsuitable for use as human food.

**Problem Statement 4C. Improved growth, handling, and storage of harvested biomass for optimized quality and utilization as feed or feedstocks and positive environmental benefits**

Research under Component 1 will identify environmental factors affecting forage crop establishment and parameters to maximize yield and environmental services. Improved plant materials for diverse environments to overcome biotic and abiotic stresses will be developed under Component 2 and tools for integrating forages into agroecosystems will be developed under Component 3. Research in this component will capitalize on results from Components 1-3 to focus on providing improved management practices that enhance the environment and increase the economic viability of growing, harvesting, and storing forage grasses and legumes for livestock, bioenergy, and bioproducts. Management methods are needed that result in a positive effect on soil fertility and soil health; protect or improve water quality and water resources; maximize plant establishment, vigor, and productivity; and have a positive economic return.

Harvested forage systems differ from grazing systems in that forages are grown, harvested, and typically stored before being delivered for their intended use, which includes feed for livestock or biofuel/bioproducts production. Due to climatic and ecological variation, improved systems for sustainable production of harvested forages are needed for each of the major agro-ecosystems in the

United States. These systems need to be flexible to adapt to changing climatic, environmental, and market conditions. To meet national and producer objectives, production, harvest, and storage systems are needed that reduce production costs and/or enhance the value of the forage. Further research is needed to improve the ability of stored forages to retain nutrient quality and quantity. The type of research depends on the end use of the forage and will include improvements in palatability and nutrient density for use as feed for livestock.

Forages are often subject to degradation after harvest from environmental factors. Spontaneous heating in hay caused by too much moisture in the plant at the time of baling costs livestock producers in terms of dry matter losses and forage quality. Baling legume forages at low moisture levels leads to greater leaf shatter and a drop in forage quality. There is a need to increase the recovery of dry matter and nonstructural carbohydrates, improve the energy density of baled hays, and mitigate the negative effects of rainfall on ensiling, storage, and feeding characteristics of rain-damaged forage crops. During harvest and early stages of ensiling, degradation of forage proteins can occur resulting in significant economic losses and loss of nitrogen to the environment. There is a need for methods to mitigate protein loss of ensiled forages. In baled silages there is a need for research on inoculants and preservatives that can promote storage and nutritional properties. There is increasing interest in dual cropping of corn silage with winter cereals to promote soil conservation and increase forage production. Harvest management methods are needed for different environments to maximize the potential of these systems.

**Research Focus**

4C.1 Identify nutrient management and animal manure supplementation practices that enhance nutrient use efficiency and reduce negative environmental impacts.
4C.2 Develop forage and biomass production systems that better utilize nutrients to increase productivity and/or reduce energy and nutrient input requirements.
4C.3 Develop methods to maximize plant establishment and vigor.
4C.4 Develop biomass harvest and storage systems that enhance the value of the feedstock for animal, bioenergy, or bioproduct production.
4C.5 Better understand the effects of the environment on stored forage characteristics.
4C.6 Enhance the utilization of inoculants and preservatives for harvested forages to maintain and enhance nutrients.
4C.7 Reduce inputs and lower costs of forage establishment, production, and harvest.
4C.8 Develop new forage cropping systems and management practices that expand opportunities for inclusion of harvested forage crops, forage intercropping, or the utilizations of annual cropping residues.

**Anticipated Products**

- Management practices and decision support tools to reduce fertilizer use and improve nitrogen efficiency, plant productivity and persistence, and optimize nutritional quality (Focus 4C.1 and 4C.2).
- Recommendations for plant production and management practices that reduce the need for nitrogen inputs (4C.1, 4C.2, and 4C.7).
- Forage and biomass feedstock production systems that limit energy loss and minimize greenhouse gas emissions during ruminant digestion (4C.1 and 4C.2).
- Management practices that reduce manure, sediment, and nutrient movement off-farm and retain plant productivity under variable environmental conditions (4C.2 and 4C.8).

- Management systems that optimize grass and forage establishment, yield, quality, and persistence (4C.3).
- Strategies to manage pests and diseases in forage production systems (4C.3).
- Best management practices, energy yield, and feedstock quality data for candidate feedstocks on marginally productive land (4C.3, 4C.7, and 4C.8).
- Information to support biomass harvest for optimal recovery of beneficial plant secondary metabolites (4C.4).
- Management practices that increase bioenergy feedstock productivity (4C.4).
- Management practices that reduce harvest costs while maintaining productivity and forage quality (4C.4, 4C.6, and 4C.7).
- Strategies to enhance the value, use, and efficiency of residual dormant forages to lower energy costs and improve the economic sustainability of livestock producers (4C.4, 4C.5, and 4C.8).
- Improved management strategies that increase preservation of dry matter, increase the energy density and retain protein of harvested forages for livestock (4C.4, 4C.5, and 4C.6).
- Economic guidelines for producing, harvesting, and storing feedstocks with available and alternative technologies (4C.4, 4C.5, 4C.6, and 4C.7).
- Preservatives and inoculants that improve the value, use, and reduce losses in stored forages (4C.6).

**Potential Benefits**

Benefits of this research will include effective methods for increasing dry matter and other nutrients in forages throughout harvest and storage prior to use. More U.S. producers will integrate perennial forage crops into cropping systems with a positive effect on soil health and water quality. Labor and costs of forage crop production will be reduced. Farm incomes will be stabilized and diversified. Storage methods will be developed that will preserve the nutrient availability of harvested forages for livestock and other uses. Handling and storage management systems that maintain forage biomass quality will also be beneficial for improved biofuels/bioenergy as well as the production of other bio-based products.

**Problem Statement 4D. Land and animal management strategies that control or mitigate invasive species and reduce the negative impacts of poisonous plants in the landscape.**

Noxious or undesirable plants in the landscape continue to present problems for a variety of reasons. Invasive annual grass species, such as cheatgrass and medusahead, are not native to a location and rapidly spread, causing reduced native biodiversity and other environmental damage. They often reduce the productivity of rangelands because their palatability to livestock and wildlife is limited, and increase the frequency and intensity of wildfire. Along with grass species, various trees and shrubs, such as Russian olive, juniper, and cedar, display invasive characteristics that reduce both wildlife habitat and livestock productivity of infested land, and may increase susceptibility to soil erosion and other environmental concerns. With regard to toxic plants, many plant species are inherently poisonous to livestock. Poisonous plants interfere with the optimum use of rangelands and contribute to livestock losses on private and public rangelands. These losses can be reproductive- (abortions), structural- (anatomical deformities), and production-related (reduced growth and efficiency) as well as direct mortality. Economically, these losses exceed $300 million for livestock producers annually. Management strategies are needed to minimize the impact of poisonous plants and improved diagnostic tools that can be used by veterinarians and land managers to identify poisoned livestock, determine effective

decisions for treatment, and risk assessment of feed and food contamination. Enhancing the ability of livestock to graze rangelands containing poisonous plants should lead to more productive and economical use of these lands. In addition, fescue and other grasses can contain toxic endophytes, which also result in poisoning or other detrimental effects on livestock that eat them. With some undesirable species, utilization is possible at certain growth stages or seasons, making informed land and livestock management even more important. Management strategies are needed to reduce the negative influence of these invasive or toxic species on the landscape and on animal production.

**Research Focus**

4D.1 Develop targeted grazing strategies to reduce invasive grasses and forbs and promote desirable perennial grasses and woody species.
4D.2 Develop and evaluate management practices to control undesirable woody, annual, and/or invasive species.
4D.3 Reduce the effect of poisonous plants on livestock.
4D.4 Improve the understanding of current and historical land-use disturbances in the semiarid steppe ecosystem or other key U.S. ecosystems, and develop biotic and abiotic information to optimize rangeland restoration and management strategies.
4D.5 Select livestock for resistance to toxic plants.

**Anticipated Products**

- Targeted grazing strategies to reduce invasive grasses and forbs and promote desirable perennial grasses and woody species (Focus 4D.1 and 4D.2).
- Improved management strategies that reduce the negative impact of annual and invasive species (4D.1 and 4D.2).
- Recommendations, plant materials, and grazing strategies for producers to reduce livestock losses from poisonous plants (4D.3).
- Science-based assessments and/or grazing management strategies for restoring wildlife habitat in key ecosystems or for key wildlife species (4D.4).
- Livestock that are resistant to toxic plants (4D.5).

**Potential Benefits**

Large areas of the landscape are infested with invasive annual grasses, shrubs, and woody species, increasing fire danger and reducing landscape productivity. Research results will effectively reduce these impacts, reduce fire danger, restore landscapes to their historical species makeup, and improve productivity of rangelands and pastures. Research results will also reduce the deleterious effects of poisonous plants on livestock that graze where these plants exist.

**Component 4 Resources**

- Boise, Idaho
- Booneville, Arkansas
- Burns, Oregon
- El Reno, Oklahoma
- Fort Collins, Colorado
- Lexington, Kentucky
- Lincoln, Nebraska
- Logan, Utah
- Madison, Wisconsin
- Miles City, Montana
- Reno, Nevada
- Tifton, Georgia
- Woodward, Oklahoma