Rangeland, Pasture, and Forages
National Program Action Plan

Introduction

Background
Our Nation's rangeland and pastures, the forages and other plants that grow on them, and the domestic and wild animals that graze them or consume harvested forages, all contribute to our agricultural, environmental, economic, and social well-being. Rangeland, pasture, and forages together comprise about 55% of the total land surface of the United States, about a billion acres. Privately owned lands comprise about 45% of this total, or about 640 million acres. These lands represent the largest and most diverse land resources in the U.S. Rangelands and pastures include the annual grasslands of California, the tundra rangelands of Alaska, the hot arid deserts of the Southwest, the temperate deserts of the Pacific Northwest, the semiarid cold deserts of the Great Basin, the prairies of the Great Plains, the humid native grasslands of the South and East, and the pastures and hay lands within all 50 states from Hawaii to Maine and Alaska to Florida.

These lands are the primary forage base for our livestock grazing industry in the U.S. They are utilized by more than 60 million cattle and 8 million sheep and support a livestock industry that contributes more than $60 billion in farm sales annually to the U.S. economy. The estimated value of hay production alone is $11 billion, our third most valuable crop to U.S. agriculture, behind only corn and soybeans. The publicly owned rangelands in the western U.S. are also important, providing forage on 260 million acres for 3 million beef cattle and sheep. Nearly 70% of dietary protein and 40% of dietary calories for the U.S. population are of animal origin, and forage resources are crucial for sustained production of our animal-based products.

The functions of these lands are of increasing importance as watersheds and as habitat for a set of biologically diverse plants and animals. Maintaining adequate supplies of clean water for urban areas, irrigated agriculture, and environmental needs is a critical function of rangeland, pasture, and forage-producing ecosystems. Rangelands and pastures also provide forage and habitat for numerous wildlife species, including 20 million deer, 500,000 pronghorn antelope, 400,000 elk, and 55,000 feral horses and burros. Associated with these functions is an array of additional demands placed on these natural resources, including camping, hiking, fishing, hunting, and other recreational activities. This multitude of uses--from grazing lands to watersheds, critical habitats, and recreational areas--require an improved understanding of basic ecological processes and the effect on these processes on grazing, livestock production, and management practices. Science-based solutions to these needs must be economically viable and socially acceptable. The overall goal of this national program is to provide the appropriate technologies and management strategies to sustain our rangelands and pastures.

Harvested and conserved forages provide a dietary resource for continuity of livestock production. This is especially important during periods of cold or drought when nutrient-rich plants are not available. Harvested and conserved forages also provide an important source of roughage and nutrients for dairy cattle in confined animal feeding operations. To meet this demand, nearly 200 million tons of forage crops are harvested each year from 73 million acres in the U.S., which is 24% of the cropland. The value of forage crops harvested as hay or silage is $16 billion annually. About one-half of these crops provide the forage requirements of dairy cattle. The remainder, along with rangeland and pasture, supplies the forage needs of beef cattle, sheep, horses, and other livestock.

To accomplish these objectives, the Rangeland, Pasture, and Forages National Program has five science-based program components: (1) Ecosystems and Their Sustainable Management, (2) Plant Resources, (3) Forage Management, (4) Grazing Management: Livestock Production and the Environment, and (5) Integrated Management of Weeds and Other Pests. The critical problems being addressed by these components include (1) identification and mitigation of livestock grazing impacts on water resources, (2) development of improved forage legume germplasm, (3) integration of strategies for management and control of weeds, (4) identification and testing of measurements and systems for monitoring rangeland and pasture ecosystems, (5) development of science-based decision support systems for sustainable resource management, (6) development of ecologically-based methods to repair degraded systems, and (7) development of efficient forage harvest and conservation techniques. Following is a brief summary of each of the five program components:

Ecosystems and Their Sustainable Management. Ecosystems consist of biological communities together with their physical environments and are characterized by complex interactions among living organisms, such as competition with animals and other plants and between organisms and the nonliving environment, such as climatic events or fire. This complexity, in turn, hinders development of general approaches to the management issues faced by producers and other stakeholders on range, pasture, and forage lands. Development of sustainable and economical approaches to managing these ecosystems requires a better understanding of how climate, soils, organisms, and disturbances influence vegetative structure and flows of energy and materials between living and nonliving components

Plant Resources. The productivity of rangeland, pasture, and forage cropping areas depends directly on the plants that grow there. Besides providing food for livestock, these plants have other uses such as turf, biofuel, and human nutrition and medicine. They also serve as buffer zones near rivers and streams and other conservation purposes. The genetic diversity of range and forage grasses, legumes, and other forbs needs to be collected and preserved. Although conventional plant breeding methods will be important in improving plant resources, new molecular biology approaches are needed to identify specific useful genes that can be manipulated to create new genetic combinations in plants. These plants will be able to overcome limitations to their growth and development, produce high quality forage, and serve a variety of conservation and other uses.

Forage Management. Harvested and conserved forages provide an indirect source of nutrients for human consumption. Managing this renewable resource involves a series of complex and interacting factors to establish, sustain, harvest, conserve, test, and utilize forages intended for animal consumption. Understanding how these factors interact is crucial in maintaining high animal productivity throughout the year. However, each of these steps is inefficient. Nutrient losses during the conservation of hay or silage, even under the best management, are estimated at more than 30%, or $3 to 5 billion annually. ARS research will identify new technologies needed to reduce losses at each step and improve the quality and quantity of conserved forages available for livestock.

Grazing Management: Livestock Production and the Environment. Properly managed livestock grazing can be an economically and ecologically sustainable use of most rangeland and pasture resources. On sites where grazing is appropriate, livestock management requires an ecological understanding of associated effects on resource values and attributes such as species diversity, water quality and quantity, and recreation and aesthetics. Livestock grazing impacts on water quality, for example, are a major concern in the management of our Nation's rangelands and pastures. New technologies are needed to mitigate grazing effects on all of these associated resources. ARS research, through a highly interdisciplinary program, will evaluate grazing impacts in different environments and will develop management practices and assessment and monitoring techniques required for sustained livestock production from these grazing lands.

Integrated Management of Weeds and Other Pests. Invasive and noxious weeds, poisonous plants, and destructive insects reduce rangeland and pasture quality in the U.S. Invasive and noxious weeds are expected to infest 140 million acres by the year 2010. Poisonous plants negatively impact livestock performance and reproduction. Insect pests consume as much as 25% of the forage produced and spread plant diseases. These plant and insect pests threaten the economic vitality of animal-based agricultural operations. An integrated pest management approach optimizes control of these pests. This approach involves the use of multiple tactics to maintain pest damage below economically unfavorable levels while minimizing hazards to humans, animals, plants, and the environment. Integrated pest management emphasizes rangeland and pasture ecosystem function rather than the pest or a particular method of pest control and reduces reliance on any one method of pest management, i.e., chemical, fire, mechanical, or biological. The goals are to make rangeland, pasture, and forage management systems ecologically and economically sustainable by using integrated pest management strategies and to transfer this technology to land managers and agricultural producers.

Beneficiaries of this National Program

Many entities will benefit from this national program, which addresses such an important and pervasive natural resource base. It will benefit the Nation's livestock producers who utilize both harvested and grazed forages in their agricultural operations and the action agencies such as the Natural Resource Conservation Service and Cooperative Extension that provide technologies and knowledge to these producers. This program also will benefit federal land stewardship agencies such as the Bureau of Land Management, Forest Service, National Park Service, Fish and Wildlife Service, Bureau of Indian Affairs, and U.S. Geological Survey (USGS), that are responsible for almost a billion acres of publicly owned lands. Beneficiaries include state land management agencies responsible for state-owned grazing lands and resource managers, policymakers, and both rural and urban community organizations that need information and technologies to evaluate and manage their rangeland resources. Finally, the public at large will benefit through improved resource conditions associated with the Nation's grazing lands and their watershed and wildlife habitat values.

Vision

Sustained and productive use of rangeland, pasture, and forages

Mission

Develop and transfer economically sustainable technologies and integrated management strategies, based on fundamental knowledge of ecological processes, that conserve and enhance the Nation's diverse natural resources of rangeland, pasture, and forages.

Planning Process and Plan Development

A program planning workshop for the Rangeland, Pasture, and Forages National Program was held in Kansas City, Missouri, September 14-17, 1999. Approximately 150 participants attended the workshop, including producers, commodity group representatives, agricultural industry representatives, representatives of non-government organizations, university scientists, and scientists and administrators from ARS and other federal and state agencies. At the workshop, our customers, stakeholders, and partners provided input concerning their problems and needs relative to rangeland, pasture, and forages research and management. This input was used to develop research hypotheses and approaches for the five component areas identified earlier.

A writing team composed of ARS scientists subsequently developed planning documents to provide a framework for ARS research. The writing team used input from the workshop, their own knowledge of the subject matter area, and input from ARS scientists to identify researchable problems that will be addressed. This planning document provides background information about the overall component and explains why a particular research area is important, how it will be addressed, and the benefits of conducting the research. After a public comment period, this planning document will be revised, and the implementation phase of the process will begin. During the implementation planning phase, specific research areas will be identified; locations and projects involved will be determined; anticipated products or information generated by the research will be identified; and the time lines and milestones for measuring progress toward achieving the goals will be developed. This approach will result in coordinated, multilocation research projects, conducted by ARS scientists and their cooperators, to address high priority regional and national research needs. All projects associated with the Rangeland, Pasture, and Forages National Program will be evaluated for scientific quality by an external peer review panel in the in FY 2002.

ARS is uniquely positioned to provide national leadership in research to understand and manage the Nation's rangeland, pasture, and forage resources. Thirty-four ARS locations across the U.S., representing the major climatic regions and ecological community types, will directly contribute to this national program (Table 1). The distribution of these research units, their land resources, their affiliations with major land grant institutions, and their histories of scientific investigation in this research area are invaluable. Table 1 illustrates the components of this national program to which each research unit will contribute.

Research activities within the Rangeland, Pasture, and Forages National Program will be coordinated with and contribute to activities in many other national programs. The primary linkages are to Water Quality and Management; Soil Resource Management; Global Change; Integrated Agricultural Systems; Animal Production Systems; and Plant, Microbial, and Insect Genetic Resources, Genomics, and Genetic Improvement.

Table 1. ARS Research Locations Contributing to the Rangeland, Pasture, and Forages National Program

Program Components						
State	Locations	Ecosystems and Their Sustainable Management	Plant Resources	Forage Management	Grazing Management: Livestock Production and the Environment	Integrated Management of Weeds and Other Pests
AK	Fairbanks					X
AR	Booneville	X		X		
AZ	Tucson	X			X	
CA	Albany					X
CO	Ft. Collins	X			X	
DE	Newark					X
FL	Brooksville	X		X	X	
France	Montpellier					X
GA	Tifton		X	X	X	
GA	Watkinsville	X			X	
ID	Boise	X		X	X	X
ID	Dubois			X	X	
ID	Kimberly	X		X		
IL	Peoria			X		
KS	Manhattan		X			
MD	Beltsville		X	X		
MN	St. Paul	X	X	X		
MO	Columbia	X	X	X		
MS	Mississippi State	X	X	X	X	
MS	Oxford				X	
MT	Miles City	X			X	
MT	Sidney			X		X

Program Components						
State	Locations	Ecosystems and Their Sustainable Management	Plant Resources	Forage Management	Grazing Management: Livestock Production and the Environment	Integrated Management of Weeds and Other Pests
NC	Raleigh	X	X	X	X	
ND	Mandan	X	X	X	X	
NE	Lincoln		X	X		X
NM	Las Cruces	X		X	X	
NV	Reno				X	X
OH	Coshocton	X			X	
OK	El Reno	X	X	X	X	
OK	Stillwater				X	
OK	Woodward	X	X	X	X	
OR	Burns	X			X	X
OR	Corvallis	X	X	X	X	
PA	University Park	X		X	X	X
TX	College Station		X	X		
TX	Temple	X			X	
TX	Weslaco					X
UT	Logan	X	X	X	X	
WA	Prosser		X			
WI	Madison	X	X	X	X	
WV	Beaver	X	X	X	X	
WV	Beckley	X				
WY	Cheyenne	X		X	X	

Component I: Ecosystems and Their Sustainable Management

PART I. INTRODUCTION

A. Background

Problems associated with the Rangeland, Pasture, and Forages National Program are complex with multiple interacting factors. This program component addresses research that integrates ecosystems and their management through systems research. Ecosystems consist of biological communities and their physical environment. They are characterized by complex interactions among living organisms and between organisms and the nonliving environment such as temperature and precipitation. Ecosystems provide commodities of immediate economic value, including food, fiber, and construction materials. They also provide critical services, including cleansing of air and water, regulation of climate and water cycles, and adsorption and detoxification of pollutants. The flow of energy and materials between living and nonliving components of ecosystems is governed by climate, soils, major groups of organisms, and disturbances such as drought or fire. These factors also determine the overall capacity of ecosystems to provide commodities and services.

The development of ecosystem management approaches to resolve issues faced by producers and other stakeholders has been elusive. "Ecosystem management," as defined for this component, is the application of ecological principles and constraints to regulate ecosystem structure and function to produce specified goods and services from a defined geographical area over an extended period. Intrinsic to this definition is the recognition that ecosystem processes such as water usage and mineral cycling must be managed to deliver desired commodities and services. Ecosystems must, therefore, be managed for functions that maintain productive potential but are of no immediate economic value. Dependable techniques are needed to monitor rangeland and pasture condition, to restore damaged systems, and to identify stocking rates for grazing animals that increase or maintain economic return while protecting the productive potential of grazed ecosystems. We also must determine how best to accommodate increasing societal and economic pressures on producers for multiple uses of rangeland, pasture, and forage-production systems.

The first step in addressing ecosystem complexity is identifying patterns in their composition and functioning. Pattern recognition leads to testable hypotheses about cause-effect relationships and ultimately to information useful for improving productivity and sustainability. A major thrust of rangeland research has been to evaluate effects of temperature, precipitation, nutrient availability, and other factors on plant production. From this work, we have learned that the distribution and productivity of different plants are controlled mainly by temperature and the availability of water and nutrients. We also have learned that factors controlling ecosystem processes and the composition and structure of vegetation operate differently depending on spatial and temporal scale. Ecosystems constantly change and tend to exhibit threshold-like behavior resulting in large responses to small changes in input. Several major challenges remain, however:

- The influence of living organisms on soils, local climate, and disturbance must be understood for effective management of our rangeland, pasture, and forage resources. Recent work has shown that changes in the composition or diversity of plants can have lasting effects on ecosystems by changing nitrogen availability and cycling or by affecting fire frequencies.

- Feedbacks among the major factors that control ecosystems (climate, soils, organisms, and disturbance) must be managed to sustain or improve rangeland, pasture, and forages. Ecosystems change in response to unusual events and during plant recovery from disturbance. These changes must be constrained within certain limits if the basic properties of ecosystems are to be sustained.

- For rangelands in particular, key processes must be identified that constrain ecosystem responses at different spatial and temporal scales. Subsequently, technologies are needed that manipulate these processes to ensure ecosystem sustainability. Constraints imposed by climate and soils limit productivity on many rangelands and may introduce greater variation in productivity on rangelands than on high-input forage systems and improved pastures. Efforts to overcome these limitations with inputs of energy in the form of fertilizers, herbicides, mechanical manipulations, and other means are generally economically, and sometimes ecologically, unsustainable. A more logical and economically realistic approach is to identify how and when controls on ecosystem processes can be manipulated with minimal input to produce or maintain desired results and to avoid undesirable change.

- There is an urgent need to identify and develop tools and techniques to translate ecological understanding into management approaches. Mathematical modeling, expert systems, and decision support systems are among the tools that may be used to accomplish this task.

- There also is a pressing need for technology that effectively incorporates enterprise-specific economic and ecological risk aversion and assessment processes. Research to develop this technology must be multidisciplinary and must address interrelationships among components of the forage and animal production system.

These and other issues are addressed in the following problem areas: (1) Ecosystem Processes, (2) Monitoring and Assessment Technologies, (3) Forecasting and Risk Assessment, (4) Ecologically and Economically Sustainable Systems, (5) Managing Degraded Systems, and (6) Decision Support.

B. Vision

Effective resource management through application of improved understanding of rangeland, pasture, and forage production ecosystems.

C. Mission

To develop economically and environmentally sustainable rangeland, pasture, and forage practices and technologies by integrating knowledge of complex interactions between organisms and their environment.

Table 2. ARS Research Locations Contributing to Component I of the Rangeland, Pasture, and Forages National Program--Ecosystems and Their Sustainable Management.

Component Problem Areas							
State	**Locations**	**Ecosystem Processes**	**Monitoring and Assessment Tech-nologies**	**Forecasting and Risk Assessment**	**Ecologically and Economically Sustainable Systems**	**Managing Degraded Systems**	**Decision Support**
AR	**Booneville**	**X**			**X**		
AZ	**Tucson**	**X**	**X**	**X**			**X**
CO	**Ft. Collins**	**X**	**X**	**X**	**X**		**X**
FL	**Brooksville**				**X**		
GA	**Watkinsville**	**X**			**X**		**X**
ID	**Boise**	**X**		**X**			
ID	**Kimberly**	**X**					
MN	**St. Paul**	**X**					
MS	**Mississippi State**	**X**					
MT	**Miles City**	**X**		**X**	**X**		
NC	**Raleigh**	**X**					
ND	**Mandan**	**X**	**X**	**X**	**X**		**X**
NM	**Las Cruces**	**X**	**X**	**X**	**X**		
OH	**Coshocton**	**X**					
OK	**El Reno**	**X**		**X**			
OK	**Woodward**	**X**	**X**	**X**			**X**
OR	**Burns**	**X**	**X**	**X**	**X**		
OR	**Corvallis**	**X**					
PA	**University Park**	**X**	**X**	**X**			
TX	**Temple**	**X**		**X**			

UT	**Logan**	**X**					
WI	**Madison**	**X**					
WV	**Beaver**	**X**					
WV	**Beckley**		**X**				
WY	**Cheyenne**	**X**	**X**	**X**			

PART II: PROBLEMS TO BE ADDRESSED

A. Ecosystem Processes

Problem Statement

Rationale. Land managers are continually challenged to understand and predict impacts of management on rangelands and pastures. This is difficult because weather and the plants and soils of these ecosystems can be highly variable over space and time and because highly variable ecosystems can react unexpectedly to management. We have learned, however, that productivity and sustainability of rangelands and pastures are closely linked to the processes of energy flow, nutrient cycling, and water use. These processes produce ecosystem services that include carbon storage and cleansing of water and air. The quality and sustainability of these services are subject to management effects on ecosystem processes and on process variation over space and time. Mismanagement can threaten the capacity of ecosystems to provide services and can negatively impact nearby ecosystems. Sustainability implies efficiency in water use and energy capture and in nutrient cycling and retention, which in turn, are frequently related to biological diversity. Effective and economical management of grazing lands and forage-production systems requires a quantitative understanding of how plant and biological composition and diversity, grazing, and disturbances such as drought and fire affect efficiencies of water use, energy capture, and nutrient cycling by constraining these processes across different scales of space and time. Such understanding will lead to the development of technologies to manipulate processes to produce or maintain desired states and to avoid undesirable change.

What is known. Reciprocal interactions between plants and soils play an important role in the function and stability of grazing and ecosystems. Soils affect water and nutrient supplies to plants, which in turn, determine plant productivity and species composition. Plants, in turn, affect soil properties such as porosity, chemical activity, and stability and influence nutrient cycling via differences in the quality of dead plant tissues. These changes influence infiltration of water and erosivity of soil and affect seed germination and seedling establishment. Grazing interacts with plant species composition and soil resources, such as water, to determine spatial and temporal variability in ecosystem processes. In arid and semiarid ecosystems, for example, grazing favors shrub invasion of grassland by increasing spatial variation in nutrients and water. Shrubs reinforce spatial variation in nutrient cycling and plant production by further concentrating nutrients. Changes in vegetative structure, species composition, and productivity will continue to occur. Some changes result directly from human activities and associated disturbances, while others result from naturally evolving environmental processes. Understanding how disturbances and other factors affect ecosystem processes is critical for managing grazing lands. Disturbances generally are defined as living or nonliving factors that change the structure and function of an ecosystem. Included are drought, heat stress, air pollution, fire, trampling and wallowing by cattle, and invasion by undesirable species. Disturbances such as fire are an inherent part of many grasslands and are critical to sustaining these ecosystems. Disturbances that are not inherent to an ecosystem can reduce ecosystem sustainability.

Gaps. Effects of plant species composition and diversity on soil processes must be clarified before plant effects on ecosystem productivity, structure, and sustainability can be defined. We must understand, for example, how plant species and functional group diversity affect nutrient cycling and nutrient conservation. This knowledge is needed to predict management effects on the productivity of grazing lands and to evaluate the potential of native and introduced plant species to enhance forage production and other ecosystem services. We must also better understand the proper time frame for defining measures of stability and sustainability for rangeland and pasture. Effects of natural and human-induced disturbances on rangeland and pasture ecosystems and on ecosystem processes must be better defined. There is a particular need to determine effects of multiple disturbances or stressors on grazing land ecosystems. We are just beginning to understand ecosystem characteristics that determine the resistance to disturbances and ability to recover from disruption. Management sometimes must be adjusted to prevent irreversible damage to grazing lands, but we lack reliable indicators of ecosystem processes near thresholds of irreversible change.

Goals

- Determine effects of plant species composition and plant species and functional group diversity on nutrient cycling, nutrient conservation, and productivity as a basis for developing management strategies to improve productivity and sustainability of grazing lands.
- Learn to integrate ecosystem processes that function over different scales of time and space to improve measures of stability and sustainability for rangeland and pasture.
- Identify measurable indicators of ecosystem processes near thresholds of irreversible change, a critical need for management of low-input grazing lands.
- Determine likely effects of multiple, regionally important disturbances and directional changes in climate and atmospheric composition on key ecosystem processes as a basis for ecological risk assessment on rangelands and pastures.
- Determine effects of plant diversity and plant spatial distribution on grazing lands as a basis for improving productivity and sustainability of newly-planted and improved pastures.

Approach

ARS has unique facilities and interdisciplinary expertise to conduct ecosystem research in a variety of regions across the U.S. Scientists will identify the knowledge gaps most suitable to their expertise and will develop hypotheses to address these gaps. Coordinated efforts across ARS locations and collaboration with public and private entities will help determine how different ecosystems function and respond to management and disturbances. Efforts in these areas will include determining disturbance effects on cycling of key soil nutrients, soil physical properties, watershed processes, and dynamics of important plant species. Because ecosystem processes are scale-dependent, data must be collected and analyzed across scales of time and space using a combination of traditional plot-level techniques and remote sensing and geographic information system (GIS) techniques. Mathematical models often will be required to synthesize available information and to extrapolate information obtained over short time scales to the longer time periods and large spatial scales needed to manage these complex ecosystems.

Outcomes

- Management strategies will be developed that promote more sustainable grazing lands.
- Measurable indicators of ecosystem processes near thresholds of irreversible change will be determined for economically important and environmentally sensitive ecosystems.
- Planted and improved pasture will sustainably meet specific needs, including needs for forage production, carbon storage, and water yield.
- Mathematical models will be developed that predict ecosystem response to management and to directional changes in climate and disturbance regimes.

Impact

Sustainable grazing lands that can be more effectively and economically managed and more easily monitored

Linkages to Other ARS National Programs

Animal Production Systems
Global Change
Integrated Agricultural Systems
Manure and Byproduct Utilization
Soil Resource Management
Water Quality and Management

B. Monitoring and Assessment Technologies

Problem Statement

Rationale. During the last decade, the demand for goods and services produced by rangelands and pastures has increased while resources allocated to manage these lands have decreased. Therefore, science-based assessment systems are needed to make informed management decisions and to allocate limited resources effectively. Specifically, we must be able to identify areas (1) with a high risk of degradation, (2) with a high potential for recovery, or (3) with potential to increase greatly in land value for production, recreation, or conservation with small increases in management inputs. Monitoring systems also are required to evaluate the effectiveness of alternative management strategies and to predict future changes in the condition of rangeland and pasture. These questions need to be addressed at a variety of scales, from the individual pasture or subcatchment to the Nation as a whole. If possible, information collected at one scale should be translated to other scales.

What is known. Much of the knowledge required to develop and implement effective assessment and monitoring systems is available but has not been adapted or applied. Relationships among vegetative covers, composition, and forage production are reasonably well understood. Many of the ecosystem processes on which rangeland and pasture depend have been described (see other problem areas in this component). In some cases, indicators that reflect the status of these processes have been developed. The use of new technologies, including remote sensing and global positioning systems (GPS), has been evaluated, and many of these approaches are being actively pursued.

Gaps. Adoption of currently available tools that are to assess and monitor our Nation's rangelands and pastures is limited by a combination of high costs, high training requirements, low repeatability, and/or a poor correlation between measured indicators and the properties and processes of interest. Furthermore, most systems are designed to address the status of an area in terms of vegetative cover and composition relative to some historical reference or its ability to support livestock production rather than reflecting society's demand for a broad variety of land uses. Most currently available approaches are limited because they are based on data collected at individual points, ignoring interactions and feedbacks among different parts of the landscape, and by their almost complete reliance on vegetative cover and composition as indicators.

Cost-effective tools are required that more accurately reflect the status of the underlying ecological processes on which all use values of rangeland and pasture depend. Predictive indicators need to reflect the long-term sustainability of the system through its ability to resist degradation and to recover after degradation.

When possible, indicators need to be directly calibrated to the ecosystem functions and use values that they are intended to represent. When direct calibration is not possible, simulation models can be used to evaluate the relative sensitivity of various indicators to changes in ecosystem functions.

Goals

- Develop and calibrate monitoring systems that reflect basic ecosystem functions and are rapid, quantitative, repeatable, and applicable at a variety of spatial scales. Systems should be designed to function in diverse ecosystems, integrate new tools as they become available, and permit users to select from a range of indicators depending on their objectives, the particular ecosystem, and available resources.
- Develop new tools to monitor and assess rangelands and pastures at large scales and others to scale up data collected at individual points in the landscape and to interpret data in the context of processes occurring across large areas.
- Develop additional tools that more precisely reflect specific ecosystem functions and that can be used to distinguish fluctuations in ecosystem processes from directional trends in these processes.

Approach

Extensive collaboration with other agencies, organizations, and individuals currently involved in monitoring and assessment is essential to develop systems that can be implemented across a variety of scales, ownership patterns, and management objectives. The ARS national network of research stations and access to extensive long-term data bases will contribute to the development, calibration, and testing of new tools and the integration of these tools with existing approaches.

Outcomes

- Techniques and systems will be developed to monitor basic ecosystem processes that will provide information for local land managers on management impacts, climate change consequences, and other factors as they relate to the structure and function of grazing lands.
- Monitoring and integration tools will be available that improve the ability of land managers and others to recognize and quantify impacts of management across different spatial scales and administrative boundaries.

Impact

Prevention of degradation in areas that are at risk and amelioration of areas that can be readily restored

Linkages to Other ARS National Programs

Soil Resource Management
Water Quality and Management

C. Forecasting and Risk Assessment

Problem Statement

Rationale. Today's environmentally conscious and economically competitive world presents producers with critical decisions regarding risk in their agricultural production systems. They must balance short-term expenditures and long-term economic viability of their operations against a host of environmental factors and off-site impacts. Such decisions are not clear-cut and must be based on an assessment of risks associated with changes in market conditions and environmental conditions. Rangeland ecosystems are complex and are affected by many living and nonliving components, the interactions of which are generally poorly understood and unlikely to be correctly forecasted by existing techniques and tools. Organizations and individuals charged with managing rangelands are under increasing pressure to consider social and ecological issues arising from demands for multiple land use. Producers need tools to aid them in this process.

What is known. There are a variety of tools to simulate different facets of agricultural production systems and their impacts on the environment. Most tools address variability in climatic conditions, making them useful for evaluating certain types of environmental risk in a probabilistic framework. Governmental agencies and other organizations need improved methods to assess the status of rangeland resources, to forecast the economic viability of producers and of rural America, and to assess the sustainability of the Nation's rangelands.

Gaps. The challenge to scientists and managers is to translate complex and incompletely understood ecosystem processes and interactions into concepts that the public can understand and that resource specialists can use. Tools are needed to simultaneously assess environmental and economic risks associated with different agricultural production systems within differing regions. Research must yield probabilistic results as opposed to average expectations. We also must develop methods to assign and compare levels of environmental risk and to communicate that risk to stakeholders.

Goals

- Provide probabilistic outcomes of interactions between agricultural practices and the environment.
- Develop cost-effective techniques to assess the status of the Nation's rangeland at local, state, national, and global scales.
- Determine effects of potential changes in climate (e.g., carbon dioxide, temperature, and precipitation) on the delivery of rangeland, pasture, and forage goods and services.
- Establish new criteria and methods to quantify and to communicate risk assessments.
- Develop tools that enable producers and land managers to modify management alternatives for their individual requirements.

Approach

Assessing the current status of rangelands and pastures and forecasting their capacity to provide goods and services will require addressing the inherent heterogeneity and the large spatial extent of the resource while accounting for processes that operate over various temporal scales. Experimental studies should continue to focus on stresses to ecosystems and on the resistance and resilience of these systems to change. Field studies should be conducted in collaboration with computer simulation modelers. ARS has a long history of decision support system development upon which risk assessment tools can be based. ARS also has unique facilities and interdisciplinary expertise to develop such tools, but must develop partnerships with universities to acquire needed funding. Strong partnerships with producers and other stakeholders must be developed to insure the applicability and utility of developed tools.

Outcomes

- Tools and techniques will be developed to assess the status of ecological sites.
- The future state of ecological sites will be predicted based on changes in management practices or changes in climatic conditions.
- Visual displays will be developed that show the extent, location, and status of the Nation's rangeland.
- Data will be either aggregated or disaggregated to enable management decisions based on the appropriate temporal or spatial scale.
- The probabilistic nature of interactions within agricultural production systems and between production systems and the surrounding environment will be evaluated.
- A formal framework will be developed to characterize risk and address uncertainty in agricultural production systems.

Impact
Improved management of ecological sites by land users and managers, including land management agencies

Linkages to Other National Programs
Global Change
Integrated Agricultural Systems
Soil Resource Management
Water Quality and Management

D. Ecologically and Economically Sustainable Systems

Problem Statement
Rationale. A consensus definition of sustainable agriculture has been difficult to establish, but most members of the agricultural community agree that sustainable agricultural systems have several identifiable characteristics. Sustainable systems are economically feasible, socially responsible, environmentally friendly, and virtually perpetual. Most customers and stakeholders of grazing lands recognize that sustainable agricultural systems must be adopted if producers and their rural communities are to thrive.

The economic reality of today's production agriculture dictates that single-use resource management may not be sustainable. Diversification is therefore a potential means of improving both the ecological and economic sustainability of many agricultural operations. Alternative economic enterprises complementary to production agriculture (e.g., tourism, fee hunting, bird watching) are needed to ensure the economic livelihood of many American producers.

What is known. Agricultural commodities are subject to price fluctuations that can cause economic stress to producers who depend on a single source of income. Export demand has diminished because of uncertainty in Asian, Indonesian, and Russian economies and the strong U.S. dollar. Escalating operating costs are decreasing profit margins for producers. Accompanying these conditions is (1) an increasing average age of the American agricultural producer; (2) a marked shifting from small, family-oriented farms to large, corporate organizations; and (3) an increasing land valuation caused by suburban sprawl. Recent population increases and shifts in demographics in traditional grazing areas also have placed pressure on the ranching community as society expects other goods and services from these lands. Although there are examples of livestock operations that currently derive income from hunting, bird watching, native plant harvests, and other alternative economic enterprises, few concentrated efforts aim at expanding current opportunities. The realization that an ecologically and economically sustainable agricultural sector is needed to ensure adequate production of food and fiber for the U.S. and other countries necessitates that alternative economic enterprises be developed to enhance incomes for agricultural producers.

Extensive research to optimize agricultural production has been conducted over the past 50 years, but research has not adequately considered the cost or the long-term environmental consequence of maximizing commodity production. Development of sustainable systems requires that a variety of other factors be considered.

Gaps. Knowledge of how multiple factors affect ecological and economic sustainability is limited, but even this limited knowledge has not been adequately incorporated into agricultural production systems. More efficient livestock production systems are needed. Challenges to meeting this need are many and include the long time periods (often a decade or more) required to determine ecological and economic sustainability. Research programs that integrate modeling tools with empirical research programs will be most effective in meeting this need. We also must develop and test alternative economic enterprises. Innovative approaches and techniques that incorporate nontraditional ideas and expertise will be required. An essential criterion will be development of user-friendly decision aid tools that are accessible to producers.

Goals

- Incorporate the use of simulation models and decision support systems into the design of research programs.
- Develop alternative economic enterprises that are ecologically and economically sustainable when integrated with production agriculture.
- Design and implement research programs that investigate multiple interacting factors affecting forage-livestock production.
- Formulate sustainable agricultural systems featuring rangeland, pasture, and forages from the results of component research.
- Test the profitability and environmental friendliness of formulated agricultural systems featuring rangeland, pasture, and forages.

Approach

Research will employ multidisciplinary teams using a systems approach to incorporate models and decision support systems into the design of basic research examining the interaction of components that control forage-livestock production systems. Research results from component investigations will be examined. From such results, agricultural systems using rangeland, pasture, and forages will be formulated. Untested under field conditions and at scales similar to those of regional farmers and stakeholders. Systems will be examined for profitability and effects on the environment and adjoining landscapes. Newly designed agricultural systems will be adapted during the trials to account for changes in economical conditions and environmental impacts. Input data sets for the models must also be collected. Models will be validated on a subset of the data collected. The approach will integrate ecological and management alternatives at various scales for use is the developing decision-support tools.

Outcomes

- Sustainable management systems will be developed for rangelands, pastures, and forages that increase profitability and ecosystem stability while minimizing environmental impact.
- Ecological and economical sustainability of alternative enterprises will be evaluated within a systems context.

- Effective cooperative relationships with other agencies will be formed and maintained to address these goals using a multidisciplinary approach to incorporate nontraditional ideas and expertise.
- Improved decision support aids and simulation models for examining the complex interaction of factors controlling forage-livestock production will be made available to natural resource managers.

Impact
Increased stability in farm and ranch profitability and decreased risk of negative environmental impacts of agricultural practices

Linkages to Other ARS National Programs
Animal Production Systems
Crop Production
Integrated Agricultural Systems
Manure and Byproduct Utilization
Soil Resource Management
Water Quality and Management

E. Managing Degraded Systems

Problem Statement
Rationale. Disturbances in rangeland ecosystems in the western U.S. diminish topsoil, introduce contaminants, reduce productivity, and lessen biodiversity. These disturbances may result from natural causes such as fire, floods, and drought or from human activities such as mineral extraction, cropping practices, timber harvesting, abusive livestock grazing, and waste disposal. Severe disturbances have created and expanded large acreages of invasive weeds. Some ecosystems can recover from disturbance though natural successional processes, but some disturbances are so severe that intervention is necessary to reestablish natural ecosystem processes.

What is known. Severe ecosystem disruption from natural and human-caused disturbance can upset the balance of processes that sustain rangelands and their functions. The degree to which a disturbed system can be restored depends on the nature of the disturbance, soil conditions, climatic factors, and the availability of suitable plant materials. Low rainfall and the presence of introduced weed species severely limit management options for restoration, reclamation, or revegetation of degraded rangeland systems. Often, disrupted systems cannot be restored to a predisturbance state because of a change in ecosystem processes.

Gaps. Current methods of evaluating functional degradation of disturbed rangelands are inadequate. Plant materials that are suited for degraded sites often are not available. In addition, invasive weeds can limit the success of restoration and revegetation efforts. Finally, climatic variability increases the difficulty of evaluating restoration strategies.

Goals

- Increase our basic knowledge of the biology and ecology of natural and degraded systems.
- Develop strategies to produce and assess plant materials for the restoration and rehabilitation of degraded rangeland systems.
- Develop new methodologies to rehabilitate degraded soils.
- Develop new techniques to use weather and climate information to plan rehabilitation.

Approach

A multidisciplinary systems approach will be used to develop management protocols to restore and rehabilitate degraded rangeland systems. Basic research under this program will target specific knowledge gaps and support larger program goals. This program will be implemented in cooperation with other programs and program components related to soil and plant resources and ecosystem management.

Outcomes

- Degraded rangeland systems will be restored and reclaimed to improve productivity for grazing animals, recreation, biodiversity, and environmental quality.
- Plant materials will be developed that are suitable for restoration and rehabilitation of degraded rangeland systems.

Impact

Restored and reclaimed rangelands for multiple uses

Linkages to Other ARS National Programs

Crop Protection and Quarantine
Soil Resource Management

F. Decision Support

Problem Statement

Rationale. The demand for goods and services produced by rangeland, pasture, and forage systems has continued to grow over the last two decades. Decision-makers need science-based information to make wise decisions regarding the use of limited human and financial resources. A decision support system is a computer program, pamphlet, data set, or other media used to transmit such data to the decision-maker. Primary objectives of ARS research include understanding the effects of agricultural management practices on environmental quality and developing environmentally sound management practices that are profitable to the farmer or rancher. Equally important is the development of a more holistic approach to acquire, process, and use information in ways similar to those in producer operations. The same holistic, producer-oriented approach is also needed to make decisions and choose alternatives from among competing uses and with limited finances across diverse landscapes.

Decision-making requires analysis of many interacting factors and supporting research. Because computer models are designed to represent the complex interaction of many factors, they are integral to summarizing knowledge and forecasting scenarios that cannot be examined experimentally. A multidisciplinary research program combining empirical research and computer modeling is necessary to develop and test integrated forage, crop, and livestock production systems that are economically feasible and environmentally sustainable.

What is known. We have models to examine integrated agricultural systems. Research methods and tools for analysis also are available. The important factors controlling forage-livestock production are known and well understood, but the interactions among these factors are not as clear.

Gaps. Much of the knowledge required to develop and implement effective decision support systems is not available or is not in a form useful to producers and managers of rangeland, pasture, and forage ecosystems. The process of formulating and developing decision support systems also will help identify needed additional research information and focus new research on more specific areas in which data are insufficient.

Goals

- Formulate an integrated approach for decision-making, including a comprehensive, structured integration of economics and ecology.
- Develop simulation models that mimic the social-economic-natural resource environment typical of those in which producers operate.
- Develop additional data bases for improved management decisions and for enhanced simulation models that producers more fully understand.
- Develop decision support systems that contrast environmental and economic risks associated with important agricultural production systems in different geographical regions.
- Develop reliable user-friendly, cost-effective, valid delivery systems.

Approach

Multiobjective decision-making using simulation models will allow practical decisions with multiple, often conflicting, objectives. This approach will help overcome issues of scale and hasten development of a three-scale approach (operator; regional; and national) that will integrate ecological and management alternatives at the farm or ranch level with regional and national socio-economic policies.

Outcomes

- Management decisions will be enhanced across local, regional, and national scales.
- Widespread availability of science-based information will promote positive changes in the agricultural economy, the environment, and relevant institutional structures and policies.
- Impacts of management decisions across different spatial scales and administrative boundaries will be more readily recognized and quantified.
- Impacts of management decisions on the landscape and on profitability will be more readily recognized and quantified.

Impact

More profitable and diverse farm and ranch operations and healthier rangeland, pasture, and forage ecosystems that will sustain multiple uses

Linkages to Other ARS National Programs

Integrated Agricultural Systems
Soil Resource Management
Water Quality and Management

Component II: Plant Resources

PART I. INTRODUCTION

A. Background

The productivity of rangeland, pasture, and forage resources depends directly upon the plants that grow in these areas. A significant portion of the gain in the production efficiency of meat, milk, and wool can be attributed to advances in the amount and quality of feed available to livestock. These advances could not have occurred without genetic improvements that increased rangeland and forage plant productivity, quality, and resistance to pests and diseases. Besides providing food for livestock, rangeland and forage plants are important in conservation for minimizing soil erosion and enhancing water quality. These plants also can be used in the revegetation, restoration, and remediation of degraded habitats resulting from natural disasters or poor stewardship. Further, these plants can capture excess elements and degrade organic compounds generated from industrial, agricultural, and urban activities. Rangeland and pasture plants have the potential for use in turf, biofuels, medicines, human nutrition, and other unique applications. The disappearance of rangeland and forage plant genetic diversity threatens our ecosystem resource base and will hinder our ability to solve future threats from diseases, insect pests, and environmental stresses. Conventional plant breeding approaches will continue to play a significant role in developing improved plant resources, but new molecular biology technologies are needed for rapid identification of useful genes that can be manipulated to create new genetic combinations of these plants. The diverse needs for feed for the livestock industry, conservation, wildlife habitat, and other unique uses will require a concerted ARS research effort to continue economic advances and protect the environment.

B. Vision

Healthy, biologically diverse, and sustainable rangeland, pasture, and forage cropping areas for livestock production,wildlife habitat,and national conservation needs

C. Mission

To provide a range of appropriate plant resources for rangeland, pasture, and forage applications to improve meat, milk, wool, and other products in an efficient way that increases economic return to producers of different operational sizes and enhances environmental quality

Table 3. ARS Research Locations Contributing to Component II of the Rangeland, Pasture, and Forages National Program--Plant Resources.

Component Problem Areas						
State	**Locations**	**Lack of Available Germplasm**	**Plant Biology and Gene Discovery**	**Overcoming Limitations to Plant Growth and Development**	**Improving Forages for Livestock Production**	**Plants Needed for Conservation and Novel Uses**
GA	**Tifton**	**X**		**X**	**X**	**X**
KS	**Manhattan**		**X**		**X**	
MD	**Beltsville**	**X**		**X**		
MN	**St. Paul**		**X**	**X**	**X**	**X**
MO	**Columbia**	**X**	**X**	**X**	**X**	
NC	**Raleigh**			**X**		
ND	**Mandan**			**X**	**X**	**X**
NE	**Lincoln**		**X**	**X**	**X**	**X**
OK	**Woodward**	**X**	**X**		**X**	
OR	**Corvallis**		**X**	**X**		
TX	**College Station**	**X**		**X**	**X**	
UT	**Logan**	**X**	**X**	**X**	**X**	**X**
WA	**Prosser**	**X**		**X**		
WI	**Madison**			**X**	**X**	**X**
WV	**Beaver**			**X**	**X**	**X**

PART II. PROBLEMS TO BE ADDRESSED

A. Lack of Available Germplasm

Problem Statement

Rationale. Native and introduced plant germplasm is a valuable resource for sustainable production on the Nation's rangelands, pastures, and forage cropping lands. This germplasm is also important for conservation uses, including revegetation, restoration, and remediation of degraded lands and in providing critical habitat for wildlife. Lack of available germplasm continues to hamper the development of highly productive forages to meet the nutritional requirements of livestock and plant resources for conservation and other purposes. Forage germplasm collections provide breeders and other scientists a source of genetic diversity for uniquely adapted plant resources. These resources will enhance the capacity of rangeland and pasture to serve grazing needs and maintain ecosystem function and structure. Native forage germplasm must be safeguarded through *in situ* preservation to ensure long-term conservation and accessibility to the genetic diversity of these valuable resources. Germplasm collections need to be characterized to ensure broad knowledge about the growth and genetic characteristics of rangeland, pasture, and forage plants.

What is known. Livestock receive the greater part of their nutrition from direct grazing or feeding on harvested wild or domesticated forage plants. Significant gains in forage production this century can be attributed to introduced plant species. Many of the wild native populations of forage species with good nutritional value have developed strategies to persist through environmental changes. However, many of these plants are not high-yielding or tolerant of heavy grazing or disturbance. In contrast, many introduced forage species are higher yielding and better adapted to repeated grazing and disturbances. Access to germplasm resources of both native and introduced forage species by rangeland, pasture, and forage researchers has led to the development of new or improved cultivars. Information about the growth and genetic characteristics of the collected forage germplasm has helped researchers develop successful grazing management systems and forage production practices that meet livestock nutritional needs. This information also has helped formulate comprehensive conservation recommendations.

Gaps. The genetic diversity of native and introduced grasses, legumes, and other forbs needs to be collected and preserved. Often valuable and threatened rangeland, pasture, and forage germplasm resources are not available because they have not been identified, catalogued, and acquired. Also, once this germplasm has been collected, it must be efficiently characterized, regenerated, and preserved to maintain viability for utilization. Regeneration and maintenance of collected germplasm in insufficient quantity and quality, or its incomplete and nonstandard characterization, contribute to limited use by plant breeders, conservationists, and others. With the increasing demand for the use of plants to reclaim degraded, disturbed, or contaminated lands, a comprehensive assessment of species and site characteristics is needed for successful establishment of native and introduced rangeland and forage plants.

Goals

- Collect, evaluate, and maintain germplasm of native and introduced grasses, legumes, and forbs that are found in unique and threatened natural environments or missing from existing germplasm collections.
- Provide collected germplasm for breeding, revegetation, restoration, and conservation purposes.

- Preserve germplasm resources to ensure genetic integrity, viability, and accessibility of native and introduced rangeland, pasture, and forage germplasm.

Approach

Curators of collected germplasm will consult with customers and cooperatively develop plans to collect, regenerate, preserve, and maintain native and introduced grasses, legumes, and other forb germplasm. Germplasm collections will help conserve the biotic diversity of important threatened gene pools in a way that addresses the dynamic needs of multiple users.

Outcomes

- Native and introduced rangeland, pasture, and forage germplasm will be available for use in cultivar development.
- Improved native and introduced plants will be available for conservation, revegetation, landscape restoration, and production of value-added products.

Impact

Improved, genetically diverse plant materials for enhanced livestock production, ecologically sound revegetation and rehabilitation of disturbed or degraded habitats, and novel uses

Linkages to Other ARS National Programs

Global Change
Plant, Microbial, and Insect Genetic Resources, Genomics, and Genetic Improvement
Soil Resource Management
Water Quality and Management

B. Plant Biology and Gene Discovery

Problem Statement

Rationale. Rangeland, pasture, and forage grasses, legumes, and other forbs provide the basis for livestock production and contribute to soil stabilization, conservation, and enhanced water quality. They also provide habitat and food for wildlife. The productivity and quality of these plants and their response to environmental stresses continue to be improved by conventional plant breeding. However, the application of new genetic approaches to supplement conventional plant breeding of these species is limited by a lack of information about basic biological processes. Knowledge about the development of plant maturity processes in these plants is needed to lengthen the grazing season and provide high quality forage on rangelands and pastures. Adaptation of new genetic technologies is limited by a lack of knowledge of basic reproductive biology.

What is known. Genetic research in other crops has identified and solved numerous problems that previously slowed the improvement of rangeland, pasture, and forage grasses and legumes. Consequently, it is important that research of this kind continue to complement conventional breeding programs. The cellular biology, chromosome number, and reproductive behavior of some forage species are well understood, and this information has contributed to the successful transfer of genes through wide hybridization. Novel breeding methods have been developed to improve grasses that do not reproduce by typical sexual reproduction. Genetic research of cells has provided an understanding of relationships among different species, which also has benefited plant breeding programs. Research in molecular biology is progressing rapidly and is generating large amounts of information, technology, and genetic materials. These advances include development of methods to identify molecular markers associated with improved plant performance; use of these markers to select desirable plants; discovery, isolation, and characterization of new genes and their use in plant improvement; and development of data-handling techniques necessary to utilize the large data sets being developed as part of this process. We are beginning to develop genetic linkage maps for several forage grasses, and genetic transformation and regeneration systems have been developed for a few legume and grass species.

Gaps. Environmental stresses that limit forage production, stand establishment, and stand persistence reduce the profitability of forage-based agriculture. Little is known about the genetic basis of adaptation of rangeland, pasture, and forage plants to these stresses or about sources of genes from related or unrelated species that have enhanced stress tolerance. Control of specific stages of plant growth and development provides a means to improve the agronomic performance of many forage species, yet little is known about basic genetic mechanisms that control vegetative or reproductive growth and forage quality in these plants. For example, a lack of understanding of the genes that control flowering in forage grasses prevents the regulation of seed production to enhance forage production and quality. Genomic information developed from model plants may be useful for identifying genes that control these processes in rangeland and forage plants, but methods are needed to screen large data bases specific to these model organisms. A coordinated effort is needed to identify, characterize, and map genes that control agronomically important quantitative traits (i.e., control “how much” rather than “either/or”) in rangeland, pasture, and forage plants. Protocols for introducing foreign genes into forage legumes and grasses are lacking or inefficient, and basic genetic information is needed. We need to identify tissue- and stage-specific promoters to regulate the expression of new genes in transformed plants. An understanding of cellular processes and reproductive behavior of novel germplasm is required for introduction into breeding programs.

Goals

- Develop and utilize procedures at the molecular and cellular levels and statistical methods to analyze and map complete sets of chromosomes of species with multiple sets of chromosomes.
- Characterize genes involved in regulating reproductive growth and develop strategies to regulate expression of these genes specifically to enhance forage or seed production.
- Identify, characterize, and clone genes and chromosomal regions in rangeland and forage plants to improve stand establishment, persistence, and environmental stress tolerance.
- Apply various molecular biology techniques to locate, activate, or introduce genes into rangeland and forage plants to enhance agronomic performance, forage quality, and competitiveness.

Approach

An integrated approach will include the efforts of molecular biologists, geneticists, plant physiologists, and plant breeders. This approach will be used to develop a better understanding of biological processes in rangeland and forage plants and identify genes that control important traits. The development of new germplasm will include the efforts of conventional and molecular breeding programs. The utility of this new germplasm will be evaluated in terms of the impacts on profitability, native ecosystems, and product safety and quality. Sources of new gene discovery will include conventional characterization of related germplasm collected from diverse environments and unrelated species with specific desirable traits.

Outcomes

- Fundamental knowledge of the genetic control of reproductive processes in cross-pollinating rangeland and pasture species with multiple sets of chromosomes will be obtained and used to improve conventional breeding strategies.
- Methods will be developed to transfer useful genetic traits from other plant species to rangeland and forage species.
- An increased understanding of the arrangement of genes in rangeland and forage plants and the application of gene sequence information will be used to improve rangeland and forage grasses and legumes.
- An improved understanding of the genetic basis for stress adaptation, growth and development, forage quality, and forage production will be developed, and sources of new genes will be identified to enhance these characteristics in rangeland, pasture, and forage plant germplasm.

Impact

Improved rangeland plant, livestock, and wildlife health; minimized grazing effects on natural resources; and more improved decisions by producers

Linkages to Other ARS National Programs

Plant Biological and Molecular Processes
Plant, Microbial, and Insect Genetic Resources, Genomics, and Genetic Improvement

C. Overcoming Limitations to Plant Growth and Development

Problem Statement

Rationale. Variable field and environmental conditions prevent rangeland, pasture, and forage plants from consistently achieving maximum performance. All stages of plant development, from seedling establishment to vegetative growth to seed production, can be adversely affected by environmental stresses that reduce the persistence and productivity of rangeland and forage plants. These abiotic stresses include temperature extremes, drought, excess soil salinity, flooding, soil acidity, and nutrient excesses and deficiencies. In addition, adverse biotic factors that may limit production include plant pathogens, insect pests, weeds, limited insect pollinators, and overgrazing by livestock and wildlife. Plant materials can be developed that withstand these environmental and biotic stresses, which ultimately impact animal productivity. Understanding the genetic basis of plant adaptation and resistance to adverse growing conditions is essential for the improvement of rangeland, pasture, and forage plants and will promote economic and environmentally sound agriculture.

What is known. Many crop cultivars have been developed to maximize productivity in specific environments and often for use with high agrochemical inputs, which may cause off-farm environmental problems. By developing forage cultivars with enhanced resistance to insects, diseases, and environmental stresses, sustainable production can be achieved with minimal need for agrochemicals. Progress has been made in developing rangeland and forage cultivars that resist pests and pathogens, tolerate grazing to improve stand persistence, and provide multiple plant uses. Genetic enhancement of plants for increased resistance to environmental stress has been limited. Wild or unimproved plants often are sources of resistance to pests and environmental stresses that can be transferred into selected cultivars. The mechanisms that resist both biotic and environmental factors range from the cell to the whole plant. Many important plant traits are influenced by interactions between genes and their environment.

Gaps. New plant materials are needed with predictable performance under a wide range of environmental conditions. To achieve this, we need to understand the interactions between plant genetic mechanisms and environmental variables that limit adaptation and productivity. Genes that can control important traits such as resistance to pests and environmental stresses, nutrient utilization, and reproductive processes must be used to further improve sustainable rangeland, pasture, and forage production. Development of this technology will require close cooperation between traditional plant breeding and biotechnology. The feasibility of transferring genes for superior characteristics from diverse organisms needs to be assessed and rapid methods developed to incorporate them. The interaction and coordinated expression of multiple genes control many agronomic traits, including forage quality and stress tolerance. The genetic, physiological, and hormonal mechanisms that control these interactions are poorly understood, particularly under grazing pressures.

Goals

- Determine the basis of interactions among genes and environmental factors that limit the performance of rangeland, pasture, and forage plants grown under diverse conditions.
- Develop efficient methods to identify and produce plants adapted to specific environments that optimize performance in animal production systems or are suitable for multiple uses.
- Understand the genetic basis for interactions among plants and pathogens, insects, weeds, and herbivores to produce sustainable rangeland, pasture, and forage systems.

Approach

Major goals will be reached through cooperative research programs involving the disciplines of agronomy, pathology, genetics and breeding, ecology, population biology, and plant physiology. Results obtained from both field and laboratory experiments will be used to develop improved plant materials and better understand the biological basis of economically important traits. Plant materials will be developed based on considerations for both economic and ecological sustainability.

Outcomes

- Improved plant materials will be developed that minimize the use of agrochemicals in forage production systems.
- Plant germplasm and cultivars with increased forage productivity and quality under grazing will be developed to improve economic return to livestock producers.
- Improved native and introduced species will be developed with superior traits for conservation of natural resources and habitat restoration.

Impact
Enhanced plant materials that increase profitability, conserve natural resources, and promote sustainable agriculture

Linkages to Other ARS National Programs
Animal Production Systems
New Uses, Quality, and Marketability of Plant and Animal Products
Plant Biological and Molecular Processes
Plant Diseases

C. Improving Forages for Livestock Production

Problem Statement
Rationale. Forage crops grazed by livestock or mechanically harvested for feed provide the bulk of nutrients for beef, dairy, horse, and sheep production by American farmers and ranchers. Perennial forages in pastures and rangelands also contribute to rural landscapes by reducing soil erosion, lowering agrochemical usage, and enhancing wildlife habitats when compared to more intensive agricultural systems. However, current forage cultivars do not supply the optimal balance of nutrients for livestock to attain their genetic potential for milk, meat, or wool production during the entire year. As a result, farmers and ranchers must supplement livestock diets with grain to achieve greater productivity and economic returns. However, excessive grain feeding can adversely affect ruminant animal health, risk economic sustainability, and contribute to degradation of water and air quality. In addition, certain forages possess specific anti-quality factors that adversely affect animal health and limit their use, even though these forages have other valuable attributes. Legumes are under-utilized in pastures in U.S. grazing systems because of limited competitive ability and persistence when grown with perennial grasses. Finally, the yield potential of some rangeland forages limits their utilization for cattle and sheep production. Overcoming these limitations to forage utilization will increase productivity, improve animal health, and enhance environmental quality.

What is known. Animal nutrition research has identified several key plant characteristics that limit the feed value of forages. Fiber is the most abundant chemical component of forage plants but is poorly digested and limits the plants value to livestock. Recent ARS research has identified key fiber components responsible for low digestibility in grasses. High fiber, coupled with low digestibility, depresses feed intake of forages by livestock. Grasses become deficient in protein content as they mature. Forage legumes have an abundance of protein, but the protein often is too rapidly digested to allow effective utilization by cattle and sheep. Rapid protein digestion is also thought to be partially responsible for bloat, which is a digestive system health problem that can result in livestock losses from grazing alfalfa and clovers. Tall fescue and other grasses can be infected with fungal parasites that increase plant survival in stressful environments but cause poor animal performance and ill health when grazed. ARS forage breeding research has developed commercial grass cultivars with significantly improved yield and digestibility, but these improvements have not been great enough to replace grain feeding. Increased forage use for livestock production will require continued forage nutritional improvements to overcome nutrient and digestive imbalances that result in noninfectious diseases such as bloat, grass tetany, and selenium toxicity.

Gaps. While much is known concerning the limitations to forage utilization by livestock, the chemical and biochemical mechanisms underlying these limitations are not fully understood. This information gap hampers our ability to identify and genetically alter these forage quality traits through the application of conventional plant breeding techniques and biotechnology methods. Rapid and inexpensive tools must be developed for accurate screening of large numbers of plants by plant breeders so improved cultivars can be made available to livestock producers. Molecular markers are needed in variety development for efficient evaluation of plant germplasm for forage quality traits. Also, appropriate genes and regulatory elements must be identified to utilize biotechnology effectively in the development of improved forages for livestock. Co-compatible legumes and grasses need to be developed for U.S. grazing systems.

Goals

- Develop forages that have reduced fiber content and more digestible fiber while maintaining agronomic performance to increase the feed intake potential and the digestible energy content of forages by cattle and sheep.
- Improve protein utilization of legumes and extend the period of peak protein content of grasses later into the growing season to better meet the nutritional requirements of livestock.
- Increase the palatability of forages and eliminate anti-quality components that limit livestock performance or degrade animal health.
- Develop persistent co-compatible legumes and grasses for use in grazing systems.
- Identify and develop forages that extend the duration of high quality forage availability to reduce the need for supplemental feeding and lower purchased feed costs.

Approach

Interdisciplinary scientific teams will identify specific plant factors that limit forage utilization and will test proposed enhancements to forage quality for their utility in the genetic improvement. Genetic approaches to improvement will range from traditional population-based selection to the insertion of foreign genes using the tools of biotechnology. New and improved laboratory methods will be developed for accurate, rapid, and inexpensive screening of forages for quality traits. Improved germplasm and forage cultivars will be tested in livestock feeding and grazing experiments to ensure that the advances achieved using laboratory measurements can be realized in cattle and sheep production systems. Emphasis will be placed on forage species and approaches to genetic improvement that are not adequately covered by private industry.

Outcomes

- Forage quality traits will be identified that can be genetically manipulated to improve livestock performance and establish the most effective methods for achieving genetic improvement.
- Forage germplasm will be developed that incorporates improved quality traits and made available for commercial development.
- In the long-term, improved forage cultivars will become available to farmers and ranchers from ARS and industry partners.

Impact

Increased profitability of forage-based livestock production systems; improved livestock health; diversion of land from grain to forage production and thus, reduced soil erosion and use of agrochemicals

Linkages to Other ARS National Programs

Animal Production Systems
Manure and Byproduct Utilization
Plant, Microbial, and Insect Genetic Resources, Genomics, and Genetic Improvement
Plant Biological and Molecular Processes
New Uses, Quality, and Marketability of Plant and Animal Products

E. Plants Needed for Conservation and Novel Uses

Problem Statement

Rationale. The natural diversity of rangeland and forage plants provides a wide range of adaptations and tolerances to both biotic and environmental stresses. The increased pressures for multiple uses of public and private lands have created a need for plants to revegetate disturbed lands, restore self-sustaining ecosystems, and improve wildlife habitats. Special-purpose plants are needed to degrade or take up organic wastes and toxic elements on lands that have been misused or contaminated by industrial, agricultural, and urban activities. As the urban population continues to expand in North America, demand will increase for genetically improved grasses for turf in parks, athletic fields, and golf courses. In addition, many rangeland, pasture, and forage plants can produce large amounts of biomass for a potential alternate source of fuel or biofactories for cost-effective production of compounds such as high value enzymes for use in paper production, proteins that act as human and animal vaccines, and polymers useful in the production of biodegradable plastics. Forage plants are also sources of human dietary supplements (neutriceuticals) that may benefit human health. Some pasture and rangeland species have medicinal properties, and unmanaged harvesting of these plants can severely damage rangelands and pastures.

What is known. Commercially available grass and legume species used to improve rangeland and pasture are well described. The fundamental biology of rangeland and forage plants associated with seed-germination requirements, seedbed preparation and prescribed management practices, salt tolerance, and water requirements has been defined. More information is needed about the use of rangeland and forage plants for remediation of sites contaminated with toxic compounds, conservation and restoration of habitats, and for urban landscapes. Relatively little is known about the use of these plants for industrial applications and the production of value-added products. Several species have been used successfully for revegetation and rehabilitation of semiarid lands; however, little information is available about basic life processes and management of many native species in these settings.

Gaps. Information is limited regarding the cultural requirements of native plants for dependable establishment. Basic information about the germination, growth, reproductive mechanisms, and seed production is necessary before these species can be fully utilized. Information is needed on the ecological and economic benefits of biological diversity both within and among species. The relative value of unimproved native collections compared to improved cultivars for use in revegetation and landscape restoration needs to be quantified. Little is known regarding the impact of improved plant germplasm on existing plant communities. In addition, limited data are available concerning long-term competition and species dynamics on areas seeded to meet multiple uses. Only a few selected species have been tested for remediation use. Thorough documentation is needed about the economic and ecological value of both native and introduced species so private and public land managers and policymakers can make informed decisions about species and costs for restoration and remediation efforts. Also, the inheritance and expression of specific value-added traits must be better understood. Although many genes are currently being identified, the efficacy of these genes in producing the traits of interest needs to be understood before rangeland and forage plants can be used commercially to produce value-added products. Few grass or legume cultivars have been developed for low-maintenance turf and soil stabilization in water-restricted environments.

Goals

- Develop meaningful data bases for identifying and utilizing selected plants in the restoration, revegetation, and remediation of disturbed land areas.
- Develop research information required to revegetate, restore, and manage sustainable pasture, grassland, and rangeland ecosystems.
- Improve methods for increasing and propagating enhanced native and introduced plant germplasm for revegetation and conservation of rangelands and pastures and for remediation of disturbed or contaminated land areas.
- Identify, select, and breed plants with characteristics for use in novel ways or in new environments and identify genetic mechanisms controlling traits critical to their utilization.
- Develop molecular technology (transformation systems and associated genes) to produce rangeland, pasture, and forage plants for the production of bioproducts or remediation of degraded, disturbed, or contaminated land areas.
- Evaluate rangeland, pasture, and forage plants for conservation and novel uses and develop necessary management strategies to optimize their potential.

Approach

Interdisciplinary, multiagency approaches will be used by teams of researchers, including plant collectors, plant geneticists, molecular biologists, plant pathologists, plant physiologists, agronomists, turf specialists, and agricultural economists to identify and select plants, determine heritability and gene action for selected traits, and evaluate performance of plant cultivars and natural types under field conditions. Plant tissue culture and molecular biology techniques will be used to develop transformation and regeneration systems. Genes and gene promoters will be tested in model systems and evaluated in the optimal plant species. Management, harvesting, and processing systems will be developed to maximize profitability while minimizing environmental impacts. Linkages will be established with restoration ecologists and wildlife biologists from other organizations to obtain their expertise and input.

Outcomes

- Appropriate and affordable plant materials will be available for use in land restoration, revegetation, and conservation.
- Degraded, disturbed, or contaminated land areas will be stabilized and transformed into productive, self-sustaining landscapes.
- Cultivars of rangeland, pasture, and forage species will be developed for high quality and low-maintenance turf or for valuable new uses that can be integrated into traditional agricultural systems, rangelands, or other environments.
- Critical scientific knowledge will be developed to further advance rangeland and pasture restoration and enhancement.

Impact

Economically and environmentally sustainable rangeland and pasture ecosystems and enhanced economic opportunities for rural communities

Linkages to Other ARS National Programs

Animal Production Systems
Bioenergy and Energy Alternatives
Manure and Byproduct Utilization
New Uses, Quality, and Marketability of Plant and Animal Products
Plant Biological and Molecular Processes
Plant, Microbial, and Insect Genetic Resources, Genomics, and Genetic Improvement

Component III: Forage Management

PART I. INTRODUCTION

A. Background

Forages provide a renewable energy resource for the world's population. During growth, these plants use photosynthesis to convert solar energy into a feed stuff that can be used immediately or stored in one of several forms for later use by animals. Forages are defined as edible parts of plants, other than grain, that can provide feed for animals. Harvested and conserved forages are important for sustaining animal production in the U.S. This national program component focuses on establishing, maintaining, harvesting, storing, utilizing, and testing harvested and conserved forages. Much of the research concerning establishment and maintenance of stands is also applicable to grazed forages. Harvesting forages during periods of abundance and conserving as green chop, hay, or silage for later feeding allow for productive year-round animal enterprises in temperate regions.

Hay and silage are produced on about 73 million acres in the U.S. Corn and sorghum silage is grown on approximately 6.4 million acres; alfalfa haylage is produced on 6 million acres; and alfalfa hay is produced on 25 to 28 million acres. The remaining 33 to 36 million acres produce a variety of other grasses and legumes in monoculture and mixed species stands that are harvested for conserved forage. Livestock and poultry consume about 60 % of their total intake as forages. A significant portion of this forage is harvested and conserved in some manner, either as silage or cured hay. Dairy, beef on feed, other beef, sheep and goats, and horses and mules consume about 60, 30, 95, 90, and 70%, respectively, of their daily intake as forages.

Forage production systems are challenged by the complexity of crops, soils, and climates under which they are produced. Forage crops include various species and cultivars of grasses, legumes, and forbs. Each of these has a set of optimum conditions for establishment, growth, persistence, harvesting, storage, testing, and utilization. Few environments provide optimum conditions. The impact of these conditions on harvested and conserved forage and the designing of alternatives that will provide optimum quantity and quality are very important. In addition, the forage must be produced, harvested, stored, and fed using sound economic and ecological principles.

B. Vision

A year-round supply of high-quality forage

C. Mission

To develop and transfer science-based knowledge needed to ensure abundant amounts of harvested and conserved forages for production of livestock and their products without degrading our natural resources.

Table 4. ARS Research Locations Contributing to Component III of the Rangeland, Pasture, and Forages National Program--Forage Management.

		Component Problem Areas	
State	**Locations**	**Forage Establishment and Persistence**	**Harvest, Storage, Utilization, and Testing**
AR	**Booneville**	**X**	
FL	**Brooksville**	**X**	**X**
GA	**Tifton**	**X**	**X**
ID	**Boise**	**X**	
ID	**Dubois**		**X**
ID	**Kimberly**		**X**
IL	**Peoria**		**X**
MD	**Beltsville**		**X**
MN	**St. Paul**		**X**
MO	**Columbia**		**X**
MS	**Mississippi State**	**X**	**X**
MT	**Sidney**		**X**
NC	**Raleigh**		**X**
ND	**Mandan**	**X**	**X**
NE	**Lincoln**	**X**	**X**
NM	**Las Cruces**	**X**	
OK	**El Reno**	**X**	**X**
OK	**Woodward**	**X**	**X**
OR	**Corvallis**	**X**	**X**
PA	**University Park**	**X**	**X**
TX	**College Station**		**X**
UT	**Logan**	**X**	**X**
WI	**Madison**	**X**	**X**
WV	**Beaver**	**X**	
WY	**Cheyenne**	**X**	

PART II. PROBLEMS TO BE ADDRESSED

A. Forage Establishment and Persistence

Problem Statement

Rationale. Forage crops provide 60 to 90% of the feedstuffs consumed by ruminant domestic livestock and contribute an estimated $24 billion of agricultural income in the U.S. The value of hay production alone in 1995 was $11 billion. Forage plants also play an important role in the Conservation Reserve Program and in enhancing water quality and carbon storage. Low-cost forage-based systems will become increasingly important as commodity price support programs are phased out. Stand establishment is a critical phase in forage crop production, and failures result in lost capital and production, increased soil erosion, and reduced environmental quality. A key advantage of perennial forages is their long-term persistence. The longer a stand remains productive, the lower the cost of production, and the less chance there is of environmental degradation through soil erosion and other factors.

What is known. Precise seed placement in the soil and favorable seedbed conditions for germination and seedling development are critical for successful stand establishment. Many forage plants have small seeds and may exhibit some level of seed dormancy. Some subtropical grasses are propagated vegetatively but have similar seedbed requirements for establishment. Each of these factors is modified by biotic and abiotic (i.e., involving living organisms vs. nonliving factors such as rainfall and temperature) stresses that can adversely affect seedling establishment. Furthermore, perennial forages often are planted on marginal crop lands with steep slopes or shallow soils on exposed sites, which compound the stress. Once established, persistence of the plant is affected by the growth environment (e.g., soil, water, nutrients, light, temperature) and management (e.g., harvest timing and frequency, competitive interactions, pest control, animal behavior). We understand how these factors individually affect productivity and persistence, but we do not know how these factors interact to mitigate or exacerbate stresses.

Gaps. We need to develop a complete understanding of seed bed ecology and seed and seedling physiology. This is especially needed for native plants and species that are hard to establish. Because stresses severely affect the seedling and productivity and persistence, we need to clarify tolerance mechanisms in forage plants, which enable the plant to cope with biotic and environmental stresses and their multiple interactions. Carbohydrates, proteins, and other reserve compounds fluctuate during plant growth. We need to understand the physiological and anatomical basis for relationships among these compounds and winter survival, defoliation tolerance, and other stresses. Decision-making tools are needed to monitor changes in forage stands; to help decide when, where, and how best to rejuvenate or re-establish forage crops; and to introduce innovations to enhance the establishment of seeded and vegetatively propagated forages.

Goals

- Improve our understanding of ecological and physiological aspects of forage plant establishment, persistence, and productivity, especially under marginal conditions.
- Design site- and species-specific management practices that result in optimal establishment, stand life, and productivity.
- Develop decision-making tools to monitor, assess, and determine when, where, and how best to establish new stands of forage crops.

Approach

A multidisciplinary approach is needed because of the many biological, climatic, and physical factors involved. The ARS has a long history of multidisciplinary, multilocation research and has modern facilities and scientists located in all major forage-producing regions. A coordinated research effort among appropriate locations and disciplines will be used. Studies will be conducted at multiple scales (controlled environment, small plot, to farm field) so that results can be readily transferred to producers. Long-term field studies will be conducted to capture the effects of climatic extremes on productivity and persistence of forages. On-farm research will be used to field-validate experimental results and rapidly transfer technology to producers. Models will be used to help assess complexities of multiple stresses and their interactions. Current technology in forage systems has relied on traditional agronomic approaches to improve persistence, productivity, and quality of forages. Now, innovative ecological approaches will be necessary to address issues related to productivity and persistence. Current and emerging technologies in the field of restoration ecology and molecular biology will be particularly useful in defining these relationships. Additionally, new sampling and statistical approaches that use spatial variability analyses, GIS, and case studies will be explored as techniques to develop and test hypotheses and extrapolate results to other environments and larger geographical areas.

Outcomes

- Stable and sustainable forage crop production and improved farm profitability will result from reduced establishment costs and longer-lived forage crops.
- Potential for environmental degradation will be reduced through reduced soil tillage and increased use of long-lived perennial crops.

Impact

Improved economic conditions of many farms based on profitable forage-based agriculture

Linkage to Other ARS National Programs

Animal Production
Crop Production
Global Change
Integrated Agricultural Systems

B. Harvest, Storage, Utilization, and Testing

Problem Statement

Rationale. Annually in the U.S., forages valued at $16 billion are harvested from about 25% of cropland and stored as hay or silage. About one-half of these crops is used to meet nearly all of the forage requirements of dairy cattle. This conserved forage provides a regular supply of nutrients and roughage for livestock, especially during periods when plants are unable to grow. Unfortunately, dry matter losses are 15 to 30% or higher under best available management. Additionally, nutrient losses of $3 to 5 billion occur annually because of leaching and reduction in protein availability. Unfavorable storage or ensiling conditions also promote microbial consumption of valuable nutrients and sometimes lead to growth of pathogenic organisms (e.g., listeria) or produce toxins affecting animal and human health. The high fiber content of conserved forage (40 to 80%) and its often poor fiber degradability (50%) limit animal production and increase manure output. Forage consumption provides the physical stimuli required for milk production, buffering to prevent acidosis, and many nutrients needed by animals. Low forage quality, combined with the inaccurate estimates of forage nutritive value, can lead to poor livestock performance or excessive use of nutrient supplements. Even when used properly, protein- and energy-rich feeds and mineral supplements cannot totally compensate for poor quality forages. Forage crop production will expand if farmers have tools to harvest, conserve, test, and utilize quality material.

What is known. ARS research has been at the forefront in documenting losses and quality changes occurring during harvesting and storage of forages. Changes in nutritive value during harvest have not been studied as thoroughly although much can be surmised from our knowledge of these operations. Theory, based primarily on oxygen movement and microbial growth, reasonably explains the variation in dry matter losses across different storage systems. However, little has been done to validate this theory. Factors affecting nitrogen transformations during storage have been studied so that we can reasonably predict the changes taking place. A limited number of studies have investigated changes in structural and nonstructural carbohydrates during storage. Little is known about particular microorganisms involved in the degradation of harvested and stored forages.

Gaps. Forage quality varies during a 24-hour period, but the effects of time-of-harvest on the quality of stored forages is not completely understood. In dry climates, afternoon cutting appears beneficial, but only limited data are available for humid climates. Losses of dry matter and quality in storage are affected by the porosity of the stored crop, but the factors affecting density in various silo types are based primarily on assumptions rather than actual research data. Relatively little is known about the enzymes in forage crops that are responsible for true protein breakdown during ensiling. Red clover and tannin-containing legumes have less protein breakdown during ensiling than other forages, but the mechanisms of protein protection are not completely understood. Gaining this understanding could lead to novel, inexpensive means of protecting silage proteins. Factors affecting the development of pathogens and microbial toxins in stored forages are poorly understood, and such knowledge is needed to devise means of inhibiting microbial growth and toxin production. Techniques for rapidly detecting microbial and toxin presence are critical for maintaining animal health and preventing their transfer to milk and other human foods.

Goals

- Determine the optimum time of day to cut forage to maximize nutritive value under various harvesting technologies, weather, and storage conditions.
- Develop novel techniques to minimize harvest losses.
- Determine key management factors that minimize losses and nutritive changes in various forage storage systems.
- Develop a more thorough understanding of the factors controlling the growth of pathogens and the production of microbial toxins in forages during storage.
- Develop rapid techniques for on-farm detection of pathogens and microbial toxins in forages and other crops.
- Develop cost-effective methods to preserve protein in silage systems.
- Develop other novel methods to improve the nutritive value of forages during storage.

Approach

Losses and quality changes during harvest and storage will be investigated and techniques to minimize losses will be improved. Rapid techniques to identify pathogens and microbial toxins must be developed. Initially these techniques will be used to monitor crop development; later some may be refined for more general use by farm consultants to diagnose problems. Biochemistry research will be used to understand protein and carbohydrate structures and transformations in forage crops during harvest and storage processes. This information will be crucial for developing means to reduce losses and improve forage quality during harvest and storage. Interdisciplinary scientific teams will identify and remedy factors limiting the supply and utilization of energy, protein, and minerals in harvested forages. Rapid, precise, accurate, and cost-effective laboratory or on-farm methods will be developed to estimate forage quality, allowing producers to adjust rations for efficient animal production. Improved forage varieties; crop management, harvesting, processing, and handling methods; ration balancing; and feeding strategies will be developed and integrated into improved forage-livestock production systems. Site-specific decision-making tools such as computer models, spreadsheets, and expert systems will be developed, enabling farmers to produce and use high quality forages cost effectively and without adversely affecting the environment.

Outcomes

- A more comprehensive knowledge base will help farmers improve their management of forage harvesting and storage.
- New or improved equipment to harvest and store forages will minimize losses of dry matter and nutritive value.
- New additives or improved germplasm will help preserve protein and/or improve forage quality during storage.
- New or improved techniques will minimize pathogens and microbial toxins in forages.
- Improved nutritive value, management, harvesting, processing, handling, and quality analysis of forages, combined with refined ration balancing, feeding strategies, and management tools, will increase forage use on farms and enhance livestock performance.

Impact
Increased annual savings to farmers of $1 billion, minimized manure production, reduced environmental impact, improved sustainability, more efficient livestock production, and a safer food supply for livestock and humans

Linkages to Other ARS National Programs
Animal Health
Animal Production Systems
Food Safety (animal and plant products)
New Uses, Quality, and Marketability of Plant and Animal Products
Plant Biological and Molecular Processes
Plant, Microbial, and Insect Genetic Resources, Genomics, and Genetic Improvement
Soil Resource Management

Component IV: Grazing Management: Livestock Production and the Environment

PART I. INTRODUCTION

A. Background

Rangelands contain hundreds of different species of vertebrate and invertebrate animals that depend wholly on plants for their survival. Pastures and forages may support fewer animal species, but an equal diversity of processes. Grazing herbivores, including domestic livestock, affect basic ecosystem processes, including nutrient cycling, primary production, decomposition, and vegetative structure. Effects of these impacts are highly varied and often poorly understood. There is extensive evidence that grazing can be effectively managed for some vegetation-related objectives, but we have a limited knowledge of management requirements for other components of grazed ecosystems. Supplying forage for livestock production is a traditional value of our rangelands and pastures. Other values of great importance include species diversity, water quality and quantity, recreation, and aesthetic values. On sites where grazing is appropriate, livestock management requires greater ecological understanding of associated effects on these other values and related attributes of these natural resources, as well as on the production of food and fiber. To sustain animal production on our Nation's rangelands and pastures, new technologies and management systems based on this knowledge are required that recognize and mitigate negative grazing effects on water, wildlife, and environmental quality.

B. Vision

Healthy rangeland and pasture ecosystems that support ecologically and economically sustainable animal production systems

C. Mission

To develop scientific knowledge and provide and transfer technology to sustain the health of the Nation's grazed rangelands and pastures, conserve their natural resource base, and provide animal products demanded by society.

Table 5. ARS Research Locations Contributing to Component IV of the Rangeland, Pasture, and Forages National Program--Grazing Management: Livestock Production and the Environment.

		Component Problem Areas		
State	**Locations**	**Grazing Impacts on Water Quality**	**Grazing Impacts on Ecosystems**	**Management, Behavior, and Production of Grazing Livestock**
AZ	**Tucson**	**X**	**X**	
CO	**Ft. Collins**		**X**	
FL	**Brooksville**			**X**
GA	**Watkinsville**	**X**	**X**	**X**
GA	**Tifton**	**X**	**X**	
ID	**Boise**	**X**	**X**	
ID	**Dubois**	**X**		
MT	**Miles City**		**X**	**X**
MS	**Mississippi State**	**X**		
MS	**Oxford**		**X**	
NC	**Raleigh**			**X**
ND	**Mandan**		**X**	**X**
NM	**Las Cruces**		**X**	**X**
NV	**Reno**		**X**	
OH	**Coshocton**		**X**	
OK	**El Reno**	**X**	**X**	**X**
OK	**Woodward**		**X**	**X**
OK	**Stillwater**		**X**	
OR	**Burns**	**X**	**X**	**X**
OR	**Corvallis**	**X**		
PA	**University Park**	**X**	**X**	**X**
TX	**Temple**		**X**	
WI	**Madison**	**X**		
WV	**Beaver**	**X**		
WY	**Cheyenne**		**X**	**X**

PART II. PROBLEMS TO BE ADDRESSED

A. Grazing Impacts on Water Quality

Problem Statement

Rationale. Rangeland and pastures comprise about 55% of the land surface of the U.S. Properly managed livestock grazing is an ecologically and economically sustainable use of these rangeland and pasture resources. Livestock grazing impacts on water quality, however, are a major concern. Just in the 19 western rangeland states alone, more than 120,000 miles of stream, river, and coastline have been classified as water quality impaired under the Total Maximum Daily Load programs mandated in each state by the Clean Water Act of 1972. The contribution of livestock grazing to these water quality problems is unclear. Recent threatened and endangered species listings of salmon, steelhead, trout, and other cold water biota that inhabit rangeland streams and rivers in the Pacific Northwest, Intermountain, and Great Basin regions of the country add renewed urgency to the need to solve water quality problems on rangelands and pastures. In the humid, temperate region of the U.S., livestock producers are turning to management-intensive grazing systems as an alternative to confinement production systems to lower production costs and avoid perceived nutrient management problems. However, these systems can create their own problems of cost and nutrient management.

What is known. The most prominent water quality impairments in rangeland and pasture systems include nutrients, pathogens, pesticides, sediments, dissolved oxygen, pH, temperature, total dissolved solids, total suspended solids, and turbidity. A very limited amount of research information is available about the impact of livestock grazing on nutrients, pathogens, and sediments. Livestock grazing can enhance water quality by stimulating the vigor and filtering, shading, and bank-stabilizing capacity of riparian vegetation. Grazing animals also can impair water quality by directly depositing manure and urine into surface water; depositing manure and urine near surface water where runoff and leaching can transport these materials into the water; accelerating erosion and sedimentation; altering aquatic habitat and stream flow; and reducing the capacity of riparian vegetation to provide shade, filter contaminants, and stabilize streambanks and shorelines. Effects of livestock grazing on water quality can be managed by controlling the timing, intensity, duration, and spatial distribution of grazing. Based on these management principles, Best Management Practices (BMPs) have been developed to promote sustainable rangeland and pasture utilization by livestock with minimal impact on water quality.

Gaps. Impacts of livestock grazing on water quality in rangeland and pasture systems are poorly understood, particularly as related to dissolved oxygen, pH, temperature, total dissolved solids, total suspended solids, and turbidity. Past research examining impacts of agriculture on water quality has focused almost exclusively on intensive farming. Rangeland and pasture ecosystems are complex and dynamic. Many water quality impairments in these systems may be functionally related; therefore, grazing impacts on water quality need to be evaluated with a systems research approach. Research evaluations, economic considerations, and risk assessments are needed for BMPs that have been implemented to minimize grazing impacts on water quality. Current water quality assessment and monitoring tools and techniques are poorly suited for water quality research and management in the diverse, complex, and often remote landscapes occupied by rangeland and pasture systems. Because of this inadequacy, background levels of water quality in rangeland and pasture systems are often unknown, thus preventing a reliable evaluation of land use impacts on water quality.

Goals

- Determine the livestock grazing impacts on water quality impairments prominent in rangeland and pasture systems.
- Evaluate the effectiveness and risks associated with grazing BMPs designed to reduce water quality impacts by livestock.
- Develop and evaluate assessment and monitoring tools and techniques to manage water quality more efficiently and effectively within diverse and extensive landscapes.
- Rapidly transfer new knowledge, tools, and techniques to producers and natural resource management and regulatory agencies.

Approach

A multidisciplinary approach will be used to determine the effects of grazing on water quality; evaluate water quality BMPs for grazing; and develop and test more effective water quality monitoring and assessment tools and techniques for rangeland and pasture systems. Scientists from different research units and other agencies concerned with water quality will collaborate to conduct research across different kinds of geographical regions and at appropriate scales so the results are readily transferable to the user.

Outcomes

- Water quality in rangeland and pasture systems will be improved through effective and sustainable grazing management practices.
- Water quality management will be more efficient and effective through use of new and improved assessment and monitoring tools and techniques.

Impact

Sustainable livestock production systems with minimal impact on water quality and associated beneficial uses of water

Linkages to Other ARS National Programs

Water Quality and Management

B. Grazing Impacts on Ecosystems

Problem Statement

Rationale. Grazing of livestock has been the primary agricultural activity on lands considered unsuitable for crops because of insufficient or unreliable rainfall, poor soils, and irregular topography. Although grazing historically has been considered as the only benefit derived from these lands by utilizing forage that would otherwise have no economic value, this view has changed within the past several decades. National and state agencies responsible for managing public lands and producers on private lands are realizing that rangeland watersheds have a high value as habitat for wildlife, preserves of biodiversity, sources of water for rural and urban communities, recreation, and aesthetics. As a result, these agencies are developing and implementing new grazing land evaluation and planning methodologies that apply to the range or ecological site scale. These technologies recognize that the health, stability, and biodiversity of an ecological site depend on a complex interaction and feedback among climate, soils, vegetation, topography, land use, and management.

Rangeland, pasture, and forage production play a role in maintaining and improving biodiversity (numbers and relative abundances of species). The U.S. includes more than 850 million acres of pasture and rangeland and cropland that is sometimes grazed. Society values and has come to expect biodiversity as a feature of these agricultural environments. A recent USGS-sponsored survey reported that land and water use and invasive species are responsible for dramatic declines in plant, animal, and ecosystem resources in the U.S. Livestock production systems are part of a diverse and productive environment and in many instances enhance environmental attributes associated with biodiversity. Farmers and ranchers can create as well as modify wildlife habitats and ensure plant diversity as a function of production practices. Wildlife, in turn, impacts agricultural systems as biocontrol agents, amenity value, and recreation (fishing and hunting), or as pests, disease vectors, and predators. Primary production could be sustained by diverse biota because of increased resistance to change caused by short-term weather patterns, land surface and natural events such as fire, and management.

What is known. At the watershed scale, grazing has direct on-site effects on vegetation, soil, water, and riparian processes and indirect off-site effects on channel and riparian processes. Most rangeland research has focused on the direct impacts of improper grazing either on the upland areas of watersheds or within riparian areas. These impacts include soil compaction and loss of canopy and ground cover, which lead to reduced infiltration, excessive runoff, increased soil detachment by wind or raindrop impact, subsequent transport of soil off-site, and changes in plant species composition. In the case of riparian areas, the direct impacts include reduction of vegetative cover, soil compaction and trampling of stream banks, and concentration of animal wastes, which can lead to changes in species composition, erosion, stream bank instability, and water quality degradation. Indirect off-site effects are caused primarily by increased runoff and sediment from upland areas through a watershed channel network. These impacts include erosion at the head of gullies and channelization of sloping field surfaces. This lowers the level of drainage networks within a system and changes the equilibrium of stream channels, which in turn, increase peak flows, sediment transport, and stream bank erosion, and destroy riparian systems.

Land use changes in the transition from intensive cropping to pasture modify habitats**.** Wildlife often graze improved pasture as well as rangelands. The mosaic of woodlands and pasture in much of the U.S. provides shelter and a diverse food source for feral ruminants as well as for birds, insects, and a range of other organisms. Invasive species are becoming a problem, and unconventional biocontrol agents such as insects would be useful replacements for chemicals. Rangelands include public and private lands that support a tremendous variety of flora and fauna. Small areas of prairies still remain in many areas now primarily in crop production.

Gaps. Watershed characteristics such as soils, vegetation, topography, and climate are highly variable in both space and time. Further, watersheds cover large physical areas, which makes traditional research techniques such as control vs. treated experimental designs difficult and expensive to implement. Adding to this complexity, many of the processes affected by grazing change or evolve over decades or longer, making it difficult to sustain an experimental program. In terms of economics, rangeland watersheds generally have a low value per unit acre compared to croplands, which has made research at this scale a low priority. Although there has been much research on grazing effects on individual components of the hydrologic cycle, local erosion, and plant species composition, little research has been done that integrates these components at the watershed scale. There is a lack of watershed data relating upland grazing management and its effects on plant composition, soil properties, runoff, erosion, and channel dynamics. The interaction of grazing intensity and climatic variations such as El Niño-La Niña impact the stability of the watershed in relation to rates and amounts of runoff and sediment. The impact of this interaction is poorly understood. Although there has been much research concerning on-site impacts of grazing, there has been little research on the impacts of upstream grazing management on downstream processes such as channel stability and riparian system integrity.

More information is needed about the effects on wildlife of management practices associated with rangeland and pasture (drainage of wetlands, land clearing, cropping, silvo-pastoral and agroforestry practices). The roles of managed pasture in sustaining wildlife, including faunal and floral interactions to provide feed and shelter, are not well understood. Similarly, we need to understand the impacts of habitat creation and degradation on beneficial components of a biological community, such as birds and insects, as well as on the detrimental components, such as coyotes that encroach on eastern pastures and invasive plants. More research is needed on forage loss as a function of grazing by feral hoofed animals.

Goals

- Document the direct and indirect effects of grazing practices on biological resources; differentiate between natural and grazing management effects on grazing land ecosystem processes; and evaluate the effects of grazing management on channel and riparian systems.
- Integrate ARS soil, water, plant, animal, and watershed process research at the national and regional levels and collaborate in integrated watershed management research and technology

transfer methods with other federal agencies, universities, public advisory agencies, and private consultants.
- Develop production practices that are in harmony with and sustain multiple use demands on rural landscapes for landscape amenities, a biologically diverse environment, and agricultural stability.
- Provide data to pasture and range managers and advisory personnel for informed decisions that protect biodiversity through livestock management practices.

Approach

Use well-designed long-term grazing management experiments to quantify grazing effects on livestock production and biological community interactions. This will be multidisciplinary, collaborative research with livestock scientists, wildlife biologists, plant ecologists, soil scientists, entomologists, and foresters. Synthesize existing knowledge of the impacts of grazing on watershed processes and riparian systems at the national and regional level and integrate current and proposed research in soil, water, plant, animal, watershed and other related areas. Maintain ARS rangeland watersheds and ensure that grazing systems are incorporated in ongoing and future research as long-term commitments. Develop formal links with national and state agencies and universities at the regional level to collaborate in related research areas (wildlife, recreation, economics, extension) not conducted by ARS.

Outcomes

- Integrated ARS range research across soil, water, plant, and animal disciplines at the watershed scale will support informed management and regulatory decisions regarding land-use, livestock production and agricultural practices, rangeland management, wildlife, and water and soil resources.
- The long-term outcome will be a scientific basis for grazing management at the watershed scale.

Impact

Sustainable use of grazing land watersheds and healthy riparian systems for domestic livestock health and productivity, habitat protection and preservation, income diversity, and environmental quality in terms of aesthetics and water quality

Linkages to Other ARS National Programs

Global Change
Integrated Agricultural Systems
Manure and Byproduct Utilization
Soil Resource Management
Water Quality and Management

C. Management, Behavior, and Production of Grazing Livestock

Problem Statement

Rationale. Forages supply about 90% of the nutrients consumed by sheep, 80% of the nutrients consumed by beef cattle, and 60% of the nutrients consumed by dairy cattle, including nutrients consumed by the breeding herd. A viable industry requires efficient production of a stable, year-round supply of high quality forage. Yet, forages are seldom a commodity; they are most commonly marketed through livestock. Problems include determining proper stocking rates, seasons of use, and ratios of grazing and rest, as well as achieving proper livestock distribution, including use of riparian areas. The interaction of management with animal behavior, including mechanisms of grazing and choice of grazing sites, may be useful in rectifying these problems.

Grazed ecosystems are characterized by a dynamic, hierarchical interaction of soil, plants, animals, and the environment. Because of the logistics of conducting research on this dynamic system, the soil-plant-animal-environment interface generally has been neglected in research. Researchers have historically followed a reductionist approach, studying only one individual component while either ignoring the others, or attempting to hold them static in empirical experiments such as grazing trials. As our scientific knowledge and information system technology has progressed, we are now able to better deal with knowledge integration in a more synthetic approach.

To utilize forage and grazing land resources efficiently, we need to understand livestock choices in their behavioral patterns of landscape utilization. Livestock interact with the grazed ecosystem to satisfy drives consisting of hunger, thirst, rumination, rest, and social activities. The strategy for foraging appears to be based on the need to maximize harvest rate of energy at a feeding station and minimize energy expenditure between feeding stations.

What is known. Animal behavior, productivity, biological and economic efficiency, and impact on the environment are affected by at least four factors: forage quantity and quality, animal genetics, current management and environmental constraints, and residual effects from previous management and environmental variables. The general relationship of grazing intensity to productivity per animal and per unit of land has been described but has not been quantified for different pasture and rangeland ecosystems. The genetic basis of animal production efficiency has been extensively studied in feedlots but seldom under grazing. Animals make cognitive decisions about locating necessary resources in the landscape. As demonstrated by rotational grazing or fencing of fragile, restricted areas, management can change animal cognitive behavior and patterns of landscape use.

Gaps. We have a general understanding of the influence of genetics, current and historical management and environmental constraints, characteristics of the forage and/or grazing land resource, and their interactions. However, quantification of the relationships of management inputs to animal behavior, production outputs, and impact on the environment, is generally unavailable over a wide range of each input. Such input-output relationships are essential to the construction of decision support systems. Such systems either do not exist or have not been evaluated under sufficient numbers of situations for reliability or confidence by end-users. Optimization of landscape use efficiency by all clients and consumers requires quantification of the interaction of inputs for the desired productivity and environmental impact of the inputs.

Goals

- Understand and quantify the influence of forage quantity and quality, animal genetics, previous management and environment, and current environment on animal behavior and production.
- Understand the factors and stimuli that affect animal behavior and production in response to the landscape and its components.
- Develop predictive relationships to determine site-specific responses of animal productivity and landscape stability to management inputs for use in decision support systems.

Approach

A multidisciplinary approach will be used to optimize efficiency of livestock production and utility of the landscape for multiple consumers, including livestock producers, recreationists, and the general public. The disciplines of ecology, economics, and the social sciences will be included with the usual agricultural, biological and physical sciences to facilitate a holistic approach to the problems. Multilocation, large scale implementation of assumed best management practices will be used to test component research findings in a system setting. Models and decision support systems will be used in early stages of experimentation to determine most likely and most sensitive management factors to examine and to provide inputs for validating and improving the models themselves.

Outcomes

- Predictable biological and ecological responses to management alternatives will be determined.
- The above responses can be applied to economic analyses of production systems and used to develop and test models and decision support systems.
- The ultimate outcome is economically sustainable livestock production on ecologically stable landscapes.

Impact

Integrated livestock production systems that account for all stimuli, inputs, and responses to facilitate improved production efficiency, economic viability, and environmental stability

Linkages to Other ARS National Programs

Animal Production Systems
Manure and Byproduct Utilization
Water Quality and Management

Component V: Integrated Management of Weeds and Other Pests

PART I. INTRODUCTION

A. Background

Invasive and noxious weeds, poisonous plants, and destructive insects can have devastating effects on rangeland and pasture ecosystems. These organisms disrupt the function and structure of these ecosystems and reduce their ability to provide the goods and services required by society. Pests adversely affect the integrity of these ecosystems and degrade their capacity to recover from man-made or natural disturbances by displacing desirable species and reducing biological diversity.

Historically, pesticides have been the primary tools used to combat rangeland, pasture, and forage pests. Although small infestations or outbreaks of pests have been eradicated, pest populations often expand despite pesticide use. There is growing recognition that the search for a single technology or tool to control pests is misdirected. The presence and spread of many pests often signal underlying management problems that must be corrected to allow sustained progress to control the pest and improve rangeland and pasture ecosystem performance. Past management practices often have created disturbance regimes that caused undesirable shifts in species composition and hastened pest establishment and population expansion. For example, the combination of overgrazing, exclusion of fire, and application of broadleaf-specific herbicides has contributed to and accelerated the conversion of complex native rangeland to simplistic communities dominated by a few exotic species and early-succession native species.

Instead of relying on a single technology, integrated pest management offers a paradigm to optimize pest control in an economically and ecologically sound manner. This integrated approach coordinates tactics to assure stable ecosystem function and maintain pest damage below economically unfavorable levels, while minimizing hazards to humans, animals, plants, and the environment. Integrated pest management emphasizes rangeland and pasture ecosystem function rather than the pest or a particular method of pest control. It also reduces reliance on any single method of pest management, i.e., chemical, fire, mechanical, or biological. Pest control tactics should be integrated with other ecologically sound and sustainable tactics to arrive at lasting solutions. Ongoing development of new technologies is important to provide additional tools to improve pest management systems.

A goal of rangeland and pasture pest management should be to reclaim or restore degraded pest-infested rangeland and pasture communities so they are less susceptible to invasion by pests. In many instances, rangelands and pastures have deteriorated such that desirable species are either absent or present in such low abundance that plant community recovery will be unacceptably slow without direct intervention. Site-specific management systems are needed that comprise multiple, complementary technologies applied in appropriate sequences to optimize improvement of degraded communities.

B. Vision

Pest levels that do not negatively impact the sustainability of rangeland, pasture, and forage systems

C. Mission

To make rangeland, pasture, and forage management systems ecologically and economically sustainable by eliminating the negative impact of invasive and noxious weeds, poisonous plants, and destructive insects.

Table 6. ARS Research Locations Contributing to Component V of the Rangeland, Pasture, and Forages National Program--Integrated Management of Weeds and Other Pests

Component Problem Areas					
State	**Locations**	**Invasive and Noxious Weeds**	**Poisonous Plants**	**Destructive Insects**	**Lack of Effective Spatial Information Technologies to Monitor and Assess Pest Populations**
AK	**Fairbanks**			**X**	
CA	**Albany**	**X**			
DE	**Newark**			**X**	
France	**Montpellier**	**X**			
ID	**Boise**	**X**			
MT	**Sidney**	**X**		**X**	**X**
NE	**Lincoln**	**X**			
NV	**Reno**	**X**			
OR	**Burns**	**X**			
PA	**University Park**			**X**	
TX	**Weslaco**	**X**			**X**
UT	**Logan**	**X**	**X**		

PART II. PROBLEMS TO BE ADDRESSED

A. Invasive and Noxious Weeds

Problem Statement

Rationale. Invasive and noxious weeds are expected to infest 140 million acres in the U.S. by the year 2010, and infestations are expected to increase at the rate of 20 million acres per year. Rangelands and pastures will be the primary land types invaded by these species. These plants aggressively occupy and expand their range at the expense of rangeland and pasture productivity, biodiversity, wildlife habitat, recreational values, and human and animal health. Most of these weeds were introduced from other countries, are not native to North America, and lack natural enemies in their new ecosystem. Prevention, early detection, and eradication are high priority goals for infestations that are still at an early stage of expansion. Chemical, mechanical, and biological control methods can temporarily reduce the competitive impact of these weeds. Revegetation and rehabilitation of these systems and proper management are needed to sustain desirable plant communities in the long-term.

In recognition of the severe impact of these plants, the President issued Executive Order 13112, "Invasive Species," which mandates development of programs to (1) prevent the introduction of invasive species; (2) detect and respond rapidly to and control populations of such species in a cost-effective and environmentally sound manner; (3) monitor invasive species populations accurately and reliably; (4) provide for restoration of native species and habitat conditions in ecosystems that have been invaded; (5) conduct research on invasive species and develop technologies to prevent the introduction and provide environmentally sound controls of invasive species; and (6) promote public education on invasive species and the means to address them.

What is known. Invasive and noxious weeds currently infest millions of acres of the Nation's range, pasture, and forage lands and are expanding at a very high rate. These weeds can alter basic ecosystem processes and succession pathways to exclude natural reestablishment of desirable plant communities. Weed control measures are incompletely effective unless the weeds are replaced with competitive perennial plants or fitness of invasive weeds is reduced sufficiently to allow desirable plants to fill niches previously occupied by the weeds. Current land management practices also may require modification to prevent subsequent weed establishment.

Gaps. Current methodologies to inventory and assess weed populations and population dynamics are inadequate. The impacts of alternative land management practices on weed establishment and persistence are not well understood. Development of effective weed control and revegetation techniques requires an expansion of our basic knowledge of the biology and ecology of both desirable and weedy plant species and their competitive ability. Effective and safe biological, chemical, and mechanical control treatments need to be developed and evaluated.

Technology for seed production of native-plant materials needs to be further developed. Successful management of weed-infested range and pasture lands requires an integrated approach for prevention, control, and restoration.

Goals

- Improve methodologies to inventory and assess invasive and noxious weed populations.
- Assess impact of alternative land management practices on weed invasion processes.
- Develop basic knowledge of the biology and ecology of both weeds and desirable revegetation species under current and potential future climatic and management conditions.
- Develop effective and environmentally safe biological, chemical, and mechanical weed control treatments.
- Develop and evaluate plant materials that can restore acceptable levels of productivity, biodiversity, and ecosystem structure and function to weed-disturbed landscapes.

- Evaluate seed bed preparation treatments and microenvironmental effects on establishment of both weeds and desirable plant species.
- Integrate prevention, control, and restoration practices into successful and sustainable weed management and restoration strategies.

Approach

An interdisciplinary approach will be used to develop sustainable management strategies to prevent, control, and restore weed-infested rangeland and pasture. This approach will be based on fundamental knowledge of ecosystem processes and the environmental response of both weedy plants and desirable revegetation species. New methodologies will be developed to detect the extent of current weed infestations and to estimate potential future expansion under alternative climatic conditions. Environmentally safe and effective control measures will be developed to reduce weed-population density. Plant materials will be developed that can persist under competition from introduced weedy species. Sustainable management strategies will be developed to ensure persistence of desirable plant communities in areas subject to potential weed invasion. This program will be implemented in close cooperation with other ARS programs and program components related to soil and plant resources and ecosystem management.

Outcomes

- Fundamental scientific knowledge of rangeland and pasture ecosystems will be used to develop more effective integrated weed management systems.
- Wildlife habitat, recreational values, biodiversity, and environmental quality of public and private rangelands will be maintained or restored.
- Economic efficiency from our Nation's rangeland and pasture will be increased.

Impact

Sustained diversity and productivity of rangeland and pasture systems for multiple management objectives.

Linkages to Other ARS National Programs

Animal Health
Crop Protection and Quarantine
Global Change
Soil Resource Management

B. Poisonous Plants

Problem Statement

Rationale. Poisonous plants are common on rangelands and pastures, and their foliage and seeds can be harvested in feed. Livestock deaths and illnesses caused by eating poisonous plants vary from 3-5% of livestock grazing western rangelands at an annual cost of about $340 million; 1% of animals are born with birth defects caused by poisonous plants. These estimated costs do not include decreased animal performance, increased treatment costs, or additional expenses from altered management programs. Furthermore, the presence of poisonous plants and subsequent risk of poisoning interfere with optimum use of rangeland, pasture, and forages.

What is known. Most of the poisonous plants with major economic impacts have been identified, and some of their toxic compounds have been chemically characterized. Specific recommendations to reduce loss are available for some toxic plants, but the most common management solution is to restrict access when the plants are most toxic or when animals are most susceptible. This approach wastes valuable forage growing with the poisonous plants, may require the use of expensive supplemental feed, or restricts use of rangeland to times when forage quality is not optimal. Herbicide control recommendations are available for the important poisonous plants; however, economic, environmental, and ecological concerns limit use of chemical herbicides in sensitive areas.

Gaps. The symptoms of poisoning are known for most economically important poisonous plants, but the specific mechanisms of action are needed to develop specific field treatments. Rapidly determining the concentration of plant toxins is crucial to solving toxic plant problems and may allow prediction of plant toxicity. Little is known about the grazing conditions and environmental factors that cause animals to graze specific poisonous plants. Information on plant toxicity must be integrated with livestock grazing behavior and environmental factors to develop and refine management strategies that reduce the risk of poisoning.

Goals

- Determine toxicity of poisonous plant populations, learn how toxin levels change during development in response to climate and environmental stress, and develop models to predict toxicity.
- Describe plant communities in which poisonous plants occur and understand their population cycles and other environmental factors that affect their density.
- Determine conditions under which livestock graze poisonous plants and are poisoned.
- Determine the effect of nutritional states on toxic plant consumption and intoxication.
- Determine the effect of intoxication on nutritional status of livestock.
- Develop grazing management strategies and cultural practices that favor suppression of poisonous plants and provide alternative palatable forages.
- Develop immunologic-based assays and potential vaccines.
- Determine mechanisms of plant toxins, develop diagnostic tools to identify poisonings, and develop treatments.
- Determine the effects of toxic plants on livestock reproduction.
- Develop integrated management strategies from research outcomes to reduce the risk of poisoning.

Approach

Chemical and immunological assays are being developed to determine the level of toxins in plants, harvested feeds, medicinal plants, and animal products. Immunologically-based methods also may yield vaccines and better diagnostic tools. Plant population studies will measure densities of poisonous plants, characterize their population cycles, and determine their response to climatic patterns. Grazing studies will determine the conditions under which livestock graze poisonous plants and test management strategies to prevent poisoning and reduce poisonous plant populations. Ecological studies will determine competitive relationships with native or seeded species to determine if specific poisonous plants can be suppressed.

Outcomes

- Predictive and preventive strategies will be developed to control poisonous plants and mitigate their effects on animals.
- Vaccines, diagnostic tools, and specific treatment will be developed or advanced.
- Results from multidisciplinary research (chemistry, toxicology, pathology, ecology, behavior, and nutrition) will be integrated to evaluate the risk of poisoning, and decision support tools will be developed and used to reduce livestock poisoning.

Impact

Reduced livestock losses from poisoning and more efficient use of rangeland, pasture, and forages

Linkages to Other ARS National Programs

Animal Health
Animal Production Systems
Food Safety

C. Destructive Insects

Problem Statement

Rationale. Rangeland, pasture, and forage insect pests consume 10 to 25% of forage production and cause substantial economic losses. These insect pests not only destroy grasses and forages used by livestock, but can facilitate the spread and severity of diseases that further limit plant growth and survival. Many pest insect species cannot be controlled with conventional insecticides. Thus, we need to develop alternative strategies such as biological control agents, plant resistant varieties, and genetically engineered plants.

Environmental and economic constraints have reduced the viability of traditional means of suppressing insect pests on rangeland. The rangeland livestock industry is beset by problems associated with natural variation in annual forage production, which is exacerbated by extreme variations in grasshopper infestations. Rangeland and pasture managers must choose among several unattractive management alternatives, including forced sale of livestock; reducing the stocking rate; buying hay; renting more pasture; spraying; or no action, which can lead to serious overgrazing.

What is known. Most of the important forage and pasture insect pests have been identified, and their basic ecology is known. Cultural methods are the usual pest control measures because of environmental concerns about insecticide use. Development of pest-resistant forages has been limited. Resistant varieties of alfalfa have been developed for aphids but not for other pests such as potato leafhopper. Control of insects with pathogens and nematodes is being developed for several species, and biological control of the alfalfa weevil has proven effective in the eastern U.S. In most rangelands, grasshopper outbreaks occur during hot, dry periods. Outbreaks can be retarded by managing the timing and intensity of livestock grazing to maintain canopy characteristics that are unfavorable for grasshoppers.

Gaps. There are gaps in knowledge about the distribution, abundance, and economic importance of many pests. Integrated management systems that incorporate a variety of pest control strategies have not been fully developed. Interactions among pests, their natural enemies, and plants they impact are complex and poorly understood. Biological control of insect pests is not reliable, and further development of biological control agents is needed. Few grasses and legumes resist insects other than aphids. Development of forage germplasm with pest resistance has been hampered by the small number of plant breeders and entomologists working in this area. The influence of grazing management systems on grasshopper outbreaks needs to be examined at multiple locations with a variety of grazing systems. This information would provide a better understanding of the interactions among livestock grazing, grasshopper diseases, grasshopper outbreaks, climate variation, and rangeland and pasture vegetation.

Goals

- Determine economic thresholds of plant injury from insect pests.
- Develop cultivars of grasses and legumes resistant to destructive insects.
- Develop biological control programs using pathogens, viruses, predators, and parasites for important insect pests of rangeland, pasture, and forages.
- Develop a resource management system to control grasshoppers.
- Understand how grazing systems, natural enemies, range vegetation, and climate variation interact to impact grasshopper outbreaks.

Approach

Field studies will be conducted to assess impacts of destructive insects. Plant germplasm will be selected and developed for resistance to important pests. Laboratory and field research will be conducted on biological control of insect pests, including insect-pathogen interactions. Integration of cultural tactics, such as grazing systems, with other insect pest control strategies that reduce intensity and extent of infestations will be evaluated. Long-term effects of grazing systems and stocking rates on grasshopper and other insect populations will be evaluated using existing or new studies. Interactions among grasshoppers, range vegetation, climate variation, and livestock grazing will be examined to determine the influence of grasshoppers on grazing system sustainability and rangeland and pasture productivity.

Outcomes

- A greater understanding of the economic importance of insect pests and their ecology will lead to new approaches for management of insect pests.
- Development of insect-resistant forages will reduce economic losses.
- Release of parasites and predators will reduce the economic damage caused by destructive insects on rangeland, pasture, and forages.
- Development of integrated grazing and grasshopper management systems will maintain or improve rangeland condition and decrease the impact of grasshopper outbreaks.

Impact

Reduced forage losses from insect pests

Linkages to Other ARS National Programs

Animal Health
Animal Production Systems

D. Lack of Effective Spatial Information Technologies to Monitor and Assess Pest Populations

Problem Statement

Rationale. Invasive and noxious weeds, poisonous plants, and destructive insect infestations are arguably the greatest threat to rangeland and pasture ecosystems. Accurate, timely, and cost-effective procedures for regional assessment and monitoring of invasive species are needed to control their introduction and spread and are essential to the development of effective integrated pest management systems.

What is known. The value of spatial information technologies (remote sensing, GIS, and GPS) for pest management on rangelands and pastures is well established. Remote sensing techniques offer rapid acquisition of information concerning the presence, distribution, change, or impact of invasive species on grassland systems. This information can easily be combined with other geographically referenced information in a GIS for rapid and cost-effective mapping and monitoring of problem populations. Reflectance studies have demonstrated the unique characteristics of various noxious or poisonous plants. Aerial and satellite imagery also have been used successfully to detect undesirable plant species and the impact of insect populations on large areas of grassland.

Gaps. Research is needed to expand the applicability of past research over a broader range of invasive species and ecological regions. New and future technologies must be evaluated to determine the contribution each can make in detecting and monitoring of pests. Technologies that must be developed and tested for integration into pest management strategies include high-resolution satellite imaging systems, hyperspectral radiometers and imaging systems, GIS and associated spatial data bases, and expert systems capable of integrating the various types of spatial data with image data to predict outbreaks. Evaluations of costs and benefits of proposed detection and monitoring protocols are needed that will allow users to make informed decisions about the most appropriate and cost-effective method to detect and monitor invasive and poisonous species.

Goals

- Evaluate state-of-the-art remote sensing capabilities for national and regional mapping of invasive species and their associated environmental impact.
- Compare/contrast the capabilities of several types and resolutions of imaging systems for detecting invasive species.
- Produce a cost/benefit analysis for each imaging method with national and regional mapping as the goal.
- Develop characteristic remotely sensed images of specific invasive/poisonous plants and environmental impacts of insect pests on grassland ecosystems.
- Develop expert systems that will incorporate various types of GIS themes, remote sensing technologies, and decision support aids to predict outbreaks and develop spatially sensitive integrated pest management strategies.

Approach
A multiple-site team approach will be used to meet the above goals. Current technologies will be evaluated, including ground reflectance measurements; digital videography; conventional aerial photography; airborne and satellite imagery; and commercial high-resolution satellite data to detect, map, and monitor invasive species impacts across multiple spatial scales. We will identify the specific pests that teams will target and the experimental design and ground collection that they will lead. Other team members will work with the lead scientist to collect the additional spatial data for which they have the specific equipment and expertise.

Data will be collected over several sites in the continental U.S. and Canada to ensure that a large number of species are investigated and that the data represent multiple biogeographical regions. Existing data will be used when feasible and appropriate. These existing data will include various dates and scales of aerial photography and videography acquired over the major study areas. Additional data will be acquired from new sensors as they become available. Ground verification techniques will utilize differential GPS technology to design and sample affected areas. Classified image data will be integrated with new or existing GIS data and evaluated to determine the predictability of occurrence and the key spatial variables influencing management and control. Potential hybrids of imaging systems (combining image data from two or more different sources and resolutions) will be examined for improved detection and monitoring.

Outcomes
- An optimal method will be found and selected to consistently detect and monitor invasive species and their impact on grassland ecosystems.
- The most reliable and cost-effective method will be determined to detect and monitor infestations.
- GIS-based expert systems and decision support tools will be developed to determine susceptible environments and optimal control methodologies.

Impact
More efficient means of detecting, mapping, and monitoring the extent and distribution of weeds and insect pests on rangelands and pastures

Linkages to Other ARS National Programs
Crop Protection and Quarantine
Integrated Agricultural Systems
Soil Resource Management
Water Quality and Management