Accomplishments Report (2001-2005)

National Program 205, Rangelands, Pasture and Forages
Agricultural Research Service
U.S. Department of Agriculture

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Introduction

Overview of the Agricultural Research Service

Role of the ARS. The Agricultural Research Service (ARS) is the principal **in-house research agency** of the U.S. Department of Agriculture (USDA). It is one of the four component agencies of the Research, Education, and Economics (REE) mission area. Congress first authorized Federally-supported agricultural research in the Organic Act of 1862, which established what is now USDA. That statute directed the Commissioner of Agriculture "... To acquire and preserve in his Department all information he can obtain by means of books and correspondence, and by practical and scientific experiments,..." The scope of USDA's agricultural research programs has been expanded and extended many times since the Department was first created.

Interaction with Cooperative State Research, Education, and Extension Service (CSREES). CSREES is also in the REE mission area and has responsibility for advancing scientific knowledge to help sustain the U.S. agricultural sector through a research, education and outreach system **external to USDA** by working with eligible partner institutions and organizations. The interrelated and complementary programs of ARS and CSREES requires these agencies to be visionary and forward thinking in effectively utilizing limited public resources through effective collaborative partnerships. Therefore, the two agencies regularly seek opportunities to increase the efficiencies of cooperative strategies and activities involving partnerships with the land-grant colleges and universities, other non-land-grant universities, Federal and State agencies and customers.

ARS size and budget. Today, ARS's workforce is approximately 8,000 employees including 2,200 scientists representing a wide range of disciplines. ARS has approximately 1,200 research projects spread over 100 locations across the country and at 4 overseas laboratories. The National Agricultural Library and the National Arboretum are also part of ARS. The annual budget is just over one billion dollars.

Mission objectives entering the 21st Century. ARS conducts research to develop and transfer solutions to agricultural problems of high national priority and provides information access and dissemination to

- Ensure high-quality, safe food and other agricultural products,
- Assess the nutritional needs of Americans,
- Sustain a competitive agricultural economy,
- Enhance the natural resource base and the environment, and
- Provide economic opportunities for rural citizens, communities, and society as a whole.

A problem-solving organization. To achieve these broad objectives, ARS identifies critical problems affecting American agriculture; develops strategies to mobilize resources (both human and financial); writes and reviews research plans to solve these problems efficiently; performs multi-disciplinary research; and reports the results to the customers. Each step of the process involves communicating and interacting with the scientific community, customers, stakeholders, partners, and beneficiaries to insure program relevancy, quality and impact.

National programs. ARS research currently organized into 22 National Programs. These programs managed by the National Program Staff (NPS) through 30 National Program Leaders

(NPLs) to bring coordination, communication and empowerment to the more than 1200 research projects carried out by ARS. The National Programs focus on ensuring the relevance, impact, and quality of ARS research. The national programs as currently structured are:

<u>Animal Production</u>
Food Animal Production
Animal Health
Veterinary, Medical, and Urban Entomology
Animal Well-Being and Stress Control Systems
Aquaculture

<u>Natural Resources</u>
Water Quality & Management
Soil Resource Management
Air Quality
Global Change
Rangeland, Pasture & Forages
Manure & Byproduct Utilization
Integrated Agricultural Systems
Bioenergy & Energy Alternatives

<u>Crop Production</u>
Plant, Microbial & Insect Germplasm Conservation & Development
Plant Biological & Molecular Processes
Plant Diseases
Crop Protection & Quarantine
Crop Production
Methyl Bromide Alternatives

<u>Nutrition and Food Safety</u>
Human Nutrition
Food Safety (animal & plant products)
New Uses, Quality & Marketability of Plant & Animal Products

Teamwork between national programs. Ideally, the entire ARS research portfolio would go through an integrated programming cycle, but this is not possible because of diversity, size and geographical distribution of agency's activities. The national program structure is an administrative construct dividing a complex research program into manageable parts. There are clearly overlaps between national programs and this is addressed by managing each national program with a National Program Team (NPT) team of NPLs that provide the appropriate mix of skills and experience.

National Program Team. The NP205 team consists of NPLs from Food Animal Production, Water Quality & Management, Soils Resources Management, Global Change, Manure & Byproduct Management, Integrated Agricultural Systems, Bioenergy & Energy Alternatives, Crop Protection & Quarantine, and Plant, Microbial, Insect Genetic Resources, Genomics, and Genetic Improvement.

National Program 205, Rangelands, Pasture and Forages

Program Scope. The Nation's public and private range, pasture, hay and turf lands contribute significantly to our agricultural, environmental, economic, and social well-being. Range pasture, and forage lands together comprise about 55% of the total land surface of the United States. Another 30 million acres are part of the multi-billion dollar turf industry that directly affects the citizenry through home ownership, school grounds, right-of-ways, parks and other recreational facilities. These lands represent the largest and most diverse land resource in the U.S. and they are found in all 50 states.

The values derived from these lands, already significant, will increase as using biomass as an energy source grows in importance. These lands continue to be 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 $80 billion in farm sales annually to the economy. The estimated value of hay production alone is around $11 billion, the fourth most valuable crop in U.S. agriculture.

The functions of these lands are of increasing importance as watersheds and as habitat for biologically diverse plants and animals. Maintaining adequate supplies of clean water for urban areas, irrigated agriculture, and environmental needs are critical functions 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--requires an improved understanding of basic ecological processes and the effect on these processes on grazing, livestock production, and management practices. Science-based solutions must be economically viable, environmentally sustainable and socially acceptable. The vision of this national program is to provide the appropriate technologies and management strategies to use and sustain these lands for the benefit of all.

Program mission. Develop and transfer economically and environmentally sustainable technologies and integrated management strategies, based on fundamental knowledge of ecological and other scientific processes, that use, conserve and enhance the Nation's diverse natural resources found on range, pasture, forage and turf lands.

Beneficiaries of this National Program. Many groups benefit from this national program. These include 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 benefits 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 on watershed, recreational, wildlife habitat and other values.

Outreach activities. To contribute to solving the Nation's problems, ARS research finding must be made available to the agency's customers. Increasing emphasis is being placed on providing information to the customers through a variety of means. While reporting data on outreach activities has not been fully standardized, estimates of outreach activities by the NP205 locations are available for the last five years:

Activity	Number of activities	Total Attendance
Field Days	107	8138
Popular Press Articles	291	
Radio-TV Items	91	
Decision-Support Tools	34	
Presentations to Customers	877	21178
Fair Exhibits	15	
K-12 School Events	122	8171
Patents & CRADAs	9	
Germplasm Releases	40	

Budget. The annual budget of National Program NP205 is approximately $43 million. This funding is used to support the program in its entirety including all local staff, facilities including maintenance and utilities, transportation, equipment, supplies and overhead to support its share of the national and area administrative functions. Part of this funding is also use to support cooperative research with universities and other partners. There are currently 30 specific cooperative agreements that have transferred over $15 million to partners.

Scientists. The names, disciplines, and locations of the scientists working in NP205 are listed in attachment one of this report. In addition, ARS scientists cooperate with scientists from universities, other government agencies and private organizations through a variety of formal and informal arrangements. There are approximately 129 scientist years (SYs) of ARS scientists plus 10 non-ARS SYs provided in the Mid-South through long-term Specific Cooperative Agreements (SCA). ARS research units outside the Mid-South also use SCAs with universities and others to contract for research to supplement their projects, but not on the same scale and time frame as in the Mid-South. (An ARS SY is the equivalent on one scientist who plans, leads, performs and publishes research for one year. The SY is almost always supported by at least one technician plus when available, post docs, graduate students and visiting scientists.)

Geographical Area*	Number of SYs
Northeast & North Central	15
Mid-South	17 (+10)**
Southern Coastal Plains	6
Southern Great Plains	14
Southwest	13
Northern Great Plains	19
Intermountain West	38
Pacific Coast	7

* Texas is included the Southern Great Plains and Arkansas is in the Mid-South. The Coastal Plains is the broad strip of land along the ocean from Virginia to east Texas.
** There are 10 SY equivalents provided through long-term SCAs.

Geography and infrastructure. ARS is uniquely positioned to provide national leadership in research to understand and manage the Nation's rangeland, pasture, and forage resources. Over thirty ARS locations across the U.S., representing the major climatic regions and ecological community types, directly contribute to this national program. (See attachment one for an overview of key locations.) The size of the research teams varies greatly from location to location with the largest having 11 SYs and smallest only one SY working on NP205 topics. When there are a small number of NP205scientists, they are part of "composite" unit where there are ARS scientists working in other national programs doing work that is similar. For example NP205 plant breeders are often in units doing work on cereal and food legume crops. The ARS scientists often work closely with the counterparts in the local universities. These arrangements provide a critical mass of research facilities, equipment and co-workers. As indicated in attachment one, research units have well equipped laboratories and a dozen of the units have land holdings in the thousands of acres with three having more than 50,000 acres. Other units such as some of the watershed units do not own land but have access through partnerships to large well-instrumented watersheds.

Role of the Assessment in National Programming Cycle

The national programming cycle. The ARS uses a five-year planning cycle to ensure research relevance, quality and impact. The planning cycle takes place in four steps: (1) gathering input from customers, (2) planning and reviewing research, (3) implementing research, and (4) assessment of results.

Step one: gathering input to identify research needs. The National Program Staff defines and articulates the scope of each program using input from customers, stakeholders, partners, and ARS scientists. This input is used to identify priority national and regional needs and state them as researchable areas and problems. Customer workshops are a key tool in gathering input for this process.

Rangeland, Pasture, and Forages National Program Customer Workshop 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, customers, stakeholders, and partners provided input concerning their problems and needs relative to rangeland, pasture, and forages research and management. This input was used in developing an "action plan" for the national program that identified the problems facing the nation and set the scope and priorities for future research. The NP205 action plan is in attachment two. The plan is organized around five component areas that are the basis for organizing the assessment report. The five are as follows:

I. 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

II. 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.

III. 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.

IV. 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.

V. 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.

Step two: Planning a five-year research program.

Identifying researchable problems and research objectives. After a public comment period, ARS NPLs and scientists used the action plan derived from the workshop combined with additional contacts with their customers and their own knowledge of unit capabilities to identify priority researchable problems and to identify the unit's research objectives for addressing these problems. The purpose of this planning step is to ensure the relevance of the research to national problems. The problems and objectives are used to develop a detailed five-year research plan. In attachment one, the research objectives are listed for all the NP205 units.

Writing and peer-review of the unit research plan. Each research unit drafted a five-year research plan outlining problems to be addressed, research objectives, desired research outputs, expected benefits to society, research hypotheses, experimental designs, milestones, contingencies and cooperation with other scientists within and outside the ARS. To ensure quality, the completed plans went to the ARS Office of Scientific Quality Review (OSQR) that arranged a rigorous external peer review of each plan in 2002.

Step three: Implementation of the plans. The implementation of the most recent five-year plans for NP205 began in 2002. Each year, the units report on their progress towards meeting the milestones contained in the five-year plan and present major accomplishments. New plans for the next five-year cycle are to be implemented in September, 2007. These results are summarized in an annual report for the national program that is posted on the ARS web site. Annual reporting helps ensure quality and impact of research results.

Step four: Assessment of the national program. About two years before the end of the 5-year cycle, the national program's NPL team conducts a retrospective evaluation of the accomplishments of each national program. With the help of an external review team, the relevance, quality and impact are assessed. The results are used to evaluate the scope, focus, productivity and impact of the national program and set the foundation for the next program planning cycle.

The next customer workshop is scheduled for Jan 24-27, 2006 in Denver, Colorado.

Component I
Ecosystems and their Sustainable Management

In this component, there are six problem areas: (A.) Ecosystem Processes; (B.) Monitoring and Assessment Technologies; (C.) Forecasting & Risk Assessment; (D.) Ecologically & Economically Sustainable Systems; (E.) Managing Degraded Systems; and (F.) Decision Support.

(A.) Problem Area: Ecosystem Processes

Rising carbon dioxide affects rangeland dynamics. Many questions remain about the effects of increasing atmospheric CO_2 on the rangeland ecosystems that make up over 40% of the land surface area. ARS scientists found increasing CO_2 levels may indirectly promote woody plant invasion of grasslands by reducing soil water depletion by grasses and promoting honey mesquite seedling survival. Above and below ground growth of honey mesquite seedlings, an invasive nitrogen-fixing shrub, were enhanced with increased carbon dioxide. Added carbon was first used to develop larger leaves and subsequently allocated to increased root growth (Derner et al. 2005). The enhanced rooting depth of honey mesquite suggests this species should continue to aggressively encroach into rangelands in CO_2 enriched environments. Scientists also found increasing CO_2 levels reduce forage quality by changing plant species composition and reducing nitrogen levels within plants (Morgan et al. 2004). Ladino white clover, grown at increasingly higher CO_2 concentrations, responded with increased total nonstructural carbohydrates (TNC) in leaves and stems and a dilution of nitrogen content. Two spotted spider mites, used as a bioassay to reflect plant changes, were positively associated with foliage TNC, but negatively related to nitrogen content (Heagle et al. 2002). Increased CO_2 concentrations also offset negative effects of elevated ozone on the nutritional value of leaves (Burns et al. 1997). Increasing levels of atmospheric CO_2 will have complex effects on ecological processes affecting rangeland dynamics (Wylie et al 2005). Effects include loss of native grasslands to woody species, increased need for livestock supplements with declines in forage quality, and an increased risk of insect damage to some plant species (Gilmanov et al. 2004a, 2004b, 2004c). Crop production and associated model development must also consider atmospheric ozone concentrations to refine predictions related to elevated CO_2 levels.

Effects of rangelands on carbon flux. Because of their world wide extent, rangelands significantly affect the global carbon cycle, but effects of management practices on source and sink dynamics of CO_2 are not well-known. ARS scientists in the sagebrush steppe found fire altered seasonal patterns of CO_2 uptake with burned areas taking up increased levels during the peak growing season (Svejcar et al. 2003). Intensive grazing in the northern Great Plains can reduce CO_2 uptake for up to 30 days, but low rainfall and a short growing season can reduce uptake for longer periods. Thus, while the carbon sink is small and is affected to some degree by grazing, annual climate dynamics have a more significant effect (Gilmanov 2003, Haferkamp et al. 2002, 2003, 2004). Properly managed rangelands in North Dakota and Oklahoma sequester carbon on a sustainable basis, while overgrazed rangelands release CO_2 into the atmosphere Frank 2002, 2003; Sims and Bradford 2003). Species diversity affects the ability of pastures to sequester carbon with uptake being greatest in pastures with intermediate numbers of species (3) compared to low (2) or high (11) species numbers (Skinner et al. 2005). Management practices, such as fire, grazing, and planting methods, can interact with climate to influence carbon sequestration in rangelands.

Improving carbon sequestration on rangelands and pastures. Increasing levels of atmospheric carbon dioxide can result in undesirable effects, so efforts to sequester carbon are needed to reduce atmospheric CO_2. Researchers found grazing increases carbon sequestration on a northern mixed-grass prairie and shortgrass steppe, but heavy grazing causes plant community shifts and moves the zone of carbonate precipitation higher in the soil profile (Reeder and Schuman, 2004, Reeder at al. 2004). Heavy grazing also results in losses of soil organic carbon during severe drought years (Schuman et al. 2005). Inter-seedings of yellow-flowered alfalfa on rangelands in northern Great Plains rangelands become progressively more effective at carbon sequestration over time (Mortenson et al. 2004). Interseeded rangelands stored more carbon than adjacent untreated areas. Interseeding with yellow-flowered alfalfa improved forage production for grazing, the soil nitrogen status, and increased storage of carbon in the soil (Mortenson et al. 2005). These effects all help reduce the observed negative effects of increased atmospheric carbon dioxide and did not increase nitrous oxide emissions even though soil nitrogen was greatly increased (Schuman et al. 2004). ARS scientists also found pasture management systems vary in their particulate and non-particulate fractions of soil organic carbon. Accumulated soil carbon in pastures is susceptible to decomposition and release as if soils were plowed. Comparisons of decomposition rates among 3 improved grasses and 2 of their native counterparts established that the improved selections decomposed faster than the native grasses (Hendrickson et al. 2001). Land managers also need to know how efficient range plants are in taking up carbon with limited water. ARS Scientists working in southeastern Arizona found that the grassland sites studied were able to take up between 1.3 and 3 times the carbon for each unit of water utilized. They also found that grazing can affect the levels of methane in these semi-arid soils through compaction and reduced infiltration. Depending on conditions, these lands can be large contributors to atmospheric carbon dioxide, nitrous oxide and methane but they could also be a strong sink for atmospheric methane (Martens and McLain, 2003; McLain and Martens, 2005). Increasing our understanding of how carbon is sequestered will provide information needed by policy makers and land managers to use rangelands as effectively as possible to impact on conditions related to global change.

Nitrogen management. Nitrogen loss as ammonia gas from dairy barns can contribute to ecosystem fertilization and particulate formation that can adversely affect human health. ARS scientists compared nitrogen cycling in a classic confinement-based feeding operation where manure is deposited then scraped from barns and land-applied versus corralling heifers on cropland to directly deposit manure. Ammonia losses are greater from the barn than corrals. The higher nitrogen return to soil in corrals enhances subsequent crop production. (Powell and Russelle 2002, 2004; Powell, 2005).

Precipitation effects on rangelands. Altered seasonal precipitation patterns and accumulations induced by climate change potentially cause major changes in rangeland condition and yield. ARS scientists found a shift to more spring and less winter precipitation had negative effects on yield and ground cover of Great Basin rangelands (; Svejcar et al. 2003; Bates et al. 2005). Intense spring drought reduced soil water content in the top 30 cm of the soil profile and reduced total herbage production by 20% to 30% in the northern Great Plains. Periodic grazing during drought minimally affected herbage production while grazing effects on non drought plots ranged from moderate enhancement to moderate suppression depending on functional groupings of plants (Heitschmidt and Haferkamp 2003; Heitschmidt et al. 2005).

Recovery was substantial recovery during the 1st post drought year with near full recovery within 2 years. These results can be used by land managers to separate weather effects from those related to livestock and vegetation manipulation programs.

Plant biology and development. Understanding key processes controlling plant growth and development is central to developing effective management techniques for producers and stakeholders. ARS scientists found that mechanisms fostering weed growth can be used to develop desirable plants capable of out competing weeds. Releases of native and introduced selections are being established on rangelands and pastures for site stabilization and forage. The new plants have better seed germination, seedling vigor, drought and salt tolerance, and elevated forage yields. These traits improved the economics of stand establishment and longevity. Similarly, basic knowledge of forage plant development, nutritional value, yield, and management requirements among different soil and environmental gradients is being used to extend the range and seasonal availability of forages and to synchronize production with the nutritional demands of stock to improve agro-ecosystem stability.

Native plant-fungal associations. Although important forage species of arid rangelands are often colonized by symbiotic fungi, the role of this interrelationship on plant growth and nutrition is poorly understood. ARS scientists transferred fungi from native rangeland species to species not typically hosting fungi and this yielded dramatic whole-plant differences in morphology and physiology. In most cases, fungal transfer at the cellular level caused more robust plants with greater reproductive potential than controls without fungal transfers (Barrow 2003, Barrow et al 2004). Transformed plants continue to grow, reproduce, and disperse more rapidly than their native counterparts and thus elevate the plant-microbe interface to ecologically significant scales (Lucero et al. 2005) The application of this transfer, a technology pending patent application, may help develop more effective methods for reclaiming degraded rangelands in the southwest US.

ARS Locations & Cooperators: Beaver, Burns, Cheyenne, Ft. Collins, Las Cruces, Logan, Madison, Mandan, Miles City, Raleigh, Temple, Tucson, University Park, Watkinsville, Woodward; and Colorado State Univ., North Carolina Agric. Research Stat., Northeast Pasture Research and Extension Consortium, Univ. of Wyoming, Smith Ranch in North Dakota, Natural Resource Ecology Laboratory in Ft. Collins.

(B.) Problem Area: Monitoring and Assessment Technologies

Monitoring manual. Knowledge of ecosystem dynamics and refined techniques are needed to more efficiently and effectively monitor ecosystem dynamics and landscape management programs (Bird et al. 2002, Bestelmeyer et al. 2003, Brown and Havstad 2004). ARS scientists released a technical manual, *Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems* that will help producers and land managers monitor soil stability, hydrologic function, and biotic integrity at the ecological site level (Herrick et al. 2005a, 2005b). This information can then be used to help assess ecological responses to land management practices and climatic variability (Havstad et al. 2003).

Monitoring willow growth and utilization. Repeatable and accurate techniques for measuring browsing impacts on willows are needed by both public and private land managers. ARS scientists tested a photographic technique for estimating willow biomass and utilization based on computerized measures of visual obstruction by willows of a background photo board

(Boyd et al. 2005). This technique accurately estimated willow biomass, reductions in biomass from simulated browsing, and minimized sampling error. The technique gives managers an easily used and effective tool for monitoring willow biomass and utilization and will help refine grazing management systems or adjust stocking rates.

Monitoring transpiration. The transpiration rate of grasses is a reliable indicator of grassland condition, yet conventional instrumentation is not capable of measuring transpiration rates over large heterogeneous grasslands. Relative transpiration rates were mapped over the heterogeneous terrain of Walnut Gulch Experimental Watershed in Arizona based on meteorological data and satellite measurements of surface reflectance and temperature. Results showed that grassland condition was highly variable across the landscape, and varied both temporally and spatially with antecedent rainfall and slope aspect (Holifield et al. 2003). With further development, this satellite-based approach may provide a viable tool to monitor grassland condition over heterogeneous regions.

Fast and accurate monitoring of forage availability. Spatial variation in quantity and quality of forage produced by native prairie pastures limits weight gains of stock and hinders efficient utilization of forage by grazing cattle. ARS scientists detected mathematical relationships that allow prediction of standing crop based upon stage of tiller development by key grass species (Northup 2002). Predictions were compared with traditional methods of clipping and weighing forage from small plots. The new method allows faster development of predictors for determining production than traditional techniques and was more than 80% accurate. These new tools will help ranchers rapidly obtain standing crop measures, so they can efficiently optimize stocking rates and make more effective use of pasture and forages.

Fast and accurate monitoring of forage nitrate levels. High nitrate concentrations in forages reduce weight gains and cause health problems among grazing livestock. Timely and accurate measures of nitrate concentration are necessary to avoid nitrate poisoning. ARS scientists compared a standard laboratory nitrate assay, novel enzymatic laboratory or field procedures, and quick-test methods using a small hand-held ion specific electrode or a test strip reflectance meter. Enzymatic laboratory and field-test methods were the most accurate (MacKown and Weik 2004). The hand-held test-strip reflectance meter was easiest to use, only slightly less accurate, generated less variability and was less likely to overestimate nitrate content which was a problem with the compact hand-held specific electrode. Inexpensive but effective tools are now available to stockman for measuring forage nitrate levels in the field.

Monitoring historic changes in vegetation. Understanding current vegetation patterns and dynamics demands knowledge historic landscape characteristics. ARS scientists published a 91-page report, *Eighty years of Vegetation and Landscape Changes in the Northern Great Plains – A Photographic Record* with photographs and written descriptions of the same range sites over the last 80-90 years (Klement et al. 2001). In most places only minor changes occurred on the rangelands of the region, but there has been a general increase in woody vegetation, non-indigenous species, and more direct human intervention from road construction, agricultural tillage, and haying. ARS scientists also documented vegetation change in the Chihuahuan Desert using historic land surveys and maps beginning in 1858. Grasslands dominated the area in 1858 and large areas had already converted to shrub dominance by 1915. The extreme 1950's drought also contributed to additional loss of grasses. This record of historic change can be used to guide future management decisions in our changing environment.

Monitoring using remote sensing. Effective rangeland management requires inexpensive measurement-based monitoring with the accuracy and precision to detect important ecological change over extensive landscapes and with minimal error rates. ARS scientists are making progress in developing algorithms to quantify grass cover, height and biomass based on Landsat imagery (Qi et al. 2003). Such information can then be interpreted to estimate forage quantities, fine fuel loads, protective ground cover, and habitat values for application in grassland management. The BLM is using results from this work to monitor the Las Cienegas National Conservation Area in southern Arizona. ARS scientists at several locations working with other federal agencies and industry are cooperating in developing and refining a low-altitude, very-large scale aerial (VLSA) photographic system and an automated image analysis package to extract key-indicator measurements of resource condition (Booth and Tueller 2003, Hunt et al 2003). Between 2000 and 2004 ARS researchers improved maximum resolution of nadir photographs obtainable from an airplane platform from a scale of about 1:600, to 1:200 (film), then to 2.2 and to 1.1 mm per pixel GSD (digital) (Booth et al. 2004b, 2005b). They also created 3 software applications (Laserlog, Merge, and ImageMeasurement) that use laser-measured altitude (± 25 mm) above ground level (AGL) to allow accurate measurement of objects like stream widths and sagebrush canopy diameters from VLSA photography (Booth et al. 2005b). Digital imagery at 2-m and 100-m AGL resulted in more precise measures of vegetation cover and, in the case of 100m AGL, was completed more efficiently than with traditional methods. Bitterroot Restoration Inc. has executed a CRADA to become a commercial provider of VLSA technology in 2007. Bureau of Land Management personnel in Casper and Lander, Wyoming; Elko, Nevada; and Idaho Falls, Idaho are using or plan to use VLSA imagery to monitor their rangelands. ARS scientists are also developing accurate, real-time measures of forage quality from remotely sensed images (Starks et al. 2004). This technology will elevate hay grower profits, help ranchers schedule livestock rotations among pastures, and refine livestock supplementation programs by supplying almost real time assessments of pasture and crop nutritional value. Scientists have developed methods for collecting remotely-sensed reflectance data over bermudagrass pastures and deriving estimates of crude protein, acid detergent fiber and neutral detergent fiber. Procedures are being validated on other forages, and a CRADA developed to furnish inexpensive multispectral reflectance sensors.

Remote Sensing/Vegetation Management/Ground Truth Sampling. The point-sample method has been a standard plotless method for measuring ground cover since 1927. The method was recently updated by development of a laser point frame (LPF) utilizing lasers in place of conventional steel pins. Data collected using a steel point frame (SPF) and the LPF were reasonably well correlated but total sampling time was almost half using the LPF. The LPF is easy to use, is preferred by technicians over the SPF, and is a potential replacement for conventional point frames (VanAmburg et al 2005). Further innovations in the measurement of ground cover are the development of a light-weight, break-down camera stand for capturing nadir digital photography from 2-meters above ground level (Booth et al. 2004a) and the use of a digital grid overlay (DGO) and calibrated software for automated image analysis to extract bare-ground measurements from digital photography (Booth et al. 2005a and 2005c).

Quantitative assessment of vegetation change is often conducted using digital analysis of aerial or vertical photography time-series. However, change analysis using repeated oblique or landscape photography has been limited to qualitative assessments. Sampling and analysis techniques for using digitized, landscape photography time-series to quantify vegetation change on rangeland landscapes have been develop by ARS Scientists. As a result, repeat landscape photography can now be used to quantitatively assess long-term dynamics of vegetation cover on rangeland landscapes with visually distinct vegetation types. This provides critical data to land managers more rapidly at lower cost. (Hunt et al. 2003, Clark and Hardegree 2006)

Rangeland Health Assessment Manual. Standardized techniques are needed to qualitatively measure rangeland health. ARS scientists, collaborating with the Bureau of Land Management, U.S. Geological Survey, and Natural Resources Conservation Service, co-authored a technical reference manual, *Interpreting Indicators of Rangeland Health* (Pellant et al. 2005). This manual helps ranchers and land managers do preliminary evaluations of soil stability (Seybold and Herrick 2001), water conditions, and plant communities to identify areas at risk of degradation (Pyke et al, 2002, Pyke and Herrick 2004).

Grassland establishment assessment tool. Land managers need to quantify establishment success when seeding or re-seeding pastures or rangeland. ARS scientists developed and tested a simple, effective tool for monitoring grassland establishment (Vogel and Masters 2001). The tool, a frequency grid, inexpensively made from concrete reinforcing sheets, is easy to use and produces reliable and repeatable results.

ARS Locations and Cooperators: Boise, Burns, Cheyenne, Dubois, El Reno, Las Cruces, Lincoln, Miles City, Tucson; and, Bitterroot Restoration Inc., Bureau of Land Management, Michigan State University, Sonoran Institute of Technology and Univ. of Sonora, U.S. Geological Survey, USDA Natural Resources Conservation Service, Crow Valley Livestock Cooperative Inc.

(C.) Problem Area: Forecasting and Risk Assessment

Wildfires. In the western United States, millions of dollars are spent each year to mitigate wildfires effects and protect human life, property, and natural resource values. ARS scientists cooperated with the Forest Service, Rocky Mountain Research Station, to study effects of wildfire on infiltration, runoff, and erosion processes as well as the effectiveness of erosion mitigation practices in forest and rangeland settings across Idaho, Nevada, Washington, Montana and Colorado. Findings determined how much runoff and erosion might be expected from different ecosystems after wildfire, how long an ecosystem takes to hydrologically recover following fire, and provided guidance on the effectiveness of practices aimed at reducing soil erosion. Scientists continue to develop and refine remote sensing tools to measure green, senescent, and total plant biomass to help managers estimate fuel loading for fire hazard assessments.

Wildfire Impacts and Erosion Risk Management. Following wildfire land managers need to rapidly predict what part of a burned landscaped has elevated risk of significant runoff and soil erosion that might contribute to significant loss of on-site productivity and/or downstream flooding. Interagency research on forested and rangeland ecosystems in Idaho, Nevada, Washington, Montana and Colorado provided land managers with information on runoff and erosion after wildfire, on how long an ecosystem takes to hydrologically recover following fire, and on how effective fire mitigation practices are at reducing soil erosion. This information was integrated into a web-based Erosion Risk Management Tool (ERMiT) for estimating the impact of rangeland wildfires on soil erosion. (Robichard and Pierson 2003, Moffet et al. 2004, Pierson et al. 2005)   A prototype of the tool is now being tested for use by interagency Burned Area Emergency Response (BAER) teams to determine where wildfire erosion mitigation practices should be applied. The use of this tool could significantly reduce the millions of dollars spent each year by management agencies to mitigate wildfire impacts.

Predicting rangeland responses to management and disturbance. New tools are needed to accurately predict rangeland responses to environmental perturbations. ARS scientists are developing predictive models capable of anticipating landscape responses to management practices or catastrophic events like prolonged drought. A general framework was developed for understanding the occurrence and consequences of catastrophic events to minimize effects on ecosystem services, atmospheric conditions, and human welfare (Peters and Herrick 2001, Peters et al. 2004a, 2004b). Results show decisions minimizing the likelihood of catastrophic events must be based on cross-scale interactions and decisions are often counter-intuitive. This framework is an important step in developing predictive tools and designing new experiments to examine cross-scale interactions.

ARS Locations & Cooperators: Boise, Las Cruces, Tucson, USFS-Rocky Mountain Research Station, Univ. of Arizona, US Geological Survey, Colorado State Univ., New Mexico State Univ.

(D.) Problem Area: Ecological and Economically Sustainable Systems

Reduced nitrogen losses with perennial crops. A combination of excessive nitrogen, annual cropping, and subsurface drainage in the Mississippi River Basin has fostered nitrogen losses from farmland. Nitrogen deposition occurred in the Gulf of Mexico with a 'Dead Zone' resulting. Methods are needed to retard nitrogen losses. ARS scientists documented the amount and spatial distribution of nitrogen fixed by alfalfa and soybeans in the basin. There are areas where both crops obtain large amounts of nitrogen from the atmosphere and others where they fix little nitrogen depending on nitrogen supplies in the soil. Both crops can absorb manure nitrogen and reduce levels of fixed nitrogen entering the Basin. Nitrate leaching losses are accelerated with annual cropping systems that do not support actively growing vegetation at critical times of the year (Huggins et al 2001). Alfalfa is particularly effective at removing nitrate from soil solutions, thereby limiting nitrate drainage and remediating nitrate-contaminated sites (Russelle 2001, Russelle et al. 2001, Russell and Birr 2004). The use of both soil nitrogen and atmospheric nitrogen by legumes allows plant response to improved growing conditions like higher atmospheric carbon dioxide (Lee et al. 2003). Land managers, environmental firms, farmers, and agency personnel are using these managed cropping techniques for easy and effective site remediation and pollution prevention (Putnam et al 2001).

Compatibility of livestock and threatened species. A lack of basic ecological knowledge about the sagebrush steppe precluded development and assessment of management guidelines integrating livestock grazing and habitat needs for species like sage grouse. Scientists measured vegetation cover and composition across the region on 107 Wyoming big sagebrush sites in excellent condition. When findings were compared with sage grouse management guidelines, the guidelines over estimated the habitat potential of the land (Bates et al. 2004). Scientists are working with land managers to develop realistic guidelines based on substantiated parameters.

Developing alternative systems. Sustainable systems can be difficult to achieve under current conditions, and alternative practices are needed. ARS scientists showed that perennial grasses provide an economically viable and sustainable alternative to non-irrigated crop production in the Central Great Plains and Midwest. Bonanza big bluestem, a cultivar released with improved production and nutritive value, had an annual net return as high as $164 per acre and averaged $119 per acre over three years in a well managed grazing system in eastern NE (Mitchell et al. 2005a, 2005b). This was 2.4 times more return per acre than non-irrigated corn in nearby fields. Findings are used to identify locations where perennial grasses are a viable alternative to cropland.

Developing integrated systems. Integration of different management strategies can help foster sustainable farming operations. Dairies in particular need cropping and feeding programs that improve long-term economic and environmental persistence of their farms. ARS scientists used comprehensive, whole-farm analyses to determine how cropping systems using soybean and small grain crops affected nutrient losses and farm profit (Rotz et al. 2001, Rotz et al. 2002a). Soybeans as a cash crop increased annual farm net return by up to $55 per cow. When soybeans were fed, most of this economic benefit was lost. For 100 to 800-cow dairies located in phosphorus restricted watersheds in southern New York, management changes that maximized the use of forage grown on farms and fed to cows eliminated the long-term accumulation of soil phosphorus while improving farm profit (Rotz et al. 2002b). Findings helped producers plan for more profitable and sustainable production programs.

Farms in the Southern Plains usually have mixed combinations of native rangeland, planted pastures, and croplands for livestock grazing. Past research concentrated solely on management of individual forage sources. ARS scientists designed an integrated management system that combined all forage types for a cow-calf operation. Integrated systems reduced the land required to support a cow from 20 to 12.5 acres. Beef production increased from 31 to 58 lbs/acre and net return doubled for rangeland versus complementary systems (Sims et al 2004). These findings can be used to identify an optimum combination of practices providing sustained economic return.

Tools for evaluating sustainable systems. New techniques are needed to refine the characteristics of sustainable systems. ARS scientists, in collaboration with other agencies, producers, and non government land management organizations, have developed state-and-transition models of rangelands that describe changes within an ecological site affected by management practices and/or disturbances. These models and site descriptions are emerging as management tools for hundreds of millions of acres of public rangelands managed by the Bureau of Land Management, US Forest Service, and property owners counseled by the Natural Resource Conservation Service (Bestelmeyer et al. 2004, Bestelmeyer et al. 2005).

ARS scientists released a whole farm simulation model for use as a research and teaching aid to develop and transfer technology and programs for more efficient crop, beef, and dairy production (Rotz et al. 2005). The model, available at http://pswmru.arsup.psu.edu, is used by researchers, educators, farm consultants, and producers focused on humid temperate regions of the world (Corson et al. 2005). Scientists also developed a simulation model of multiple plant species in temperate pastures of the northeastern US that illustrated how accurate measures of standing crop (Sanderson et al. 2001 in dairy pastures can save producers up to $80 per acre per year, depending on the type of grazing system employed. The model provides decision support for producers wishing to optimize pasture systems (Rotz 2004, Rotz and Oenema 2005, Sedorovich et al. 2005).

ARS Locations & Cooperators: Burns, Las Cruces, Lincoln, St. Paul, University Park, Woodward; and, Univ. of Maryland, West Virginia Univ., Northeast Pasture Research and Extension Consortium, Bureau of Land Management, US Forest Service, and property owners counseled by the Natural Resource Conservation Service.

(E.) Problem Area: Managing Degraded Systems

Weather forecasting and revegetation. Millions of acres of rangeland in the Great Basin and Columbia Plateau region of the western United States are seriously degraded or are at risk of conversion to annual weedy species after wildfire. Climate variability is the dominant factor in determining revegetation success but it is difficult to predict potential establishment under variable conditions of soil temperature and moisture (Hardegree, et al., 2003; Hardegree and Van Vactor, 2004). ARS scientists used environmental models to evaluate climatic effects on establishment-potential and identified the utility of incorporating weather forecasts into emergency-fire rehabilitation, and rangeland restoration plans (Flerchinger and Hardegree, 2004). Despite progress, forecasting technology for Intermountain rangelands is still inadequate for assisting revegetation planning.

Seedling establishment for rangeland restoration. Understanding the seed ecology of native grasses to improve seeding success is critical to restoring degraded rangeland ecosystems. Researchers found establishment of several grasses is promoted by seed caching native animals. In some cases, this interrelationship is species specific. For example, Merriam's Kangaroo rat is a key disperser of Indian rice grass in low-elevation salt desert communities. Scientists also found that structural attributes of little bluestem in restored prairies changed predictably with age, demonstrating general patterns that will benefit land managers attempting to restore former croplands to prairie (Dener et al. 2004). Spring burning, coupled with an imazapic application decreased Kentucky bluegrass among North Dakota native grasses, but suppressed standing crops. Scientists noted cultural practices, including soil management, mulching, and seeding rates affect initial establishment of Wyoming big sagebrush on disturbed lands (Booth 2002). Reducing grass seeding rates below those typically employed resulted in larger sagebrush plants after 5 years when compared with shrubs growing on higher grass seeding rates (Williams et al. 2002, Vicklund et al. 2004). Lower grass seeding rates are recommended because they allow natural recruitment of native species and more rapid growth of big sagebrush seedlings. ARS scientists also studied seedbed ecology, seed technology, and revegetation methods for key species on rangelands mined for coal. Efforts generated improved recommendations for storage of winterfat seed compared to those published in Agricultural Handbook 450 (Booth et al. 1999). ARS scientists also found the combined use of fall-applied herbicides and fire, that removed dead vegetation just prior to planting, improved establishment of desirable native grasses and legumes in leafy spurge infested rangelands, increased forage yields, and suppressed the noxious weed (Masters et al. 2001). A method of using glyphosate tolerant soybeans as a management tool in pasture reclamation efforts was demonstrated in the Midwest and Central Great Plains. Techniques suppress and kill existing vegetation, control weeds, and reduce costs by providing income during renovation (Michell et al. 2005).

Restoration and grazing. Effects of post-fire grazing are largely unknown for many rangelands. ARS scientist examined post-fire grazing effects on Northern Great Plains rangelands. Summer fires were applied and pastures stocked the next spring with several levels of utilization. To date, no detrimental effects of post-fire grazing are apparent. ARS and University of Idaho scientists collaborated to determine the optimum time after a fire to begin sheep grazing and promote recovery of native plants over invasive weeds. Fall grazing, 15 months after a wildfire, had no negative impacts on the standing crop and species composition of desirable plants. Because of declining sage grouse populations, ARS scientists cooperated with Texas A&M and the Idaho Fish and Game to develop a model that simulates effects of fire and grazing on sagebrush communities and sage-grouse population dynamics. The model indicates frequent, large scale fires may contribute to sage-grouse extinction. Sheep grazing may cause declines in sage-grouse numbers, but not cause extinction (Pederson et al. 2003). The model is a useful tool for managing rangelands to benefit sage grouse. ARS scientists assessed the effects of early spring grazing following juniper cutting in eastern Oregon (Bates J. 2005). This prescription had: 1) no impact on recovery of existing herbaceous plants among grazed and ungrazed treatments, and 2) found early grazing was detrimental to seed production on cut-grazed areas when compared to ungrazed cut treatments. Restricted seed production could potentially limit site recovery. Findings are helping managers develop fire/grazing prescriptions after juniper control.

Prescribed Fire. Land managers are increasingly using prescribed fire for hazardous-fuel reduction and control of woody-invasive weeds on western rangelands. The first two of a series of prescribed fires were conducted at the Reynolds Creek Experimental Watershed to evaluate landscape-scale fire effects on soil moisture, infiltration and erosion, water quality, grazing animal distribution, fuels reduction, invasive-weed control, and vegetation recovery patterns. This research program has produced data and models for evaluating fire impacts and predicting potential outcome of alternative fire-management strategies (Wilcox et al. 2003, Moffet et al. 2005, Seyfried et al. 2005).

Restoration and fire. Decline of aspen stands in the Great Basin and Intermountain region is a major concern; and in some cases is linked to western juniper invasion. ARS scientists evaluated herbaceous, shrub, and aspen response to a combination of selective juniper cutting and seasonal prescribed fires aimed at restoring aspen woodlands. Results showed: 1) selective cutting combined with fall burning was highly effective at removing juniper and stimulating aspen recruitment, but reduced understory productivity and diversity; 2) selective cutting combined with spring burning was less effective at removing juniper and stimulating aspen response, but increased herbaceous standing crop and diversity; and 3) spring burning safely removed high fuel loads without risk of fire escape (Bates et al. 2005). Private and public managers are using these results to restore stands of aspen.

Impacts of fire on sagebrush steppe. The impact of fire size and type of fire (prescribed or wild) on soil movement, vegetation establishment, and plant population dynamics is not understood in the sagebrush steppe region. In cooperation with scientists from Idaho State University, staff from the U.S. Forest Service, and the Bureau of Land Management, a 200-ha prescribed fire, with replicated point fires (simulating wildfires) of different sizes, were conducted on ARS lands in eastern Idaho (DiCristina et al., 2004; Germino et al., 2004a,b). All before and after fire data on vegetation and soils have been collected and a third set of prescribed fires is planned for the autumn of 2005. Results from this research will enhance our understanding of fire (size and type) on the sagebrush steppe ecosystem, which in turn will allow better decisions to be made about management strategies to be used after wild and prescribed fires.

Long term recovery dynamics. Arid rangelands often respond slowly to management practices, so treatment effects must be tracked for many years. ARS scientists reevaluated conservation practices applied in the 1930s in the northern Chihuahuan Desert. The 60+ year old water management practices were found more effective than originally thought (Herrick et al. 2005, Rango and Havstad 2003, Rango et al. 2005). Findings are affecting strategic planning and monitoring of management practices on public western rangeland.

ARS Locations & Cooperators: Boise, Burns, Cheyenne, Dubois, Las Cruces, Lincoln, Mandan, Miles City, Reno; and, Idaho State Univ., Texas A&M Univ., Idaho Fish and Game, Bureau of Land Management, and U.S. Forest Service.

(F.) Problem Area: Decision Support

Improved management for drought. Although drought is typical of western rangelands, it is difficult to study processes associated with drought because of its unpredictable nature. Scientists are using automated rainout shelters to control the amount of rainfall received on plots in the Northern Great Plains. Effects of drought/irrigation treatments on soil water dynamics were limited to the upper 60 cm of the soil profile (Heitschmidt and Vermeire 2005). Above ground effects on live and dead herbage were linked closely to soil water dynamics in the upper 30 cm of soil water. Primary production was nearly equal under the various treatments, but wet summers favored growth of warm-season perennial grasses over cool-season perennial grasses. Forage quality varied among treatments. When findings were combined with local rainfall probability estimates, a simple yet effective drought decision support system emerged giving management personnel the confidence to adjust grazing intensities long before forage resources were depleted.

Riparian Vegetation and Water Budgets. Semiarid riparian ecosystems harbor a disproportionate degree of biological diversity in comparison to their area coverage and riparian vegetation water use can be a major component of the overall basin water budget. The ARS-SWRC in collaboration with researchers from the University of Arizona, University of Wyoming, Columbia University - Biosphere, and two Mexican research organizations have conducted multi-year field studies along the San Pedro River in southeastern Arizona. Using a synthesis of field measurements of transpiration from the major vegetation groupings made during the 2001, 2002 and 2003 growing seasons, they improved estimates of riparian vegetation groundwater use for much of the Upper San Pedro River and summarized these findings in a final report submitted to the Upper San Pedro Partnership (and in press from the USGS). The new estimates were significantly greater than the most recent in-situ measurement and modeling-based results. Once published, this revision will be incorporated into future reports that the Partnership is required to submit to Congress. In addition to improving the understanding of the basin's water budget, this multifaceted research has produced many new insights into the functioning of riparian ecosystems (Scott et al. 2003, 2004; Yepez et al. 2003; Hultine et al. 2004).

Tools for evaluating long-term impacts. Because of the extent of our nation’s rangelands, the cost of adequately monitoring and assessing the conditions and trends of these lands is prohibitive. ARS and Natural Resources Conservation Service scientists compared statistical options for analyzing data collected on the Jornada Experimental Range and data from the National Resources Inventory (NRI). Within-plot replication of data collection for monitoring and assessment at the landscape to regional scales was significantly reduced from protocols previously used. Applications of these findings will generate a 25% savings for NRCS rangeland data collection.

Using models for evaluating alternative management scenarios. Land managers are demanding science-based tools to help select proper management techniques prior to field applications. Such products reduce risks for range and livestock managers. ARS scientists evaluated the Great Plains Framework for Agricultural Resource Management (GPFARM) model in simulating forage and cow-calf production in the Central Great Plains. The GPFARM model has functional utility for simulating forage and cow-calf production with satisfactory accuracy at semiarid-temperate sites, such as southeastern Wyoming and northeastern Colorado (Andales et al. 2005). Continued development will improve modeled plant responses to environmental stresses and the model's functionality as a decision support tool for ranch management.

Changes in upland vegetation and soil stability can lead to reductions in site productivity and off-site impacts such as flooding and sedimentation. Land managers are demanding science-based tools to assist them in selecting appropriate and alternative management techniques to protect rangeland watershed function and optimize production of goods and services. Cooperative research efforts have combined attributes of WEPP, a state-of-the-art process-based surface hydrology and erosion prediction technology, with the SPUR model that simulates soil-plant-animal-climate interactions and processes. The resultant "SPUR-WEPP" modeling technology provides process-based model estimates of runoff and erosion from rangelands to aid land managers in quantifying resource benefits associated with alternative rangeland conservation practices (Moffet et al. 2003, Spaeth et al. 2003, Spaeth et al. 2004a,b, Pierson et al. 2004, Moffet et al. 2005)

ARS Locations & Cooperators: Cheyenne, Fort Collins, Las Cruces, Mandan, Miles City, Tucson; and, Natural Resources Conservation Service, Texas Tech, Univ. of Arizona and Wyoming, Columbia University Biosphere, Crow Valley Livestock Cooperative Inc.

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Component II
Plant Resources

There are six problem areas in this component: (A) Lack of germplasm and preservation techniques, (B) Lack of germplasm evaluation and enhancement, (C) Plant Biology and Gene Discovery, (D) Overcoming Limitations to Plant Growth and Development, (E) Improving Forages for Livestock Production, (F) Plants Needed for Conservation and Novel Uses

A. Problem Area: Lack of germplasm and preservation techniques

Germplasm collection: Genetic variation for desirable plant traits is fundamental to any plant improvement program and dictates potential progress. Assembling diverse germplasm pools provides a broad genetic base for obtaining variation for selection, manipulation and genetic advancement of desirable characteristics. Efforts in National Program 205 were undertaken to collect, preserve, and expand the germplasm base of important forage and restoration species.

Forage, turf, bioenergy and restoration germplasm [based on Crop Germplasm Committee (CGC) recommendations] has been collected in many locations. Collection sites include Mongolia (Jigjidsuren and Johnson, 2003) and the western USA for native range plants, and the more humid regions of U.S. Hardiness Zones 2 to 5 for switchgrass (Table 1).

Forage kochia (*Kochia prostrata*) is a semi-shrub that can provide nutritious forage for grazing during the fall and winter, but is limited by short stature and a lack of genetic diversity. In 1999, there was only one forage kochia cultivar in the USA, and no National Plant Germplasm System (NPGS) collections with viable seed. To address this problem, ARS scientists initiated the only forage kochia breeding project in the USA and led a germplasm collection trip to Russia and Kazakhstan in October of 1999, and a germplasm exchange trip to Uzbekistan (exchange of USA germplasm for Uzbek germplasm) in October of 2002 (Waldron et al., 2001a, b; Waldron et al., 2005). Field, greenhouse, ploidy count, and AFLP data was used to assemble a representative, manageable "core collection" that was started in the greenhouse and deposited as seedlings with the USDA National Plant Germplasm System.

Basalt milkvetch (*Astragalus filipes*), western prairie clover (*Dalea ornata*), and searls prairie clover (*Dalea searlsiae*) are promising native legume species for fire restoration. Seeds of these three legume species were collected across a six-state area and into British Columbia, Canada. Soil samples and nodule samples were also collected to isolate strains of *Rhizobium* for nitrogen fixation (Johnson et al., 2005). Results of these studies will form the basis for the release of one or more populations of *A. filipes* for use in fire restoration efforts in the western USA.

Gulf-Coast cattle producers depend heavily on tropical grasses for forage, but the nutritional value of these grasses drops during the late summer and fall. ARS scientists have shown that the tropical forage legume, rhizoma peanut, can produce high cattle gains throughout the late summer and fall (Williams et al., 2005). Use of current cultivars is limited to the warmer, well-drained sites in the Gulf Coast region. Material better adapted to cold and wet conditions needs to be identified to expand the impact of this forage species. As the result of two plant collection trips (2003 and 2004) to Paraguay, 65 new accessions of perennial peanut have been identified and placed in the USDA, ARS, GRIN for use for cultivar development (Williams et al., 2004b). In addition to forage potential, some accessions appear to have potential for low maintenance turf and ornamental use.

Germplasm preservation: After germplasm is collected and evaluated, the ability to maintain long-term seed viability is critical in preserving germplasm for future use. However, many warm-season grasses are vegetatively propagated and alternatives to seed storage are needed to preserve these materials. ARS scientists developed cryopreservation methods using meristem tissues for long-term genetic stock storage (Chang et al., 2000; Reed et al., 2005). This approach will preserve genetic diversity without the need to maintain isolated large field populations and will drastically reduce storage costs of these germplasm collections.

Locations; Cooperators: Brooksville, Corvallis, Logan, Madison

B. Problem Area: Lack of germplasm evaluation and enhancement

ARS has active evaluation and breeding programs in native and introduced forage species which continue to result in a wealth of adapted species and improved germplasm/cultivars in the USA, particularly grasses where the demand remains high for improved cultivars. Breeding procedures, including modified recurrent selection, and various hybridization schemes have been employed in the development of new germplasm/cultivars. Traits selected for include increased stand establishment (germination and seedling vigor), productivity and quality, disease, drought and salinity tolerance, ecological compatibility, and persistence under abiotic stress.

Germplasm evaluation: The effective use of plant materials for an array of objectives including conservation, restoration, renovation, landscaping, and bio-remediation requires knowledge of the adaptation of each species and more specifically, cultivars, strains, accessions, or ecotypes of a species to specific sites or regions. Rangeland, grassland, park, and restoration project managers often lack the resources to determine adaptation areas for plant materials because of the large number of species that are used and the extensive geographical areas that are serviced.

Problems often arise in delineating adaptation areas for plant materials of both native and introduced species. To address these problems, ARS scientists at Lincoln, NE developed Plant Adaptation Regions for the USA by combining ecoregion and plant hardiness zone classification systems into a single Plant Adaptation Region (PAR) map and GIS database. ARS scientists in Corvallis, OR, Prosser, WA, Columbia, MO and Washington, D.C. integrated collecting-site ecogeographic data with plant morphologic and molecular marker characteristics to describe relationships between germplasm collection diversity and habitat of origin (Steiner et al., 2001). This research led to a new approach to benchmark accessions in core subset collections using ecogeographic and genetic characteristics and provided criteria to determine which existing or newly acquired accessions are redundant with holdings already in germplasm collections. Based on their geographic origin and test results, plant materials and their general areas of adaptation now can be classified by using the PAR map and GIS database. The effect of latitude and longitude were also evident in evaluations of smooth bromegrass (Casler et al., 2001) and switchgrass (Casler et al., 2004a) at multiple locations. Based on increased persistence and productivity, species within the following genera were most adapted to the Central Great Plains *Agropyron*, *Psathyrostachys*, *Thinopyrun*, some *Elymus*, several previously unevaluated *Leymus* species, and *Pascopyrum* (Vogel and Jensen, 2001). The relationship between latitude of collecting site and flowering ability of birdsfoot trefoil was determined to find specific genetic materials that are best suited to natural reseeding (Steiner, 2002).

The genetic identity of cultivated seed sources, in relationship to natural populations and other varieties, is a major concern of seed producers and land managers. National Program 205 scientists used high-throughput DNA fingerprinting and DNA sequencing to characterize genetic identities, genetic diversity, and genetic relationships among cultivated and natural germplasm sources of native and introduced range plants. Information was used to characterize and in some cases facilitate the release of numerous germplasms and varieties (Garcia de los Santos et al., 2001; Hu et al., 2001; Jensen et al., 2005a,b,c; Jones and Larson, 2002; Larson et al., 2001a,b; Larson et al., 2003a,b; Larson et al., 2004; Massa et al., 2001; Massa et al., 2004; Massa et al., 2005; and Patterson et al., 2005; Steiner and Garcia de los Santos, 2001).

Roundhead lespedeza, *Lespedeza capitata*, is a deep-rooted, perennial legume native to the eastern and central USA and is relatively common on remnant upland prairies throughout the Midwest. Information on condensed tannin (CT) concentration from available germplasm is needed for cultivar development and to develop management and feeding strategies. Springer et al. (2001c) analyzed the CT concentration from leaves, stems, and inflorescences from 39 roundhead lespedeza plant introductions grown in two environments. Variation due to environment was low, variation due to genotype was high, and variation due to genotype x environment interaction was high. Eight accessions that had low CT concentrations in leaves at flowering were selected. The CT content of these accessions, however, was still relatively high when compared with other *Lespedeza* species bred for low tannin content.

Enhancement (germplasm/cultivar development): ARS researchers have developed and released new, improved cultivars for use in pastures, rangeland, and conservation plantings in the USA. Cultivars and germplasm officially released or pending release during the period 2001 through 2006 are summarized in Table 1. Many of these cultivars have increased productivity and enhanced biodiversity in rangelands and pastures. These new cultivars provide rangeland and pasture managers with new plant materials that can more effectively renovate disturbed areas, reduce soil erosion, and generally improve water quality. Use of these new plant materials will reduce invasion of undesirable weeds and resulting wildfires on rangelands, and enhance livestock production.

Locations: Booneville, College Station, Corvallis, El Reno, Lincoln, Logan, Madison, Tifton, Woodward; Japanese Forage & Seed Association, Georgia, Nebraska, Oklahoma, Texas and Utah Agric. Exp. Stations, Oklahoma State Univ., Univ. of Missouri, USDA-NRCS.

C. Problem Area: Plant Biology and Gene Discovery

Tissue culture and plant transformation - Technologies such as tissue culture and genetic engineering are potentially valuable approaches to develop improved grasses. The development of *in vitro* callus inducement and regeneration system for grasses provides a useful method for mass propagation of clones and enables future genetic manipulation and transformation of useful forage species. In collaboration with scientists from the University of Georgia, ARS scientists successfully developed tissue culture techniques for TifEagle bermudagrass (Goldman et al., 2004a). Herbicide resistant plants were developed through biolistic transformation of embryogenic callus (Goldman et al., 2004b). TifEagle hybrid bermudagrass is completely sterile, which should limit unintended transfer of herbicide resistance to other bermudagrasses through outcrossing. ARS scientists in the southern Great Plains evaluated the effectiveness of several types of tissue culture media and hormone concentrations in inducing callus and plant regeneration in 'Jose' tall wheatgrass. A modified Murashige and Skoog basal salt medium was found to be optimum for inducing callus and obtaining efficient levels of plant regeneration (Kindiger, 2002).

Genetic maps for forage improvement - Scientists at Logan, UT developed genetic linkage maps for gene discovery research in North American range grasses (Wu et al., 2003). These genetic maps provide model systems for growth habit (bunch vs rhizomatous) (Larson et al., 2006), seed dormancy, seedling vigor, salt-tolerance, mineral content (Larson and Mayland, 2005), forage quality, low-temperature growth (Hu et al., 2005), and flowering characteristics. Scientists at Corvallis, OR and Columbia, MO created the first birdsfoot trefoil molecular marker linkage map (Fjellstrom et al., 2003) and determined birdsfoot trefoil's mode of inheritance (Fjellstrom et al., 2001). These experimental systems have provided a truly unique framework for gene discovery research and plant improvement in long-lived, stress-tolerant, range and pasture grasses and forages.

There is a need for more productive and better adapted forage grasses for the southern USA. Most grasses adapted to this region are complex polyploids that often reproduce by apomixis and are difficult to improve with conventional breeding methods (Jessup et al., 2002; Jessup et al., 2003). The effective use of plant germplasm of polyploid grasses in breeding programs requires information on the ploidy level (number of copies of each chromosome), mode of reproduction, and other genetic characteristics of each accession. Basic DNA content and cytogenetic information on genomes of smooth bromegrass and related species was developed for use by plant geneticists (Tuna et al., 2001; Tuna et al., 2004). ARS scientists at College Station, TX in cooperation with Texas A&M University scientists constructed genetic linkage maps of both buffelgrass (*Cenchrus ciliaris*) and Texas bluegrass (*Poa arachnifera*). The buffelgrass map included nine markers linked to apomixis (asexual reproduction) (Jessup et al., 2002; 2003). This linkage map provides a bridge for comparative genomic resources of sorghum and major cereal crops. Two markers on the Texas bluegrass map were linked to dioecy (separate male and female plants) (Renganayaki et al., 2005). A cDNA library was made available from buffelgrass through the publicly-accessible Genbank database (http://www.ncbi.nlm.nih.gov/Genbank/index.html). Seventy EST-SSRs were identified and characterized from these buffelgrass cDNAs.

Apomixis is a method of vegetative reproduction through the seed that would greatly simplify hybrid development. In cooperation with the University of Georgia, ARS scientists identified and characterized the genomic sequence that confers apospory, a form of gametophytic apomixis. Bacterial artificial chromosome (BAC) libraries were developed from buffelgrass and an apomictic derivative of *Pennisetum squamulatum* and pearl millet. Analysis of these clones indicated that the apospory-specific regions were duplicated in coupling in both genomes. (Roche et al., 2002)

Fungicide applications to reduce disease outbreaks are one of the largest expenses on highly managed turfgrasses such as creeping bentgrass. One way to reduce the number of fungicide applications on creeping bentgrass and other turfgrass species is to develop new varieties with enhanced fungal resistance to *Sclerotinia homoeocarpa* and *Rhizoctonia solani*. ARS scientists used genetic markers to develop genetic linkage maps of creeping bentgrass

(Chakraborty et al., 2005) that identified regions of the genome involved in enhanced disease resistance. Genetic marker information has also been used to study the mode of inheritance in this polyploid bentgrass species in order to optimize breeding strategies leading to the development of improved disease resistant plant material.

Expressed Sequence Tags (ESTs) were generated from leaf, stem, crown, and callus tissue of tetraploid switchgrass plants. These expressed sequences were used to create a gene inventory of 7810 unique gene clusters in cooperative research by ARS scientists and a Univ. of Nebraska scientist at Kearney, NE (Tobias et al., 2005). This research will result in the development of stable molecular markers and the molecular genetic improvement of switchgrass as a biomass energy crop.

The effective use of plant germplasm of polyploid grasses in breeding programs requires information on the ploidy level (number of copies of each chromosome), mode of reproduction, and other genetic characteristics of each accession. Basic DNA content and cytogenetic information on genomes of smooth bromegrass and related species was developed for use by plant geneticists (Tuna et al., 2001; Tuna et al., 2004). ARS scientists at College Station, TX in cooperation with Texas A&M University scientists constructed genetic linkage maps of both buffelgrass (*Cenchrus ciliaris*) and Texas bluegrass (*Poa arachnifera*). The buffelgrass map included nine markers linked to apomixis (asexual reproduction) (Jessup et al., 2002; 2003). This linkage map provides a bridge for comparative genomic resources of sorghum and major cereal crops. Two markers on the Texas bluegrass map were linked to dioecy (separate male and female plants) (Renganayaki et al., 2005). A cDNA library was made available from buffelgrass through the publicly-accessible Genbank database (http://www.ncbi.nlm.nih.gov/Genbank/index.html). Seventy EST-SSRs were identified and characterized from these buffelgrass cDNAs.

Forage and turfgrass quality diminishes during the transition from vegetative to reproductive growth stage (Casler et al., 2003; Casler et al., 2004). A linkage map was constructed by ARS researchers, in cooperation with others, from a cross between annual and perennial ryegrass populations (Warnke et al., 2004). This linkage map was populated with RAPD, RFLP, AFLP, SSR, and isozyme markers that showed seven linkage groups containing two major Quantitative Trait Loci (QTL) for vernalization and photoperiod (Barker and Warnke, 2001; Sims et al., 2005). Other QTLs for gray leaf spot resistance have been found in this mapping population (Curley et al., 2003; Curley et al., 2005).

Cytoplasmic inheritance in switchgrass Switchgrass has two distinct ecotypes, upland and lowland. A genetic study conducted at Lincoln, NE demonstrated that the two switchgrass ecotypes have the same basic genome and that the cytoplasmic DNA is predominately maternally inherited (Martinez-Reyna et al., 2001). A pre-fertilization incompatibility system was identified that ensures cross-pollination. A post-fertilization incompatibility system was identified that occurs when plants with different chromosome numbers are mated and inhibits the production of viable seed (Martinez-Reyna and Vogel, 2002). This system is responsible for preventing inter-mating between plants with different ploidy levels in native prairies.

Medicago genomics - ARS scientists have used the *Medicago truncatula* library databases and developed genomic alfalfa (*M. sativa*) libraries for Simple Sequence Repeat (SSR) molecular markers appropriate for use in mapping (He et al., 2004). A molecular map has been developed in cooperation with Iowa State University with eight consensus linkage groups. Mapping of the SSR markers allowed a large phenotypic database to be analyzed and new Quantitative Trait Loci (QTL) for biomass production, forage quality, and winter hardiness to be identified. These markers were also utilized in the separation of some of the major alfalfa germplasm sources in the U.S (He et al., 2005).

While barrel medic (*Medicago truncatula),* a close relative of alfalfa, has been adopted as the model species for legume genomic studies, little data are available on the comparability of this species with alfalfa for many important agronomic traits. In collaboration with scientists at the University of Minnesota, ARS scientists developed a DNA microarray with more than 6,000 individual genes from barrel medic. The microarrays were used to detect the genes expressed in plants resistant to two foliar pathogens. These microarrays will be used for measuring gene expression in both barrel medic and alfalfa in response to pathogens and environmental stresses to identify genes for improving plant performance (Federova et al., 2004; Samac et al., 2004a). To determine if barrel medic is a good model for improving forage quality in alfalfa, the stem anatomy and cellular composition of barrel medic was compared to alfalfa. Although alfalfa has an erect stem growth habit and barrel medic stems have a prostrate growth habit, the cellular anatomy and fiber chemical composition during stem development of these two species was very similar. Results from this study give confidence that barrel medic is a good model for alfalfa and the genomic data obtained from barrel medic will be applicable to alfalfa improvement.

Enhanced aluminum tolerance in alfalfa - Tolerance of crop plants to aluminum in acidic soils is needed to reduce costly soil amendments and expand cropping areas. Although aluminum tolerance has been studied in grain crops, little is known about aluminum tolerance in legumes such as alfalfa. A set of 90 barrel medics was screened for aluminum tolerance and plants that exclude aluminum from roots were found in addition to plants that use novel tolerance mechanisms. Expression of 16,000 genes was evaluated after aluminum treatment and a large number of genes with no previously known function were expressed after aluminum treatment (Chandran et al., 2004). These genes could be used to better understand tolerance mechanisms and as markers in developing aluminum-tolerant varieties.

One strategy for reducing fertilizer inputs is to increase the efficiency of nitrogen fixation in legumes. ARS researchers found that malic acid produced by alfalfa facilitates nitrogen fixation (Schulze et al., 2002). They isolated the malic-acid synthesis gene, and found by over-expressing this gene in the plant, they can significantly increase the efficiency of nitrogen fixation and enhance tolerance of alfalfa plants to the aluminum that is released in acid soils (Tesfaye et al., 2001, 2003).

Improving transgene expression in alfalfa - Highly expressed gene promoters are needed for driving the expression of many traits in transgenic plants, but few promoters have been tested for activity in alfalfa. Partially funded by a Cooperative Research and Development Agreement (CRADA) with Forage Genetics International, ARS scientists compared the activity of five promoters using two marker genes (Samac et al., 2004c). The promoter from the cassava vein mosaic virus was found to confer the highest level of gene expression yet obtained in alfalfa and to direct transgene expression in all parts of the alfalfa plant. This promoter will be useful for obtaining high levels of gene expression throughout the alfalfa plant, particularly for synthesis of value-added products. In addition, a signal peptide from white lupine was shown to direct the secretion of proteins from alfalfa roots (Tesfaye et al., 2005). This peptide can be used in production of co-products in alfalfa and for expression of genes that protect alfalfa roots from pathogens and insects.

New technique for plant genotyping and marker assisted selection. The great majority of molecular markers linked to important agronomic traits are dominant markers, meaning that plants with two copies of the marker (homozygote) cannot be distinguished from plants that have only a single copy (heterozygote). This delays progress and increases costs for plant breeding programs, because in order to unambiguously detect homozygous plants it is necessary to produce an additional generation of seed and evaluate progeny for the trait of interest. ARS scientists developed a multiplex real-time PCR assay and a method of data analysis that can be used to accurately genotype bean seedlings for the *bc-1*^{2} and *I* genes, which epistatically confer resistance to bean common mosaic virus (Vandemark and Miklas, 2002 and 2005). Breeders currently use the assay for genotyping plants. This assay can save breeders up to several thousand dollars per cycle of selection in reduced costs by providing a method for identifying promising parental materials as seedlings.

Marker-assisted selection in beans - Bean improvement programs focus considerable efforts on enhancing resistance to virus diseases, many of which are seed-transmitted and are responsible for global disease epidemics. Evaluating plants under greenhouse and field conditions for virus resistance is a costly and time-consuming process for breeding programs. Scientists at Prosser have developed several molecular markers that can be used to rapidly screen beans for the presence of resistance genes to Beet Curly Top Virus and Bean Common Mosaic Virus (Larsen and Miklas, 2004; Larsen et al., 2005). Breeders currently use these markers to reduce costs and improve efficiency of developing new disease resistant bean varieties.

Locations; Cooperators: Albany, Beltsville, College Station, Corvallis, El Reno, Kimberly, Lincoln, Logan, Prosser, St. Paul, Tifton; Forage Genetics Int'l, Clemson, Iowa State Univ., Univ. of Georgia, Minnesota, and Nebraska

D. Problem Area: Overcoming Limitations to Plant Growth and Development

Disease – Stem rust is the most damaging disease in grass seed production in the Pacific Northwest. Over 400,000 pounds of fungicide at a cost of $10 million are used annually to control this disease. ARS scientists developed the first stem rust resistant tall fescue germplasm that is now utilized by most major tall fescue breeding programs in the US and Europe (Barker et al., 2003). Application of these results lowers production costs to growers and increases environmental quality. A web-based decision-support tool was developed that accurately predicts rust epidemics. The model also provides information that improves the timing and effectiveness of fungicide application.

Infection by rust (*Puccinia substriata* var. *indica*) reduces digestible dry matter yield of pearl millet, and can significantly shorten the grazing interval of a pasture by causing complete crop failure. ARS scientists have identified new sources of resistance and developed new breeding strategies to maintain the effectiveness of resistance gene(s) (Panwar and Wilson, 2001; Wilson and Gates, 2002; Wilson et al., 2001a). RFLP markers were used to identify linkage groups associated with partial rust resistance in a forage inbred (Wilson and Devos, 2004). These linkages differ from previously known rust resistances, and will increase diversification of genetic resistance.

To protect domestic production of pearl millet, ARS Scientists are monitoring global distributions and movement of pearl millet pathogens and describing the etiology of less understood diseases (Wilson 2002a). Bacterial stripe of pearl millet (*Acidovorax avenae*) was recently identified for the first time in the USA (Gitaitis et al., 2002). Due to its seed-borne nature, this pathogen is capable of possible wide spread distribution. Stalk rots, such as *Fusarium* *moniliforme*, can affect forage regrowth and are capable of colonizing asymptomatic stems (Wilson, 2002b). Scientists characterized the USA germplasm collection of wild pearl millet for resistance to the parasitic weed striga (*Striga hermonthica*). Secondary and tertiary gene pool species were highly resistant, but transfer to cultivated varieties may be slowed by interspecific crossability barriers. Four resistant accessions in the primary gene pool were identified and progress in breeding for striga resistance is expected (Chee and Wilson, 2004; Wilson et al., 2001b; Wilson and Devos, 2004). The collection of cultivated pearl millets were genetically characterized using SSR and EST sequences. These molecular markers will be useful for more efficiently transferring desirable traits into cultivated pearl millet.

Alfalfa diseases in the US cause losses exceeding $1 billion annually. Diseases of alfalfa are exclusively controlled through cultural methods and the cultivation of resistant varieties, since it is not economical to apply agrochemicals for controlling disease in alfalfa production. ARS scientists are developing new means of controlling diseases that affect alfalfa using biological control agents and protease inhibitors. Biological control agents were shown to decrease the severity of foliar diseases, Phytophthora root rot, and damage from root-lesion nematodes (Samac et al., 2003; [illegible] et al., 2002). Protease inhibitors were also effective against root-lesion nematodes (Samac and Smigocki, 2003).

The soil borne pathogen *Aphanomyces euteiches* is responsible for root rot of alfalfa throughout the temperate USA. ARS scientists have determined the relative importance of both genes and the environment towards the expression of root rot resistance in alfalfa (Vandemark et al., 2004). Knowing the importance of genetic factors on trait expression will help plant breeders to more efficiently develop disease resistant varieties. The great majority of alfalfa cultivars are not resistant to race 2 of *A. euteiches*. Several populations of *M. truncatula* were identified that are highly resistant to *A. euteiches* race 2 (Vandemark and Grunwald, 2004). These resistant populations will be useful for isolating genes conditioning disease resistance in legumes.

Pathogen detection and disease diagnosis- Rapid and accurate methods for detecting pathogens are needed for disease diagnosis and the identification of highly resistant plants. ARS scientists are developing molecular diagnostic tools and databases for rapid detection and accurate identification of species and sub-species taxa of fungal pathogens, including *Stemphylium, Pleospora, Phoma, Ophiosphaerella,* and *Colletotrichum* (Camara, 2002b; Vigi et al., 2004). Molecular taxonomic relationships based on biological species concepts, strain identification, and genetic diversity were determined for species, races, and strains in these genera (Bao et al., 2004; Camara et al., 2002a; Tooley et al., 2002a, 2002b. They determined the pathogenic potential and virulence among pest populations and geographical regions (Bailey et al., 2004; Baker et al., 2002; Kaminski et al., 2002; Liu et al., 2005; Makie et al., 2003; O'Neill and Bauchan, 2003; Saunders and O'Neill, 2004). The research will enable scientists and breeders to make informed decisions about pathogen selection for screening programs to identify and improve disease resistance.

ARS scientists have developed molecular assays for several pathogens responsible for severe diseases of alfalfa, including *Aphanomyces, Phytophthora, Phoma*, and *Verticillium* (Larsen et al., 2002; Vandemark et al. 2003a). The assays can be used to detect and quantify pathogens in plants and soil. The assays provide pathologists with new and improved methods for the diagnosis and detection of plant diseases (Larsen et al., 2004b) and are also used by plant breeders to simultaneously identify plants with high levels of resistance to multiple diseases (Larsen et al., 2004a; Vandemark et al., 2002a,b; Vandemark and Barker, 2003b; Vandemark and Grunwald, 2005).

Choke is an important disease of orchardgrass, which can results in yield losses of 30% for seed producers. ARS researchers developed a PCR based approach to detect choke in orchardgrass. The assay is capable of screening for latent infections in otherwise asymptomatic plants (Baldwin et al., 2005) and will help pathologists detect the pathogen before a disease epidemic starts. The method also is useful for breeders in selecting the most resistant plants possible.

Insects and Nematodes - Genetic resistance and tolerance in grasses to insects can reduce insecticide use and simplify management. The presence of root knot nematodes (*Meloidogyne incognita* and *M. arenaria*) in cotton and peanut production fields results in significant yield losses. The development of a nematode resistant pearl millet would have a significant impact in crop rotations utilizing cotton and peanuts. Pearl millet hybrids with resistance to both nematode species were developed (Timper et al., 2002). This is the first time resistance to these nematodes has been identified in pearl millet. . Resistance to nematodes is important and can afford protection to other crops grown in rotation.

Zoysiagrass and seashore paspalum are more resistant to injury from two-lined spittlebug than bermudagrass and centipedegrass (Shortman et al., 2002). Cultivars 'Sea Isle 2000' Zoysiagrass and 'Tifway' bermudagrass had more regrowth following spittlebug feeding. Larval weight gain of fall armyworms was less on tall fescue than bermudagrass and zoysiagrass (Braman et al., 2002). Genetic variation for resistance exists and can be used in breeding programs to improve plant materials.

Heat and drought - While studying the inheritance of heat tolerance and developing a high through put procedure to quantify superoxide dismutase (SOD) (Banowetz et al., 2004; Warnke et al, 2002), ARS scientists observed that grasses subjected to heat stress accumulated compounds that reduced SOD enzyme activity. Being able to measure SOD efficiently is an important step in understanding plant processes that inhibit plant protection during times of stress and will ultimately help plant breeders increase plant tolerance to stress. Nucleic acid sequences for superoxide dismutase gene and the Lon protease from *Dichanthelium lanuginosum* are located in Genebank accessions AF385581 and AF385580, respectively.

They also demonstrated that drought tolerance in grasses is accompanied by the accumulation of a protein from the dehydrin family (Lopez et al., 2002a; Lopez et al., 2003; Nyanghulu et al., 2005). Plants that accumulated dehydrin proteins earlier in their life cycle were more tolerant to drought. Identifying plants that accumulate this dehydrin will help scientists select plants for breeding programs to increase drought tolerance in wheat (Hess et al., 2002; Lopez et al., 2002b) and grasses (Liu et al., 2002).

"Stay-green" is a mechanism of drought tolerance characterized by the retention of green leaf area at crop maturity under water-stressed environments. ARS scientists have developed a stay-green pearl millet, and characterized it using a quantitative assay that measures the magnitude and retention of relative chlorophyll content. The stay-green trait was dominant or slightly over dominant in expression, which will allow its use in hybrid cultivars (Awala and Wilson, 2005). In other crops, stay-green varieties have greater drought tolerance, greater leaf nitrogen, and more basal stem sugars than senescent genotypes. Stay-green varieties utilize fertilizers more effectively and have improved digestible energy content of forage. The identification of stay-green in pearl millet and ability to measure it will be valuable for improving drought tolerance and forage yield and quality of this important forage grass.

Drought and extreme temperatures greatly limit plant productivity and persistence on western North American rangelands. Scientists at Logan, UT demonstrated that native perennial grass *Poa secunda* does not have the same temperature dependent physiology as the invasive weed downy brome, even though these species are remarkably similar in phenological development (Monaco et al., 2005b). Native shrub studies have shown that subspecies of sagebrush (Smith et al., 2002) have distinctive physiology that enables them to persist across environmental gradients. Studies on the invasive weed *Isatis tinctoria* demonstrated that this species has unique physiological and morphological mechanisms to persist in nutrient poor sites as well as invade shaded (Monaco et al., 2005a). Researchers at Corvallis, OR showed seedlings of two native grasses were shown to be more competitive with tall fescue seedlings during cool temperature periods (Steiner et al., 2001) and that their competitive differences were due to thermal dependence of the glutathione reductase enzyme (Griffith et al., 2001). A greater physiological and ecological understanding of invasive weeds and the native species impacted by their spread provides land managers with different options in the control of invasive weeds.

Increased water-use efficiency (WUE) is important in the selection of grasses for drought tolerance in pastures in semiarid regions of western North America. ARS scientists evaluated irrigated and semiarid grasses under a line-source irrigation system for carbon isotope discrimination (CID) (Jensen et al., 2002a; Jensen et al., 2004; Johnson et al., 2003). Results established genetic parameters for CID in pasture and the premise that water-use efficiency can be improved through traditional breeding schemes. In addition, germination test were used to study the effects of drought on the germination and early seedling growth of chaffy-seeded grasses (Springer, 2005). In general, seed germination and seedling growth were reduced as drought stress increased. Seed processing also affected the rate of germination and seedling growth of the native plant species used in the study. The germination and seedling growth of an introduced yellow bluestem was least affected by low water potentials or seed processing. Given the amount of genetic variation within most cross-pollinated species, this procedure could be used as a selection tool for breeding cultivars with improved germination and seedling growth at low water potentials.

Forage quality - Lignin concentration reduces the digestibility of forages by ruminants and is potentially a main inhibitory compound in the conversion of biomass to ethanol. However, in populations of some species, reduction of lignin concentration can adversely affect plant survival and agricultural fitness (Casler et al., 2002; Pederson et al., 2005; Vogel et al., 2002). Lignin concentration can be reduced in plants if selection pressure is maintained for fitness or biomass yield or via heterosis.

Gulf-Coast cattle producers depend heavily on tropical grasses for fall and winter forage, but their nutritional value drops during the fall and winter. ARS researchers are evaluating six lines of forage peanut in an Environtron at the University of Florida where air temperature and day length can be controlled. Their research suggests that breeding programs should focus on finding germplasm less sensitive to day length (Coleman and Moore, 2003; Williams et al., 2002b; Williams et al., 2004). The effects of induced polyploidy in Russian wildrye on forage quality and mineral composition was studied in the northern Great Plains (Jefferson et al., 2001; Karn et al., 2004; Karn et al., 2005).

Common dallisgrass is an important forage grass in the southern U. S. Venuto et al. (2003) evaluated the nutritive value, forage yield and grazing tolerance of several different dallisgrass biotypes, including common. One biotype, Uruguayan, had superior traits and one accession is in the process of being released as a new cultivar. This and several other biotypes will also serve as parental materials for developing additional improved dallisgrass cultivars for use in grazing systems.

Rhizome Development and Persistence of Birdsfoot Trefoil- A multi-location study on the expression of rhizomes in birdsfoot trefoil and their effect on persistence was completed by ARS scientists at Columbia, MO in cooperation with other ARS scientists at Booneville, AR, Corvallis, OR, Logan, UT, and Madison, WI plus university scientists at Iowa State and Cornell. While both lines being evaluated produced rhizomes at all locations, there were noticeable variations in the extent of rhizome expression and in plant persistence indicating the significant role of environment in birdsfoot trefoil performance (Beuselinck et al., 2005). Characterization and utilization of the rhizome trait led to the first commercial cultivar of birdsfoot trefoil incorporating a specific improved trait and that was selected under grazing management (Beuselinck and Steiner, 2003).

Weed Competition - *Bromus tectorum* (downy brome) is the most problematic weed in the western USA because it alters ecosystem level processes including hydrology, fire frequency, biodiversity, and reliability for grazing animals and wildlife. Rangelands invaded by downy bromegrass alters soil morphology and structure in ways that compromise the ability to restore native species on these damaged ecosystems (Norton et al., 2004a; Norton et al., 2004b). Growth of downy bromegrass was found to be more sensitive to treatments that reduced the availability of soil N (Monaco et al., 2003a; Monaco et al., 2003b; Monaco et al., 2004). Effective use of herbicides to control rangeland weeds requires an understanding of how target weeds and the non-target native species will respond to herbicide applications. Research has identified that a number of desirable perennial grasses can be negatively impacted by sulfosulfuron, sulfometsuron, and imazapic, particularly as young seedlings (Monaco and Creech, 2004). Efficacy of herbicide treatments improved when surface leaf litter was removed by prescribed fire. The importance of application rate and season of application. The importance of application rate and season of use were also identified (Monaco et al., 2005c). This work provides private and public land managers with information of how to more effectively control invasive weeds.

Salinity - Saline soils are wide spread throughout the semiarid Intermountain region of the Western USA and limit crop growth and production. Improvements in plant materials for salt tolerance have been largely unsuccessful due to inadequate selection protocols. ARS researchers developed a protocol to screen large numbers of plants that provides consistent separation of genotypes based on their relative ability to survive under saline conditions (Peel et al., 2004). This research and protocol development provides a direct benefit to the scientific community focused on increasing the salt tolerance of plants. This procedure resulted in the development of salt tolerant wheat (Wang et al., 2003a; Wang et al., 2003b), grass (Jensen et al., 2005) and alfalfa germplasm. This protocol enables selection for salt tolerance within most crop species.

Alfalfa yield is reduced due to salinity in many areas in the western USA. ARS scientists in collaboration with university scientists have identified populations of *M. truncatula* with varying levels of salinity tolerance (Veatch et al., 2004b). Identifying sources of genes conferring tolerance to salinity allows plant breeders to better utilize available germplasm for developing improved alfalfa varieties.

Seed production and seedling vigor - The Federal Seed Act (FSA) specifies that perennial ryegrass seed must be tested for annual ryegrass contamination using seedling root fluorescence (SRF) test, a procedure that has been shown to be inaccurate. A maturity grow-out test protocol to predict growth habit in ryegrass was developed by ARS (Barker et al., 2000; Barker et al., 2001; Floyd and Barker, 2002). Use of this test has resulted in an annual increase of $7 million to the seed industry due to the elimination of misidentified seed fields.

Failure to get successful establishment after planting causes economic losses and often results in increased weed problems. Garrison meadow foxtail can be successfully established in wet meadows by using herbicide-fallow and no-till planting (Han et al., 2004). This is important because tillage on meadow soils often results in failed seedings and increased weed problems. In another study, ARS researchers showed that introduced and native grasses can be successfully planted together on semiarid rangelands (Waldron et al., 2005). This research coined the term "ecological bridge" to define the process of stabilizing environments with introduced plants while slower native plants become established.

Seedling vigor of selected Russian wildrye plants is currently being evaluated in greenhouse tests, and final selection of parents for synthetic populations are planned for 2005 (Berdahl and Ries, 2002). Russian wildrye with induced polyploidy was developed in a cooperative project between two locations and has resulted in plant materials with greater plant vigor, particularly seedling vigor and water-use efficiency (Frank and Berdahl, 2001; Jensen et al., 2005a,b,c; Karn et al., 2003).

ARS scientists at College Station and Temple, TX have developed switchgrass germplasm with reduced post-harvest seed dormancy. This germplasm serves as a source of genes for developing switchgrass varieties that germinate earlier, which will greatly improve seedling establishment and stand yields. This germplasm is in the process of being released.

Locations and Cooperators: Beltsville, Booneville, Brooksville, College Station, Columbia, Corvallis, El Reno, Logan, Mandan, Madison, Prosser, Temple, Tifton, Woodward; and, Cornell, Haryanna Ag. Univ. (India), John Innes Centre, ICRISAT, Iowa State Univ., Utah State Univ., Montana State Univ., Oregon State Univ.,Univ. of Arizona and Florida, and the Namibian Ministry of Agriculture, Water, and Rural Development.

<u>E. Problem Area: Improving Forages for Livestock Production</u>

Forage cultivars – ARS scientists have developed hybrid populations between Texas bluegrass and Argentine bluegrass (Goldman and Sims, 2005). The undesirable cottony inflorescence of Texas bluegrass was reduced or eliminated in the hybrid offspring. This research will expand the genetic resources in developing a persistent, perennial, cool-season forage grass with heat and drought tolerance and provide a perennial alternative to winter wheat which would enhance the forage-livestock industry in this region.

ARS scientists also demonstrated that diverse *Poa* species can hybridize with Texas bluegrass and produce fertile F_1 hybrids. This expands the gene pool to include over 300 bluegrass species (Kindiger, 2004) for forage and turf selection. These interspecific hybrids will result in new gene combinations for improving bluegrass varieties.

Evaluation of the effects of limited irrigation on pasture grasses has been done to help develop grass cultivars specifically adapted to irrigated pastures in the semiarid western USA. Broad germplasm bases were assembled and breeding populations were developed for tall fescue, meadow brome, orchardgrass, and several legumes. The effects of limited irrigation on the production and forage quality of these species were elucidated and it was determined that tall fescue and meadow brome were best adapted for use in limited irrigation pastures (Asay et al., 2001; Asay et al., 2002; Jensen et al., 2001; Jensen et al., 2003; Waldron et al., 2002). Through plant breeding and evaluation, tall fescue and orchardgrass populations with improved forage yield, quality, and leaf softness are being tested. Grass cultivars adapted to limited irrigation will have an economic impact by stabilizing yields in semiarid regions. See Table 1 for list of germplasm/cultivars their traits and adaptations developed by ARS scientists.

Fall and winter forage - Russian wildrye has the potential to be a valuable forage grass for late fall and winter grazing (Jensen et al., 2002[TS17]a) in the northern Great Plains but low seedling vigor has limited its use. New varieties were developed with much better seedling vigor than the existing varieties of the grass (Jensen et al., 2005[TS18]a,b,c). Evaluations at eight locations in the region comparing the new grass to13 other cool-grass species showed that the new Russian wildrye ranked near the top in successful initial establishment plus it had better fall and winter forage characteristics.

The real value of forage kochia to extend the grazing season into the fall and winter is relatively unknown to land managers (Gordon, 2005a). To address this problem, team research documented forage kochia's adaptation (Waldron et al., 2001[TS19]; Harrison et al., 2000), potential weediness (Monaco et al., 2003), and forage (Wood, 2005; ZoBell et al., 2003; ZoBell et al., 2004) and reclamation value. The team has shown that forage kochia is well adapted to the western USA, will usually not spread into perennial plant communities, is distantly related to annual and native kochia, can improve the economic sustainability of livestock production, and can be used to stop the spread of wildfires (Harrison et al., 2002).

Bloat free legumes - The relative forage production of sainfoin, a non-bloating legume, was compared to alfalfa under decreasing levels of irrigation (Peel et al., 2004). Sainfoin is equal or greater to alfalfa in stability across decreasing irrigation levels for spring growth, and best suited for grazing where an early non-bloating legume is required.

Better adapted forage for the Gulf Coast region - Tropical grasses are the backbone of the cattle industry in the Gulf Coast region, but the nutritional value of these grasses drops dramatically during the fall and winter (Coleman and Moore, 2003; Williams et al., 2002a). Incorporating adapted legumes that produce well into the fall period and developing tropical grasses, such as bahiagrass, that grow better in the winter should improve cattle performance during this time of the year (Williams et al., 2002b). ARS researchers, in cooperation with University of Florida, determined why the tropical forage legume, rhizoma peanut, does not produce much forage in the fall (Valencia et al., 2002; Williams et al., 2004a). Six lines of this forage peanut were evaluated in an Environtron at the University of Florida where air temperature and day length can be controlled. They found that, similar to bahiagrass, above ground growth decreased with shorter days so breeding programs should focus on finding germplasm less sensitive to day length.

Improving grazing tolerance in alfalfa - Incorporating alfalfa into grasslands has the potential to improve forage quality and quantity and potentially carbon sequestration on grazinglands throughout the northern Great Plains. Yields between cool-season grass monocultures and grass-alfalfa mixtures were compared to identify planting strategies for maximizing grazing potential (Berdahl et al., 2001). Relatively few grazing tolerant alfalfa varieties have been tested in the region. Sixteen alfalfa entries representing a range of populations from the USA and Canada were heavily grazed by cattle to evaluate their persistence under grazing near Mandan, North Dakota (Hendrickson and Berdahl, 2003). Low temperatures in November and December of 2000 caused entries developed in warmer climates, to have the largest percentage drop in survival while cultivars which were developed in colder climates, had the least percentage point drops. Climate extremes and grazing tolerance important in selecting alfalfa cultivars for use in grasslands. Seed is being increased under contract with private industry for one alfalfa population (Mandan A1991) that has good potential for grazing in semiarid climates.

Enhancing forage digestibility - Increasing the value of alfalfa for feeding high-producing dairy cows requires that the neutral detergent fiber (NDF) digestibility of the stem be improved. Knowledge of the environmental influence and variability of stem NDF digestibility (NDFD) traits will be essential in a plant breeding program to improve these traits. ARS scientists identified individual alfalfa plants that differed in stem NDF dry matter disappearance after 16 and 96 hours of digestion to estimate the rate and extent of stem NDFD. Stem NDFD was repeatable and environmentally stable in alfalfa, which demonstrates potential for genetic improvement to enhance forage quality in alfalfa (Lamb and Jung, 2004). A gene from soybeans that is pivotal in the production of pectin was inserted into alfalfa and the impact from expression of this gene on fiber concentration and composition was evaluated in a field trial. Contrary to expectations, addition of the soybean gene increased fiber and decreased pectin content of alfalfa stems, while the amounts of lignin (an inhibitor of digestion) and another fiber carbohydrate (xylose) increased (Samac et al., 2004b). Future efforts to alter alfalfa stem fiber must consider unintended consequences that can arise when genes are inserted.

Reducing protein loss when ensiling forage crops - Alfalfa and some grasses have significant protein loss during the ensiling process that results in economic loss because more protein supplementation can be required. There are also adverse environmental impacts as nitrogen compounds are released into the environment. The enzyme, polyphenol oxidase (PPO), helps to reduce the breakdown of protein during ensiling. ARS scientists from two locations have worked together to clone a PPO gene from red clover and insert it into alfalfa. The modified alfalfa produced PPO (Sullivan et al., 2004). The potential of these plants to reduce protein loss under various management options is being evaluated. This work is closely linked with research in another national program on cell wall structure and digestibility (Marita et al., 2003).

Mixtures of native, warm-season grasses and legumes - Producers need information about the ability of both cool- and warm-season species to coexist and thrive together. Determining the combining abilities for species presently grown or having the potential to be grown together for forage is important. The compatibility of native, warm-season grasses and legumes in binary mixtures could not be predicted solely on dry matter yields (Springer et al., 2001a). Compatible mixtures, however, were identified with greater confidence when other variables, such as crude protein concentration, *in vitro* digestibility, and visual observations, were taken into account. Based on total forage protein (dry matter yield times crude protein concentration), the only compatible grass-legume mixture was indiangrass-Illinois bundleflower.

Locations; Cooperators: Booneville, Brooksville, Corvallis, El Reno, Logan, Madison, Mandan, St. Paul, Woodward; Noble Foundation, Forage Genetics, Oregon State Univ., Universities of Arkansas, Florida, Missouri

F. Problem Area: Plants Needed for Conservation and Novel Uses

Eastern Gamagrass a multipurpose species – Eastern gamagrass is a native, warm-season, perennial, bunchgrass with many attributes that contribute to its value as a species for grazing, stored forage, and soil amelioration and conservation (Springer and Dewald, 2004). As the number of hectares of eastern gamagrass increases in the USA it has become more evident that diseases and insects common in maize are causing serious problems in gamagrass. In the southern Great Plains, the maize billbug, southern cornstalk borer, and southwestern corn borer reduce seed production of gamagrass by feeding on leaves and stems (Maas et al., 2003, Maas and Springer, 2005). At present, no resistance to these insects has been found in gamagrass germplasm. In other ARS research, seed germination was found to be affected by caryopsis weight, that dormancy was due to the cupulate fruit-case, and that the force required to open the fruit-case did not significantly change after a 4-wk moist prechill. It was conclude that late winter plantings would be adequate if soil temperatures and moisture were favorable (Springer et al., 2001b). In addition, the forage dry matter yield of gamagrass can be maximized by planting pastures to 4.8 plants per square meter (Springer et al., 2003). High stand densities reached equilibrium much faster than lower stand densities. Use of narrower row spacing and slightly higher seeding rates may hasten stand establishment for increased forage production early in the life of the stand. N, P, and K requirements for irrigated eastern gamagrass should be monitored closely by soil testing. Nutrient amendments should be applied to meet the needs of the individual harvests rather than the entire growing season. In addition, eastern gamagrass has the potential to be converted to ethanol. Weimer et al. (2005) developed a bioassay which correlated in vitro gas production to ethanol production. This assay is useful for biomass and plant breeding research.

Manure Management with Forages - Concentrated dairy manure can be a significant source of water pollution, but when coupled with plant production, can be an effective source of plant nutrients. ARS researchers found that N and P recoveries were greater for corn silage/bermudagrass hay/rye haylage system, and that bermudagrass utilized more of the remaining excess nutrients than if a second corn silage crop was used (Newton et al., 2003). Manure applied at rates to supply necessary N resulted in excess P applications, requiring modified applications to reduce potential surface water contamination. Intensive forage systems that include bermudagrass into the system had both environmental and economic advantages.

Springer et al. (2005b) determined the effects of applying solid cattle manure, liquid swine effluent, or commercial fertilizer (urea) at three application rates on the growth, yield, and quality of buffalograss under irrigation. They found that all sources of fertilizer nitrogen produced greater dry matter yields than unfertilized buffalograss and age of stand affected crude protein concentration and in vitro organic matter digestibility. Nitrogen, phosphorus, or potassium levels did not significantly change in the soil over the study period; however, monitoring the long-term effects of fertilization with animal manure on possible accumulation of these and other elements in the soils was advised.

New Pearl Millet for Managed Wildlife - In addition to its use in beef and dairy production systems, pearl millet is also used in managed habitats for bobwhite quail, an important game bird in the recreational wildlife and agro-tourism industry of the southern USA ARS scientists identified an important market niche and released a pearl millet hybrid particularly desirable for wildlife due to its improved seed production (Hanna et al., 2005a; Hanna et al., 2005b). In addition to its use in managed habitat, growers are harvesting the premium-quality grain for use in penned bobwhite quail production. Management practices have been summarized in a production bulletin to support transfer of this new technology (Lee et al., 2004 Wilson et al., 2004a). When grown in stressed dryland systems, its seed is not contaminated by carcinogenic aflatoxins or fumonisins (Jurjevic et al., 2005; Wilson et al., 2004b).

Herbicide Tolerance in Turf Bermudagrasses - Public caution about the application of genetic engineering is based in part on the accidental release and spread of engineered genes into nature. Studies were conducted to identify naturally occurring resistance to three herbicides in three commercial bermudagrass turf varieties. Common bermudagrass was most tolerant to glufosinate and glyphosate (Webster et al., 2004). TifSport was relatively tolerant to clethodim and glufosinate, but sensitive to glyphosate. 94-437 was sensitive to each herbicide. Differences in herbicide tolerances existed, but a high level of herbicide resistance was not found. In future studies of herbicide resistance, screening rates should be at least four times the registered use rate.

Native grasses in the Northeast - The use of native grasses for ecosystem restoration and conserving biodiversity is an important national priority. ARS scientists in the northeast worked closely with the NRCS plant specialists to assess the potential for introduced pasture grasses with native grasses. They evaluated several collections of Virginia wildrye for yield and persistence in multiple locations in the Northeast (Sanderson et al., 2004a). The wildrye produced less than half the dry matter of orchardgrass because the ryegrass had a lower capacity for tillering especially during re-growth (Sanderson et al., 2004b; Sanderson et al., 2004c). Virginia wildrye may have potential for conservation objectives but not those involving livestock grazing.

Identifying superior stress-tolerant cultivars of turfgrass. The National Turfgrass Evaluation Program (NTEP) located at Beltsville, Maryland in cooperation with forty states and five Canadian provinces continue to evaluate grasses to provide information to turf managers and home owners to aid in selecting cultivars that will reduce input costs and maximize environmental benefits while meeting user objectives. Each year, summary reports on evaluated grass species are mailed to over 1400 users.

Determining composition of forage biofuels - Decreasing America's dependence on imported oil will require production of ethanol from difficult to process biomass crops that are often variable in their chemical composition. In collaborative research among ARS units in Peoria, Lincoln, Madison, and St. Paul, samples of the potential biomass crops alfalfa, reed canarygrass, and switchgrass were harvested at several stages of development, analyzed for their chemical composition, and evaluated for the efficiency with which these biomass crops could be processed to sugars that can be fermented to produce ethanol (Dien et al., 2005). The amount of potentially available sugars increased in all biomass crops when harvested at more mature stages of plant development, but the efficiency with which these sugars could be released from the biomass crops declined due to maturation effects; and alfalfa stems were more difficult to process than either of the grasses. These results will be of importance to industrial engineers as they design processing facilities for ethanol production from biomass crops so that these systems will be able to deal with the variation in chemical composition and efficiency of processing that occurs within and among biomass crops.

Enzyme Pretreatment of Lignocellulositic Feedstocks for Ethanol - Before lignocellulositic feedstocks can be used in ethanol production, research must improve system economics through improved fermentation or greater yield of co-products. ARS Scientists at two locations evaluated esterase and cellulose enzyme pretreatments of napiergrass and bermudagrasses to improve fermentable substrate (Anderson et al., 2005). They found that pretreatment with a commercial ferulic acid esterase and cellulase, increased free ferulic acid, arabinose, xylose, and glucose over a cellulase treatment alone.

Estimating forage biofuel production - Producing liquid fuels from forage biomass offers opportunities to increase national energy independence, diversify rural economies, and reduce greenhouse gas emissions. ARS scientists have evaluated procedures for estimating how much ethanol can be produced from biomass stocks such as alfalfa. They found that the common analytical system (detergent fiber analysis) used to estimate cellulose and other polysaccharides for livestock production are not adequate for biofuel estimates because it overestimates potential production. This information will help producers and government agencies more accurately estimate production potential from bioenergy sources and improve the analyses of investment choices.

Developing forage germplasm for the production of biofuels - Increasing the yield and profitability of ethanol production from alfalfa will require development of varieties that reliably have less lignin, an inhibitor of processing, and more fermentable sugars when grown under diverse environmental conditions. A group of alfalfa plants identified by ARS scientists that have low or high concentrations of lignin and various types of carbohydrates were grown on sandy and more fertile soils for two years, and harvested three times each year. It was found that differences in lignin concentration among the selected low and high lignin alfalfa plants were consistent across soils, years, and harvests; although total amount of lignin varied widely among harvests. Carbohydrate concentrations did not always differ consistently between the low and high selected alfalfa plants. Lignin concentration is a more stable alfalfa trait across growing environments that should be emphasized by breeders developing this crop as a feedstock for ethanol production (Lamb and Jung, 2004). Yields of alfalfa for biomass can be increased by decreasing plant density to approximately 45% of that conventionally used in alfalfa hay production stands and delaying harvest until the green pod stage maximized both leaf and stem yield (Lamb et al., 2003).

Some perennial grasses have the potential to be converted into ethanol providing an alternative energy source as well as economical and environmental benefits to agricultural producers. The cultivar ‘Sunburst’ switchgrass was identified as having the greatest biomass potential for the northern half of the Northern Great Plains, while ‘Trailblazer’ was the most productive cultivar for the southern half of this region. Additional research suggested that big bluestem may have a higher ethanol producing potential than switchgrass.

[TS25]**Nitrogen fixation in the Mississippi River Basin**. The combination of excessive amounts of nitrogen, annual cropping, and subsurface soil drainage in the Mississippi River Basin contribute to the development of the ‘Dead Zone’ in the Gulf of Mexico. For the first time, the amount and spatial distribution of nitrogen fixation by alfalfa and soybean were estimated for the Basin by ARS scientists (Russelle and Birr, 2004). Results show areas where both legumes obtain a large amount of nitrogen from the atmosphere, but others where they fix little nitrogen, depending on the supply of soil nitrogen. This research highlights the potential for using these legumes to absorb manure nitrogen, thereby reducing the amount of fixed nitrogen entering the Basin. These new findings should help land managers reduce the amount of nitrogen being added to the River, thereby helping solve the problem of hypoxia in the Gulf of Mexico.

Improving alfalfa to remediate nitrate contamination - Nitrate contamination of drinking water can occur from land where too much nitrogen is present in the soil, such as under fertilizer spills or abandoned barnyards. Nitrogen is not distributed uniformly at these sites. As a result, most crops grown to clean up these heterogeneous sites will grow unevenly, reducing overall yield and the levels of nitrogen removal (Huggins et al., 2001; Russelle, 2001). Legumes, like alfalfa, have a remarkable ability to convert (fix) atmospheric nitrogen into a useful form (Putnam et al., 2001). Legumes like other plants can also take up nitrogen from the soil. Therefore, legumes have the option to taking up nitrogen from the soil, or if soil supplies are inadequate, fixing nitrogen from the atmosphere. At an abandoned barnyard site, ARS researchers compared normal alfalfa with an experimental non-fixing type. Neither alfalfa type completely eliminated nitrate leaching to groundwater on sandy soil, since water moved the nitrate too quickly through the root zone, but both types removed large amounts of nitrogen, 60 to 250 kg N/ha, in the harvested hay (Russelle et al., 2001). Both hay yield and nitrogen removal were better with the normal alfalfa than with the non-fixing type. The non-fixing alfalfa that could not get nitrogen from the air to make up soil deficiencies did not grow well where soil nitrogen supply was lower, so hay yield and quality were impaired (Lee et al., 2003). Legumes with flexible strategies for nitrogen acquisition can help remove excess nitrogen at affordable costs and still produce a uniform, high quality crop on sites where excess nitrogen is heterogeneous in concentration.

Producing valuable by-products from alfalfa stem gasification for biomass energy - Biomass crops are candidates for sustainable, alternative fuel sources for the growing global electrical energy demand. A particularly appealing biomass crop is alfalfa, which can be separated into stems for gasification and leaves for value-added livestock feed. The ash from gasified alfalfa stems was found to contain high concentrations of potassium and phosphorus, numerous micronutrients, and little hazardous organic compounds (Mozaffari et al., 2002). It also is a valuable liming agent. This research demonstrated that the ash can be used as a reliable source of plant nutrients and as a liming material. As electric generation from alfalfa is developed, this new knowledge will help generate markets for the ash and reduce regulatory limitations.

Producing industrial raw materials in alfalfa - ARS scientists and University of Minnesota researchers introduced three bacterial genes for the production of a biodegradable plastic polymer, polyhydroxybutyrate (PHB), into alfalfa plants (Saruul et al., 2002). Plants produced at least 1.8 g plastic per kg dry leaves and the trait was stably inherited in offspring. These plants could be used profitably in a multiple product biorefinery system in which PHB is extracted from leaves, leaf protein is used to produce animal feed supplements, and alfalfa stems are used to produce energy.

Locations; Cooperators: Athens, Beltsville, Lincoln, Madison, Mandan, Peoria, St. Paul, Tifton, University Park, Woodward; Univ. of Georgia and Minnesota, Pennsylvania State Univer., USDA/Natural Resources Conservation Service

Table 1. ARS developed forage and and rangelenad plant cultivars and germplasms released from 2001 through 2006.

Species	Cultivar or Germplasm	Cultivar or Germplasm Name	ARS Location & Citation	Attributes	Adaptation Area
Intermediate wheatgrass	Cultivar	Beefmaker	Lincoln, NE (Vogel et al., 2005b)	Excellent forage quality & forage yield	Central & northern Great Plains & intermountain West.
Intermediate wheatgrass	Cultivar	Haymaker	Lincoln, NE (Vogel et al., 2005c)	High forage yields	Central & northern Great Plains & intermountain West.
Crested wheatgrass	Cultivar	NU-ARS AC2	Lincoln, NE (Vogel et al., 2005d)	High forage yields	Central & northern Great Plains & intermountain West.
Big bluestem	Cultivar	Bonanza	Lincoln, NE (Vogel et al., 2004a)	Forage quality, yields, & high animal gains	USDA Plant Hardines Zone 5 and lower 4, Midwest & Great Plains.
Big bluestem	Cultivar	Goldmine	Lincoln, NE (Vogel et al., 2004b)	Forage quality, yields, & high animal gains	USDA Plant Hardines Zone 6 nd lower 5, Midwest & Great Plains.
Forage triticale	Cultivar	NE422T	Lincoln, NE (Baenziger and Vogel, 2003)	Forage yield & quality	Central Great Plains, winter annual.
Switchgrass	Germplasm	WS4U & WS8U	Univ. Wisc. & Lincoln, NE. 2002	Germplasms for future use by breeders	Upper Midwest & Great Lakes region.
Sweetclover	Genetic stocks	50 Genetic stocks	Lincoln, NE (Vogel et al., 2005a)	Genetic stocks for future use by breeders	Northern half of USA.
Indian ricegrass	Pre-Variety Germplasm	Ribstone	Logan, UT (Jones et al., 2004c)	Improved germination	Southern Alberta
Indian ricegrass	Pre-Variety Germplasm	Star Lake	Logan, UT (Jones et al., 2005)	Improved germination	Arizona, New Mexico, and Lower Colorado Plateaus

Indian ricegrass	Pre-Variety Germplasm	White River	Logan, UT, Pending	Improved germination	Upper Colorado and Green River Plateaus
Indian ricegrass	Germplasm	Blue Powder	Logan, UT, Pending	Ornamental – glaucous foliage	Northern portion of the Intermountain Region
Bottlebrush squirreltail ssp. elymoides	Pre-Variety Germplasm	Fish Creek	Logan, UT (Jones et al., 2004a)	High seed yield	Upper Snake River Plain
Bottlebrush squirreltail ssp. californicus	Pre-Variety Germplasm	Toe Jam Creek	Logan, UT (Jones et al., 2004b)	High seed yield	Lower Snake River Plain and northern Great Basin
Bottlebrush squirreltail ssp. brevifolius	Pre-Variety Germplasm	Pueblo	Logan, UT Pending	High seed yield and late maturing	Rocky Mountains of Colorado and New Mexico
Bottlebrush squirreltail ssp. brevifolius	Pre-Variety Germplasm	Wapiti	Logan, UT Pending	High seed yield and late maturing	Rocky Mountains of Colorado and New Mexico
Green needlegrass	Pre-Variety Germplasm	Cucharas	Logan, UT (Jones et al., 2004d)	High germination and seed yield	Western central Great Plains
Bluebunch wheatgrass	Pre-Variety Germplasm	P-7	Logan, UT (Jones et al., 2002)	High-genetic diversity and increased seed yield	Northern Intermountain Region
Meadow bromegrass	Cultivar	Cache	Logan, UT (Jensen et al., 2004)	Increased forage yield after defoliation, drought tolerance, and seedling vigor	Irrigated pastures
Altai wildrye	Cultivar	Mustang	Logan, UT (Jensen et al., 2005)	Increased seedling vigor	Great Basin and Northern Great Plains
Russian wildrye	Cultivar	Bozoisky-II	Logan, UT (Jensen et al., 2006)	Increased seedling vigor	Great Basin and Northern Great Plains
Wildrye hybrid	Germplasm	Leymus-1 Hybrid	Logan, UT (Jensen et al., 2002)	Three species hybrid – breeding for winter forage	Great Basin

Hybrid wheatgrass	Germplasm	RS-H Hybrid	Logan, UT (Jensen et al., 2003)	Caespitose growth habit and leafyness	Great Basin and Northern Great Plains
Sandberg bluegrass	Pre-Variety Germplasm	Reliable	Logan, UT (Waldron et al., 2006b)	Broad-based germplasm	Pacific Northwest and Great Basin
Western yarrow	Pre-Variety Germplasm	Harrison	Logan, UT (Waldron et al., 2006a)	Broad-based germplasm	Pacific Northwest and Great Basin
Bufflegrass	Cultivar	Frio	College Station, TX (Hussey and Burson, 2005)	Increased cold tolerance	South Texas Plains and North Eastern Mexico
Dallisgrass	Cultivar	Sabine	College Station, TX Pending	Increased forage and persistence under grazing	Adapted to sites where common dallisgrass grows from East Texas to South eastern USA
Annual ryegrass	Cultivar	Shiwasuaoba	El Reno, OK and Japanese Forage, Seed Assoc. (Kindiger et al., 2004)	Early spring forage production	Adapted to areas where annual ryegrass is grown
Wheat	Germplasm	W4909 and W4910	Logan, UT (Wang et al., 2003)	Increased salinity tolerance	To be used as a gene source for salt tolerance in breeding programs
Wheatgrass Hybrids	Genetic Stocks	TBTE001 and TBTE002	Logan, UT (Wang, 2006)	Blue-leaf plants	
Sand bluestem	Cultivar	Chet	Woodward, OK (Springer et al., 2005)	Increased forage sand seed yield	Pasture, hay, soil stabilization on marginal croplands in central and southern Great Plains

Eastern gamagrass	Cultivar	Verl	Woodward, OK (Maas et al., 2003; Springer et al., 2003)	Increased forage yield	Pasture, hay in the eastern and southern United States
Reed canarygrass	Cultivar	Windfall	Madison, WI & WI Ag. Exp. Stn. (in review)	High-yielding, improved establishment, higher tiller density	Pasture, hay, conservation in Mid-West, North Central and Northeastern States
Meadow fescue	Cultivar	Winter	Madison, WI & WI Ag. Exp. Stn. (in review)	Superior forage, persistence, drought tolerance, and forage quality	Pasture, hay, conservation in Mid-West, North Central and Northeastern States
Festulolium	Cultivar	Hidden Valley	Madison, WI & WI Ag. Exp. Stn. (in review)	Superior forage, persistence, drought tolerance, and forage quality	Pasture, hay, conservation in Mid-West, North Central and Northeastern States
Tall fescue	Cultivar		Booneville, AR (Nihsen et al., 2004)	Novel endophyte – does not produce toxins	Irrigated Pastures
Birdsfoot trefoil	Germplasm	RG-BFT	Corvallis, OR (Steiner & Beuselinck, 2001)	Photoperiod insensitive and rapid flowering	Any environment
Birdsfoot trefoil	Germplasm	ARS-2622	Columbia, MO (Beuselinck & Steiner, 2003	Rhizomes	Any pasture environment
Narrow leaf trefoil	Germplasm	ARS-NLT-SALT and ARS-NLT-SALT/B	Corvallis, OR (Steiner & Bañuelos, 2003)	Saline soil growing conditions	Any environment

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Component III
Forage Management

This component contains two problem areas: (A.) Forage Establishment and Persistence, and (B.) Harvest, Storage, Utilization and Testing.

(A.) Problem Area: Forage Establishment and Persistence

Soil characteristics limit forage establishment. The soil characteristics of a site often effect establishment of forage species. For example, the use of Kura clover, a spreading perennial legume that produces high quality forage, has been limited due to its low seedling vigor and slow stand establishment. Recent research has indicated that Kura clover is best established in soils with a pH between 6 and 7 (DeHaan et al., 2002). Using limestone to neutralize pH alleviated elemental toxicities and nutrient deficiencies typical of acid soils, resulting in more root nodules and increasing the supply of nitrogen to the plants. Additionally, the failure to reestablish alfalfa after severe winter injury is a common problem and thought to be due to autotoxicity caused by chemicals released from the previous alfalfa plants. Alfalfa seedlings were 15% smaller following alfalfa than other crops, and the age and cultivar of the alfalfa in the previous crop had no apparent impact (Seguin et al., 2002). However, the later the reseeding took place in the growing season the more significant the impact on the seedlings. Reseeding success following alfalfa can be increased by moldboard plowing in the spring and planting as soon as possible.

Poor nutrient availability in the sandy soils of the Gulf Coast region often limits perennial grass establishment. Using dredge materials from lake bottoms on bahiagrass pastures enhanced pasture establishment and reduced the need for disposing the material in landfills (Sigua et al., 2004a). The concentrations of heavy metals and human pathogens in lake-dredged materials were well below levels approved by EPA, and the dredged materials increased both plant height and dry matter production (Sigua 2004b). The average bahiagrass biomass in plots treated with dredged materials was 173% greater than plots not treated with dredged materials (Sigua et al., 2003). Using dredged materials for pasture establishment creates both economical and environmental benefits including a use for dredged materials that would otherwise be a disposal burden (Sigua et al., 2004a).

Effectively managing soils during grass and legume establishment can increase sustainability by increasing the return on investment costs while protecting the soil and water resources from erosion. Establishment of small-seeded legumes is problematic in Appalachian soils and often is attributed to soil acidity related challenges. Soil amendments supplying Ca were not as effective at increasing nodulation of clovers as was soil pH (Brauer et al., 2002). Increasing sward productivity was associated with increasing clover as a fraction of total sward composition. Clover productivity increased with increased pH (Ritchey et al., 2004). Simple practices such as liming would have a major impact on total herbage production in Appalachian pasture.

Determining establishment in first-year switchgrass stands is difficult. It is often difficult to determine if first-year stands have met the objectives of a perennial grass seeding. Field scale trials in Nebraska, South Dakota, and North Dakota were used to determine threshold or minimal stands for switchgrass when grown as a biomass energy crop. The three-state evaluation indicated that an establishment year stand frequency level of 40% or greater as determined by a frequency grid can be considered a threshold for successful establishment and subsequent biomass yields for switchgrass grown as a bioenergy crop in the Northern Great Plains (Schmer et al., 2005). An establishment year stand frequency of 25% would be adequate for a switchgrass conservation planting for which no harvests would be planned for several years. The herbicide combination of atrazine plus quinclorac resulted in acceptable first year stands and high biomass yields, and is an excellent herbicide combination for establishing switchgrass for biomass production in the Great Plains (Mitchell et al., 2005). Other broad-leaf herbicides can be substituted for atrazine. In related research on establishment of native prairie species, addition of carbon sources, such as sawdust, to the soil before seeding reduced soil N supply, reduced weed growth, and improved establishment of the native species (Blumenthal et al., 2003)

Harvest management determines annual grass self-seeding. Limited-resource farmers often cannot use annual forage grasses because of the high costs associated with annual reseeding. ARS scientists evaluated alternative harvest practices for annual ryegrass to determine the harvesting dates for optimizing forage yields while leaving sufficient grass to mature and produce adequate seed for self-seeding next year's stand. The greatest seed deposition resulted in July following mid-April harvest. Maximum forage yield resulted from mid-May harvesting but produced inadequate seed for reseeding (Bartholomew and Williams, 2004, 2005). Farmers need to evaluate the tradeoffs between seed production and forage yield in deciding when to harvest annual ryegrass.

Environmental stresses lead to forage deficits in the Northeast. Livestock grazers in the Northeast face periods when environmental stresses lead to forage deficits that result in lower livestock production. Maintaining profitability requires that the forage deficit periods be reduced without using expensive inputs. Planting a mixture of plants in pastures instead of only one or two species resulted in fewer weeds and more forage production without any reduction in dry matter intake or milk production in Holstein cows (Sanderson et al., 2005). Additionally, they found that planting mixtures of up to five forage species together increased productivity under drought stress (Skinner et al., 2004). English plantain, a forb from New Zealand, was productive during drought, but was susceptible to freezing stress and does not survive Northeastern winters (Sanderson et al., 2003; Labreveux et al., 2004; Skinner et al., 2004; Skinner, 2005). The length of the forage-producing season is determined by the frost-free interval (Feldhake, 2001). An inexpensive sensor was developed that measures forage-canopy temperature at night (Feldhake et al., 2005). They found that conifer silvopasture systems can provide a forage canopy temperature increase of up to 10 degrees C during a radiation frost event. The higher temperature can reduce the damage to the forage crop and extend the grazing season in the spring and autumn. The temperature increase was linearly correlated with the amount of long-wave radiation emitted by the area of tree foliage obscuring the sky field-of-view of the forage canopy. This information can be used to design agroforestry systems to balance the tradeoffs between lengthening the growing season and lowering overall forage production.

Environmental stresses limit forage persistence in the Great Plains. Maintaining productive grasslands in the Northern Great Plains is difficult because of recurring drought and lack of winter-hardiness in perennial legumes. Planning for drought conditions is a major concern for ranchers. ARS scientists correlated perennial grass production to precipitation timing and distribution over many growing seasons and found that perennial grass production is tied closely to spring precipitation and only loosely linked to autumn precipitation (Heitschmidt et al., 2005). About 90% of grass production occurs before 1 July due to limited summer rainfall. Using this information, ranchers can determine if they are entering a period of drought and low forage production early in the summer and make early adjustments to their livestock grazing plans instead of waiting until later in the summer when forage shortages become a crisis. Additionally, the effect of grazing during drought conditions on perennial grasses is poorly understood. ARS scientists evaluated the effects of defoliation and soil water on yield and tiller recruitment for two perennial grasses and discovered plants that were not defoliated had 1.6 times as many tillers as the moderately defoliated plants and 2.7 times as many tillers as the severely defoliated plants while water stress mainly effected tiller size not tiller numbers (Hendrickson and Berdahl, 2002). These results suggest that grazing management following drought may be as critical to long-term persistence as grazing during the drought period. Incorporating alfalfa into grasslands in this region can improve forage quality and quantity and potentially carbon sequestration. Sixteen alfalfa entries were evaluated for persistence in grasslands under heavy grazing pressure (Hendrickson and Berdahl, 2003). For varieties developed for colder climates, grazing reduced alfalfa survival by 2.8% to 4.1%. In contrast, warmer-climate varieties were reduced by 43% to 49%, indicating that climatic origin had more impact than grazing pressure on survival.

ARS Locations and Cooperators: Beaver, Booneville, Brooksville, Burns, Corvallis, El Reno, Langston, Lincoln, Logan, Madison, Mandan, Miles City, St. Paul, University Park; and, Cornell, Iowa and Pennsylvania State Univ., and Univ. of Florida, Minnesota and Nebraska, USGS Orlando Sub-District, South Florida Water Management District, Southwest Florida Water Management District.

(B.) Problem Area: Harvest, Storage, Utilization and Testing

Recommended practices for harvest and storage: Forage producers must choose among a wide variety of available technologies when developing or refining their harvest and storage practices. Choosing the right combination of equipment, treatments and related practices to obtain the most efficient and economical production system is complex, and reliable, unbiased guidance is often difficult to obtain. ARS scientists synthesized research information from the past 40 years to develop recommended practices and procedures for forage conservation. Farm and machinery models were used to determine complementary machinery systems for optimal hay and silage production over a wide range in farm sizes (Rotz, 2001; Rotz et al.,2003; Rotz and Skinner, 2005). An evaluation of technologies and recommended practices were presented to producer groups and distributed through producer and extension oriented publications. This information is being used by forage producers, and those consulted by producers, in the selection and implementation of more efficient and cost effective hay and silage production systems.

Technology for harvesting and handling seed from chaffy-seeded grasses is limited. Novel seed harvesting and seed handling equipment for chaffy-seeded grasses has been developed. These patented inventions include the 'Woodward Flail-vac Seed Harvester', the 'Woodward Seed Shucker', the 'Woodward Seed Scalper', and the 'Woodward Seed Conditioner' (Dewald and Beisel, 2002; Dewald et al., 2003). This equipment made it possible to supply the millions of pounds of seed that was required to plant the CRP acreage. The Seed Conditioner 2000 is designed to condition even the most problematic chaffy seed such as Texas bluegrass. It utilizes a unique delivery system, a conditioning chamber for removal of trash, lint and fuzz, an aerodynamic classifier combining the Venturi principle for acceleration, the Coanda effect for seed and trash separation, and momentum discrimination for seed quality classification.

Harvest timing impacts hay yield and nutritive value. Little information is available concerning the effects of harvest date or time of day on hay yield and nutritive value. Harvesting forage for hay, as opposed to grazing, increases production cost. Management strategies that increase the nutritive value of harvested forage would help offset the fixed cost of harvesting and storing. Harvesting cool-season forages in the late afternoon increased nutritive value (Burns et al., 2005; Griggs et al., 2005). Afternoon harvested hay had higher sugar concentrations, was preferred by ruminants, and resulted in more consumption and increased digestibility (Fisher et al., 1999, 2002). In the Midwest, the optimal time to harvest switchgrass for biomass yields is at the 3.3 (R3) to 3.5 (R5) stage of maturity (panicles fully emerged to post-anthesis) (Vogel et al., 2002). Maximum first cut yields were obtained at these growth stages. In some years, sufficient regrowth may be obtained for a second harvest after a killing frost. These morphological stages usually occur the first three weeks of August for adapted cultivars. This would be a good time for most Midwest farmers because corn and soybeans are not ready for harvest and other field work has often been completed by this time. To obtain optimal yields, approximately 20 lbs N per acre should be applied for each ton of switchgrass biomass produced when harvested at the R3 to R5 maturity stages. Yields for harvests at these maturity stages averaged between 5 and 6 tons dry matter per acre. At these fertility levels the amount of N removed in the biomass was approximately the same as the amount applied.

Grazing exclusion reduces forage nutritive value and contributes to overgrazing. Pacific Northwest and northern Great Basin rangeland grasses that are not grazed during the growing season become nutritionally deficient by mid summer and will not sustain cattle gains. The effects of grazing exclusion and seasonal cattle grazing on fall and winter nutritional characteristics of six grasses were studied. Cattle grazing reduced fall standing crop by 32 to 55% but increased forage crude protein content and digestibility in late summer and early fall (Aguilera and Ganskopp, 2005). When given a choice, cattle spent 70% of their time in areas grazed the previous year and avoided areas with accumulated litter in ungrazed areas. Consequently, animals concentrate in previously grazed areas and create a self-perpetuating cycle that wastes forages in under-grazed areas and contributes to overgrazing in other areas. This demonstrated that managed seasonal cattle grazing can be used to improve late summer and fall nutritional value of grasses with findings benefiting rangeland managers striving to generate high quality, late season forage for cattle or wildlife.

Grazing seeded forages with native rangeland in the Northern Great Plains. Complementary use of seeded perennial cool-season grass pastures with native rangeland can increase available forage and provide a high plane of nutrition for grazing livestock. We compared performance of yearling beef heifers grazing native rangeland with those grazing pastures seeded to >Rosana= western, >Luna= pubescent, or >Hycrest= crested wheatgrass in spring, and pastures seeded to 'Alkar' tall wheatgrass, 'NewHy' hybrid wheatgrass, 'Bozoisky' Russian wildrye, or 'Prairieland' Altai wildrye in autumn. All heifers grazed native rangeland during summer. Heifers gained more on seeded pastures than on native rangeland in spring and autumn of most years, and in 2 out of 3 years, heifers that grazed native rangeland during spring gained more on native rangeland during summer than heifers that grazed seeded pastures in spring. Results suggest a management paradigm wherein Hycrest is grazed in spring and Prairieland is grazed in autumn, but because response in livestock performance may not be consistent across all years, management tactics may need to be modified to take full advantage of seeded pastures. (Haferkamp et al. 2005) These findings will assist land managers in the selection of the most ecologically and economically effective forage species for land restoration.

Livestock production in the southern Great Plains is limited by forage supply and nutritive value. The forage supply limitations that occur in the spring, late summer, and autumn are critical to the livestock production systems of the southern Great Plains. Many forage-livestock systems in the southern Great Plains are dependent on cool-season annual forages for winter-spring grazing. Complementing or replacing the annual forages with perennial forages could reduce inputs and soil erosion but cool-season perennial grasses have not been extensively tested under dryland conditions in this region. Forage quality of four cool-season perennial grasses was high but production declined over the years and weedy grasses invaded in all test plots. Intermediate and tall wheatgrasses were not adapted, but western wheatgrass and Russian wildrye showed enough potential to warrant further research (Gillen and Berg, 2005). Tall fescue and wheatgrasses can be incorporated into the traditional wheat/warm-season perennial grass forage production system of the region to meet forage demand. These perennial cool-season grasses could be grazed about one month earlier in the autumn and one month later in the spring than wheat, and they provided 497 to 589 stocker grazing days in autumn and spring (Northup et al., 2005a). While average daily gain of stocker calves was consistently less on these perennials than on wheat, other measures of their value compared favorably with wheat pasture (Northup et al., 2005b). These species are not thought to be well-adapted to the southern Great Plains, but this research demonstrated that perennial cool-season grasses can provide high-quality forage during spring and autumn when no other sources of forage are available. Early-, intermediate- and late-maturing pigeonpea ecotypes were evaluated to determine their forage production patterns and nutritive value (Rao et al., 2002). Forage yields were high relative to other grasses and legumes, and protein content and digestibility compared favorably with other forages (Rao et al., 2003). Because it is productive and nutritious in late summer when other forages are unproductive, pigeonpea has considerable potential for filling the summer/autumn forage gap in a year-round supply of high quality forage. The performance and adaptation of two legumes, grasspea and chickling vetch, offer solutions to forage gaps by providing high yields of high-quality forage in spring (Rao et al., 2005a). Some new forage-type soybean varieties are well adapted and productive in late summer, when production and quality of other forages declines (Rao et al., 2005b). Additionally, kenaf has been grown successfully in Oklahoma, has good nutritive value and dry matter intake (Phillips et al., 2002b), and can be used as a substitute for alfalfa in diets for fattening lambs (Phillips et al., 2002a).

The nutritional value of bermudagrass declines in late summer. Thousands of farms across the South raise beef cattle on bermudagrass pastures that decline in nutritional value in the late summer. Supplementation of stocker steers on pasture with 2 pounds of corn per animal per day increased average daily gain by 26%; 3 pounds by 42%; and 5 pounds by 40% (Aiken and Brauer, 2002). Economic analysis showed that 3 pounds per day provided the best net return over a wide range of cattle and corn prices, and negated the effects of the late-summer decline in bermudagrass nutritive value.

Carcass Quality Models for Beef Cattle: ARS scientists in Arkansas with scientists from Texas A&M University developed a model to assess how stocker cattle at the end of the grazing phase will perform in the feedlot in terms of percent retail product, marbling score, and carcass hot weight. Field tests of the model indicate that animal data gathered at the end of the grazing phase can aid in predicting the economic value of feedlot finishing. Such information will be helpful to stocker producers who are considering retaining ownership through the feedlot (Aiken et al., 2004).

Extending the grazing season in the shortgrass steppe. Grazing fourwing saltbush-dominated shorgrass steppe in late fall and/or early spring would extend the grazing season in this ecosystem. The effects of light and moderate stocking rates on weight gains of heifers grazing fourwing saltbush pastures in late fall (November to mid January) and in early spring (April to mid May) were evaluated for four years (Derner and Hart, 2005). Average daily gain was 58% greater for light stocking rates in the late fall grazing period, and 115% greater with light than moderate stocking rates in the early spring grazing period. Beef production per land unit area did not differ between stocking rates. Lengthening of the grazing season in the shortgrass steppe should be economically desirable to land managers as feed costs could be lowered and animal gains obtained through minimal input.

Overcoming spatial limits to forage-based livestock production in Appalachia. The complex terrain of the Appalachian region provides a diversity of sites that can be used to extend spatial boundaries and temporal intervals of forage production. Silvopasture is one means of extending spatial boundaries of forage production (Benfeldt, et al., 2001), and swards can be established successfully by planting in summer and grazing in the following year (Neel and Belesky, 2003). Sward productivity and nutritive value can be sustained by maintaining greater residual, post-defoliation mass (Belesky, 2005a, 2005b). Forage production is reduced but nutritive value is improved in modest shade relative to open sites (Neel et al., 2003; Feldhake et al. 2004; Burner and Belesky 2004; Belesky et al., 2005. Forage grasses adapted to full-sun systems are productive and persistent in partial shade. Growing ruminants achieve comparable average daily gains on silvopasture relative to full-sun pasture; however, reduced herbage productivity restricts stocking density so that livestock production per unit land area is less. Simple herbage energy-protein models were constructed to integrate forage productivity with nutritive value for plants in silvopasture, and were evaluated in terms of ruminant blood urea N. Renovating pastures could improve herbage supply and nutritive value. The influence of long-standing tall fescue swards on the establishment of small-seeded legumes varied within a growing season and did not appear to have a detrimental influence on nodulation (Staley and Belesky, 2004).

Extending the interval of herbage production in the Appalachian Region. Establishing persistent forages that extend the grazing season, provide increased nutritive value, and synchronize production and nutritive value with livestock requirements are needed in Appalachia. The time of herbage availability during a growing season is as important as the amount of available herbage. Finding ways to extend the interval of herbage production would help increase the efficiency of forage-based, livestock production systems. A wide array of species occur in pasture in the Region (Fedders and Belesky, 2002). Novel forage plant resources including prairiegrass, and forage brassicas (Belesky et al., 2004; Belesky, 2005) can extend the availability of herbage production with acceptable nutritive value into late autumn, while chicory (Belesky et al., 2001; Clapham et al., 2001; Alloush et al., 2003; Belesky et al., 2004; Turner and Belesky, 2002) is compatible with traditional forages grown in the region and can supplement productivity and quality in mid season when cool-season forage production slows because of heat and limited water. Certain warm-season grasses including bermudagrass and Old World bluestem also can be used to supplement summer herbage production without adopting new or complicated management practices (Belesky et al., 2002; Belesky 2005).

Protein degradation during ensiling reduces available protein to the animal. Degradation of protein in ensiled forages is a problem because nonprotein nitrogen is poorly utilized by ruminant animals, leading to economic and environmental costs. The oxidation of endogenous *o*-diphenol compounds by polyphenol oxidase in the leaves of red clover is responsible for reducing protein breakdown during ensiling of this forage crop and this natural protein protection system works for other forages, such as alfalfa (Sullivan et al., 2004a). Development of the polyphenol oxidase/o-diphenol system as a practical treatment for ensiled forages could save farmers $100 million annually in protein supplements and greatly reduce release of excess nitrogen into the environment (Sullivan et al., 2004b).

Testing forages for fatty acid concentrations. Forages differ in their nutritional quality among species, stages of development, and as a result of the environment. Forage fatty acid intake can affect meat quality and flavor, but forage fatty acid profiles are scant in the literature. Growth chamber, greenhouse and field studies were conducted to determine the fatty acid levels and relative concentrations within conventional and novel forages (Clapham et al., 2005b). Three fatty acids, alpha-linolenic, linoleic and palmitic fatty acids were found to constitute most of the forage fatty acid. However, alpha-linolenic was the major constituent. Members of the grass family had consistently higher alpha-linolenic fatty acid in comparison to legumes that had generally higher levels of linoleic (Clapham et al., 2005a). Levels of alpha-linolenic acid were greatest in the early spring and in early autumn (Clapham et al., 2004). Quantifying forage fatty acids requires a series of expensive analytical procedures. A series of calibration equations was developed for accurately quantifying fatty acids using near-infrared reflectance spectroscopy (NIR) and was validated using wet chemistry (Foster et al., 2005). Using NIR to determine fatty acid profiles (as well as other quality factors) allows us to process a large number of samples at low cost. The data suggests that fatty acid intake can be manipulated by choice of forage and management. Forage finishing systems can be developed that meet the nutritional requirements for finishing livestock and these systems can be configured to deliver desired fatty acids resulting in superior meat quality.

Hair Sheep Breeds for the Humid South. To identify appropriate sheep breeds for grazing and finishing in the hot, humid South, ARS scientists and the University of Arkansas compared the growth and carcass traits of three hair sheep breeds (Dorper, St, Croix and Katahdin) and one traditional wool breed (Suffork). The best results in terms of animal performance, carcass muscularity and quality for lambs weaned at 60 days and managed on a finishing ration till harvest at 180 days of age came from Dorper x St. Croix cross (Burke et al., 2002; Burke et al., 2003; Burke and Miller, 2004).

ARS Locations and Cooperators: Beaver, Booneville, Burns, Cheyenne, El Reno, Kimberly, Lincoln, Madison, Mandan, Raleigh, St. Paul, University Park, Watkinsville, Woodward; and, North Carolina Agric. Research Service, Univ. of Georgia and Nebraska.

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Component IV
Grazing Management: Livestock Production and the Environment

This component contains three problem areas: (A) Grazing Impacts on Water Quality; (B) Grazing Impacts on Ecosystems; and (C) Management, Behavior, and Production of Grazing Livestock.

A. Problem Area: Grazing Impacts on Water Quality

Grazing near lakes does not cause phosphorous problems. Forage-based livestock systems have been implicated as contributors to deteriorating water quality, particularly for phosphorous (P) in fertilizers and manures affecting surface and ground water quality. Little information exists regarding possible magnitudes of nutrient losses from pastures used in cow-calf operations that are managed for both grazing and hay production and how this might impact adjacent bodies of water. Analyses by ARS scientists in Florida demonstrated that water quality in lakes associated with long term cattle production was "good" (30-46 TSI) based upon the Florida Water Quality Standard (Sigua et al., 2003c). Similar analyses of nutrients in lakes showed that properly managed cow/calf operations were not major contributors of phosphorous to surface waters in Georgia (Franzluebbers et al., 2002). Grazing and hay production do not appear to cause significant water quality problems in the Southeast.

Ponds and grassed waterways mitigate nitrates, phosphorous and bacteria in runoff. In cooperation with the University of Central Oklahoma at Edmund, ARS scientists demonstrated that nitrate concentrations in streamflow leaving 2,500-acre agricultural watersheds in central Oklahoma were low at less than 1 mg/L, even below a watershed supporting a 350-head grazing-based dairy (Daniel et al., 2004). Movement of streamflow from the pastures and fields of the watersheds through grassed channels on native rangelands and through 1-acre ponds further reduced concentrations of nitrates, and dramatically reduced levels of phosphorus, coliform bacteria, and other bacteria before the streamflow entered a river. ARS Scientists in Georgia also examined the impact of farm ponds and associated stream buffers on losses of *E. coli* and *Enterococci* bacteria from grazing lands. Numbers of microbes in the stream above a pond were elevated by grazing animals but numbers in the outflow of the pond were lower than observed in a wooded creek without domestic animals (Fisher et al., 2000; Stuedemann et al., 2004). Positioning livestock in the landscape above a pond during periods in which runoff is likely may provide a means of limiting losses of pathogens from grazing systems to the environment. Native grass channels and ponds appear to be economical and effective conservation practices for mitigating impacts of livestock production on surface waters and enhancing water quality.

Mitigating livestock impacts on groundwater where recharge is rapid. Grazing animals are known to influence surface water quality but impacts of livestock waste on groundwater, particularly in areas underlain by limestone or fractured bedrock, are not well understood. ARS scientists in West Virginia found animal waste was a primary contributor of groundwater contaminants including nitrate (Boyer and Alloush, 2001; Ritchey et al., 2003), pathogens (Boyer and Kuczynska, 2003; Kuczynska et al. 2003), phosphorous (Alloush et al., 2003), and sediment. They developed a technique to quantify *Cryptosporidium* oocysts in environmental water to assess grazing effects on water quality. Sampling in open pastures and silvopastures indicated water quickly reached the soil/bedrock interface. On ungrazed, forested sites, however, water did not reach the interface as quickly as in sites that were grazed. Water transported fecal pathogens that could reach aquifers in stress-relief fractured sedimentary bedrock. Hydraulic models were developed to provide a predictive understanding of groundwater impacts by grazing animals on complex landscapes (Springer et al., 2003). Management practices based on information derived from these models have helped to maintain good groundwater quality (Boyer, 2005).

ARS locations and cooperators: Beaver, WV; Brooksville, FL; El Reno, OK; Watkinsville, GA; University of Central Oklahoma.

(B) Problem Area: Grazing Impacts on Ecosystems

Grazing does not cause nutrient loading of sandy soils. Pasturelands are considered a major source of phosphorus pollution in Florida because of the large acreage they occupy. Long-term buildup of nutrients such as P and N in the soil around and beneath cattle congregation sites (water troughs, mineral feeders, and shade) in mature pastures has been implicated in water quality issues. ARS scientists in Florida determined changes in soil fertility levels due to hay and grazing management in beef cattle pastures over a 15-year period. In deep sands of central Florida, soil fertility levels showed a declining trend for the levels of P and other crop nutrients. Overall, there was no spatial or temporal build up of soil P or other crop nutrients despite the annual application of P containing fertilizers or daily in-field loading of animal waste (Sigua et al., 2003a; Sigua et al., 2003b). Regardless of distance to the congregation site, the soils were not found to be nutrient rich. In a separate study with collaborators from the University of Florida and Arcbold Research Station, ARS scientists examined the effect of cattle stocking rates on phosphorous loadings, forage production, animal performance, and ranch economics in southern Florida. When compared to the ungrazed control, none of the stocking rates evaluated caused increased phosphorus loading, but the higher stocking rates increased net income (Sigua et al., 2004). This information facilitates the development of baseline nutrient levels for use by action agencies and local and regional government agencies.

Nitrogen and phosphorous accumulation and leaching from pasture soils. ARS scientists studying various bermudagrass management systems in Georgia found no difference in inorganic nitrogen accumulation in soils whether fertilizer was from inorganic, clover plus inorganic, or poultry litter sources. Fertilization strategies had similar effects on soil nitrogen, but grazing returned feces to soil and led to the highest accumulation of total nitrogen, which was composed mostly of particulate organic nitrogen (Franzluebbers and Stuedemann, 2003). Little evidence could be found of leaching of inorganic nitrogen, suggesting that high nitrogen input can increase soil fertility of intensively-managed pastures while posing little risk of groundwater contamination. Grazing of pastures with cattle may be a preferred alternative to haying or other approaches to harvesting forages if the goal is to enhance retention of nitrogen within a landscape.

Long-term effects of grazing and fertilization on soil quality. Long-term sustainability of grazing-based livestock production depends on developing an understanding of the effects of management on soils of pastures supporting a variety of forages. Physical, chemical and biological soil properties were combined with animal and plant data and compared for a long-term native grass exclosure, a moderately grazed native pasture, a heavily grazed native pasture established in 1916 and a fertilized crested wheatgrass pasture established in 1932 near Mandan, ND. Heavy grazing increased soil bulk density and shifted species composition compared to moderate grazing on the native pastures, and soils of the fertilized crested wheatgrass contained higher total N, organic C, and N-mineralization rates compared to the native pastures (Weinhold et al., 2001). Forage decomposition rates from monocultures of improved grasses were compared with native grasses in undisturbed stands. The improved grass monocultures decomposed faster than the native grasses in the undisturbed stands, returning nutrients to the soil more rapidly (Hendrickson et al. 2001). These indicators suggest that conventional management practices such as moderate grazing on native rangelands and fertilization of crested wheatgrass are sustainable management options in the northern Great Plains.

Grazing and forage management influence soils and runoff. Research conducted at El Reno, OK, in collaboration with colleagues at the Samuel Roberts Noble Foundation at Ardmore, OK, demonstrated that grazing may have impacts on soil and water quality. Grazing native tallgrass prairie at stocking rates ranging from light to heavy increased compaction of the soil, but only at the surface, relative to ungrazed rangeland. The compaction reduced water infiltration rates, negatively influencing soil water availability (Daniel et al., 2002). Grazing winter wheat pastures also caused compaction of the upper few inches of soil (Daniel and Phillips, 2000), and grazing increased the proportion of rainfall that left the pastures as runoff water (Daniel, 2003). The runoff from grazed wheat pastures was reduced if a summer legume was grown and grazed between wheat crops, which increased the efficiency of use of rainfall relative to grazing wheat alone. More intensive approaches to forage production do not appear to worsen soil compaction problems and may enhance water use in the Southern Great Plains.

Grazing enhances carbon content and biological activity of surface soil. New knowledge concerning effects of forage management strategies on carbon cycling is important to the understanding of greenhouse gas emissions, agronomic productivity, and changes in soil quality. ARS scientists in Georgia evaluated grazed pastures during 4 years for effects on particulate and biologically active carbon pools. Whether fertilization was from organic or inorganic sources had no effect on soil organic matter pools, whereas soils of pastures grazed by cattle grazing accumulated twice as much particulate and biologically active carbon pools than did unharvested pastures or those harvested for hay (Franzluebbers and Stuedemann, 2003a). Cattle grazing has the potential to enhance soil quality (Franzluebbers et al., 2001, 2004 b) and the biological activity of soil. Those changes were shown to enhance the level of environmental management (Stuedemann et al., 2004; Franzluebbers et al., 2004a; Franzluebbers and Stuedemann, 2005) and were directly related to greater forage productivity (Franzluebbers et al., 2004c).

Grazing enhances both organic and inorganic soil carbon contents. Research on carbon (C) storage in rangelands has focused on the influence of management practices on organic C storage in the soil, but inorganic C is a major component of soil carbon in many arid and semi-arid rangelands. ARS scientists in Colorado found that the masses of both organic and inorganic C in a shortgrass steppe were higher in the soil profile under heavy grazing than where livestock grazing was excluded, and that inorganic C represented proportionally more (69%) of the difference in soil C than did organic C (31%) (Reeder and Schuman, 2002; Schuman et al., 2002; Reeder et al., 2004). These results provide additional evidence that grazing does not adversely affect soil quality. They also emphasize the importance of including analyses of inorganic C in assessments of the influence of grazing management on C sequestration and dynamics in arid and semi-arid grazing lands.

Avoiding excess phosphorus in dairy cattle feed eliminates accumulations of phosphorus in soils. Dairy producers need supplemental feeding procedures which efficiently and economically meet cattle nutrient requirements while at the same time minimizing potential adverse environmental effects from excessive nutrients in manure. A survey of farms in the upper Midwest found that dairy producers frequently feed excess supplemental phosphorus because of a current myth that dairy cattle must be fed above recommended levels to prevent the loss of milk production and poor reproduction (Powell et al., 2002). ARS scientists in Wisconsin found recommended levels easily met the animal's needs for milk production and reproduction without using phosphorus from the bone (Wu et al., 2001). A study of cornfield applications of ^{15}N labeled dairy manure indicated 13 to 22% of the nitrogen was taken up in the harvested corn silage while 50 to 65% of the nitrogen remained in the top 3 feet of the soil. Avoiding excessive phosphorus supplements in dairy diets resulted in a better balance of nitrogen and phosphorus in the manure so plant uptake of phosphorus was more complete (Powell et al., 2001). Results suggested that reducing phosphorus supplementation to recommended levels would save the U.S. dairy producers $100 million annually in direct costs and reduce by 60% the number of farms where the phosphorus in manure exceeds the phosphorus used by crops. In a comprehensive analysis of 100 and 800-cow dairy farms located in a phosphorus restricted watershed in southern New York, management changes that maximized the use of forage grown and fed on these farms were found to eliminate the long-term accumulation of soil phosphorus while improving farm profit (Rotz et al., 2002). These studies demonstrate that management alternatives are available that reduce accumulations of nutrients in agricultural soils.

Effects of manure slurries and fed grains on forage and livestock diets. ARS scientists in Wisconsin demonstrated that the amount of dairy manure slurry applied to pastures interacts with geographic location, soil type, and soil fertility to cause large spatial variation in the mineral contents of pasture forages. Concentrations of some minerals were high enough to cause nutrient imbalances in the cattle and metabolic problems such as grass tetany or milk fever (Soder and Stout, 2003). This large variability emphasizes the need for a comprehensive forage testing and ration balancing program on farms to ensure proper mineral nutrition of grazing livestock. A comprehensive whole farm analysis showed that increasing the amount of grain fed to grazing cows increased profitability with no adverse environmental effects. Thus, dairy producers that rely upon grazing as a major source of forage should take advantage of inexpensive grain to increase milk production (Soder and Rotz, 2001, 2003). As a supplement to grazing, feeding grain in a partial mixed ration improved annual farm profit by $230/cow compared to feeding a separate concentrate.

Climatic and grazing effects compared. Environmental effects, such as climatic variability, are often confused with and attributed to livestock grazing. ARS scientists in Oklahoma completed a 20-year experiment assessing the impact of livestock grazing on forage production and weed populations. They found that the commonly held belief that weeds increase and forage production declines significantly as grazing intensity increases is not valid in their region. Climatic fluctuations over the years had a much more significant impact on forage production than did any reasonable levels of livestock grazing (Gillen and Sims, 2002; Northup et al., 2002; Gillen and Sims, 2004; Northup et al. 2004). These studies indicate that maintaining efficient grazing levels and ecological integrity are not incompatible goals.

Grazing during and after drought. Perennial forage grasses in the Northern Great Plains are often grazed under water-limiting conditions. The effects of defoliation and soil moisture dynamics on herbage yield, tiller recruitment and number of crown positions for two perennial forage grasses were evaluated in a greenhouse experiment by ARS scientists in North Dakota. In this experiment, undefoliated plants had 1.6 times as many tillers as the moderately defoliated plants and 2.7 times as many tillers as the severely defoliated plants. Water stress mainly affected tiller size, not tiller numbers (Hendrickson and Berdahl, 2002). Results need to be validated in the field, but they suggest that grazing management in the period following drought may be as critical to long-term persistence as grazing during the drought period.

Riparian areas are not impacted by proper grazing management. Conflicts over the sustainability of livestock grazing along streams are difficult to resolve because the effects of grazing intensity on herbaceous riparian vegetation are not well understood. ARS scientists in Oregon found riparian plants could re-grow and meet riparian ecological standards after being grazed by livestock. Previous research had shown that too much forage removal or grazing late into the summer tended to limit re-growth excessively. This 3-year study demonstrated adequate re-growth occurs if grazing ceases in June when a plant height of 2 inches is left. If grazing continues into July, more than 2 inches may be desirable (Boyd and Svejcar, 2004). This information will help public and private grazing managers develop grazing management plans that will provide forage for livestock while maintaining riparian ecological health.

Early spring grazing after juniper felling. Information on livestock grazing after juniper cutting is needed by land managers to make informed decisions in order to maximize herbaceous plant recovery. ARS scientists worked with the Otley Brothers Ranch in Eastern Oregon to evaluate effects of early spring grazing following juniper felling on sites (Bates 2005). Early spring grazing had no impact on recovery of existing herbaceous plant cover and density. Early grazing was, however, detrimental to seed production under the felled-grazed treatment when compared to the felled-ungrazed treatment. The felled-grazed treatment, consequently, has the potential to limit future site recovery. This research is assisting managers in developing grazing prescriptions after treatment of juniper-dominated grazinglands and has provided an important foundation for generating additional grazing research on treated rangelands.

Exclusion from grazing adversely affects plant species diversity. Maintaining high plant biodiversity can enhance many ecosystem functions including productivity, resistance to and recovery from environmental stresses, and resistance to weed invasions. Responses of plant species diversity to differing levels of livestock grazing, however, are poorly understood, as are grazing animal responses to differing levels of plant biodiversity. Long-term stocking rate studies conducted by ARS scientists on western rangelands, including exclusion from grazing, indicate species richness and evenness were greatest in light and moderately grazed areas and lowest in non-grazed areas (Hart, 2001). Exclusion from grazing appeared to increase the presence of introduced species including annual weeds. Planting of eastern pastures to high levels of plant biodiversity resulted in fewer weeds (Tracy and Sanderson, 2004; Tracy et al., 2004) and in increased forage production, especially during periods of drought (Krueger et al., 2002; Sanderson et al., 2004; Sanderson, et al., 2005; Skinner, 2005). Dairy cattle grazing diverse pastures in Pennsylvania had similar dry matter intake and milk production as those grazing more traditional grass/legume mixtures (Sanderson et al., 2005). Vegetation sampling techniques have been compared to ensure that pasture biodiversity can be accurately evaluated across locations (Goslee, 2005). These studies suggest that well-managed grazing lands can maintain higher levels of biodiversity than if grazing is excluded and that diverse grazing lands can better resist weed invasion and maintain high levels of livestock productivity.

Grazing and wildfire interact to influence biodiversity. Potential impacts of grazing on plant biodiversity are hotly debated, but little data have been gathered to illuminate the debate. ARS scientists in Idaho quantified plant biodiversity on lands where a wildfire in 2000 burned paddocks that had been grazed differently for the previous 50 years (Seefeldt and McCoy, 2003). Two years after the wildfire, there was no evidence that biodiversity was affected by timing of grazing (fall vs. spring) before the fire or grazing versus not grazing after the fire, although the time of grazing shifted plant populations toward or away from invasive weeds. These results contributed important information to the debate about biodiversity, the way biodiversity is measured, and the consequences of grazing. ARS transferred this information to Forest Service and Bureau of Land Management personnel who are using it to make land management decisions.

Managing Vegetation with Grazing. Mountain big sagebrush canopies can become too dense, suppressing other vegetation needed for grazing. At the U. S. Sheep Experiment Station, sheep with a high dietary preference for mountain big sagebrush were compared with sheep with a low dietary preference in their ability to reduce the canopy of a dense stand of mountain big sagebrush (Seefeldt, 2005). There was no difference in the reduction of mountain big sagebrush canopies between the two types of sheep; however, the high preference sheep consumed more antelope bitterbrush, an important plant species in sagebrush steppe rangelands. This research documents the care that must be taken to determine the consequences of altered diet selection for one plant species.

Grazing influences evapotranspiration (ET). In the semi-arid areas of the northern Great Plains, water limits forage production. ARS scientists in North Dakota determined how alternative forage management systems affect ET rates. They compared over 3 years the response of an ungrazed mixed-grass prairie, a grazed mixed-grass prairie, and a grazed western wheatgrass pasture. Growing season ET for the grazed mixed prairie was 7% lower than for the non-grazed prairie and 8% lower than that of the western wheatgrass pasture. Results indicate that a properly grazed prairie with considerable biodiversity uses water more efficiently than an ungrazed prairie and a grazed grass monoculture.

Grazing at sustainable levels can benefit plants important to wildlife. Concerned about the effects of livestock on wildlife habitat in the Great Basin, scientists with ARS, BLM, and the Oregon Department of Fish and Wildlife studied the impact of livestock grazing on antelope bitterbrush in Oregon. This shrub is an important wildlife forage species because its nutritional value remains high throughout the late summer and winter when other forages are of low quality. These scientists compared excluding livestock grazing with the effects of light and heavy spring cattle grazing (Ganskopp et al., 2004). They found that with light spring stocking rates, cattle focused on grazing the grasses intermixed with the bitterbrush. Under these conditions, reduced competition with the grasses stimulated bitterbrush growth. On average, the shrubs grew 11% taller and 27% wider than the shrubs in the ungrazed stands. This study demonstrates that livestock grazing can benefit wildlife habitat when science-based management strategies are developed and applied.

Simulating management impacts on sage grouse. Sage grouse are declining in numbers throughout their native range. A model was developed by ARS scientists in North Dakota and Idaho in collaboration with Texas A&M University and the Idaho Department of Fish and Game that simulates the effect of grazing and fire on temporal and spatial aspects of sagebrush community vegetation and sage grouse population dynamics. Results suggest high-frequency, large-scale fires may contribute to the extinction of sage grouse populations, and that sheep grazing may contribute to the decline but is unlikely to cause the extinction of sage grouse (Pedersen et al., 2003). The publication of this model was used to determine that sage grouse should not be listed as an endangered species.

ARS locations and cooperators: Boise, ID; Brooksville, FL; Burns, OR; Cheyenne, WY; Dubois, ID; El Reno, OK; Fort Collins, CO; Madison, WI; Mandan, ND; University Park, PA; Watkinsville, GA; Woodward, OK; Bureau of Land Management; Oklahoma State University; the Samuel Roberts Noble Foundation at Ardmore, OK; Otley Brothers Ranch of Oregon; Oregon Department of Fish and Wildlife; Oregon State University; Texas A&M University; University of Florida.

C. Problem Area: Management, Behavior and Production of Grazing Livestock

A new tool for estimating biomass of woody species. No repeatable and reliable techniques for measuring browsing impacts on willows are available to public and private land managers. ARS scientists in Oregon tested a photographic technique for estimating willow biomass and utilization that relied on computer-derived estimates of percent visual obstruction of a photoboard. Results suggested this technique accurately estimated willow biomass and disappearance of biomass associated with simulated browsing, while minimizing sampling error (Boyd and Svejcar, 2005). This field technique provides managers with a clearly defined tool for monitoring willow biomass and utilization that will be useful in developing grazing systems and adjusting stocking rates.

Lower stocking rates maximize economic returns and environmental benefits. Stocking rates are considered the most important factor in determining the sustainability of rangeland grazing on the Great Plains. ARS scientists in Oklahoma analyzed the interrelationships between cattle stocking rates, economic performance, and potential environmental impact on sand sagebrush range (Gillen and Sims, 2002). They found stocking rates that maximized calf production per cow or acre did not maximize net economic returns. This research demonstrates that lower stocking rates can be both economically and environmentally sustainable.

High-tech control of livestock distribution. Fences are the principal means of controlling livestock distribution on rangeland but these structures are inflexible and expensive to construct. A device worn externally by cattle has been developed and patented by ARS scientists in New Mexico for autonomous control of grazing livestock location and containment (Anderson and Hale, 2001; Rango et al., 2003; Anderson, 2004). Signals and hardware are activated through a computer system linked to satellite-based global positioning systems. Stimulation is triggered based on location programmed into a geographic information system as a cue to change in location. Stimuli are programmed to be administered only when an animal penetrates a predetermined boundary. The device is being licensed by a private company for eventual production. It has the potential to control livestock distribution on rangelands without the need for traditional fencing.

Livestock preferences allow new approaches to grazing management. Understanding how livestock utilize forages can provide valuable insight into designing grazing systems. A cafeteria grazing system that allowed livestock free-choice between introduced forage pastures and native rangeland was compared to monoculture pastures of introduced forages and native rangeland to evaluate animal preference and performance by ARS scientists in North Dakota. Animal performance varied by year but over the 3 years of the study, average daily gain was higher on the free-choice system than on native range or crested wheatgrass pastures (Karn and Ries 2002). Livestock preference for forage species changed throughout the season. This research showed that cattle will rotate themselves among various pasture types if allowed access to different forages, which raises the possibility that the need to fence smaller pastures separately might be eliminated (Fehmi et al. 2002).

Grazing enhances late-season forage quality. Pacific Northwest and northern Great Basin rangeland grasses that are ungrazed during a growing season become nutritionally deficient for stock by mid summer and will not sustain cattle gains. ARS scientists in Oregon and their cooperators with Oregon State University examined the effects of grazing exclusion and season of cattle grazing on fall and winter nutritional characteristics of 6 prominent rangeland grasses (Ganskopp et al., 2004). Cattle grazing reduced fall standing crop by 32 to 55% but increased forage crude protein content and digestibility in late summer and early fall. These results demonstrated that managed seasonal cattle grazing can be used to improve late summer and fall nutritional value of grasses with findings benefiting rangeland managers striving to generate high quality, late season forage for cattle or wildlife.

Calving and weaning dates affect beef cattle performance. Effects of calving and weaning dates on cow-calf performance are not well understood. ARS scientists in Montana investigated effects of calving during late winter, early spring, and late spring and the effect of two weaning dates on cow and calf performance in a rangeland-based beef operation in the Northern Great Plains. Results indicate choice of calving season can have large effects on product outputs (Grings et al., 2003). Calf weaning weights were affected by both time of calving and age at weaning. Careful consideration of all goals is required in choosing the optimal calving time for a specific enterprise. Calves with greater weights at weaning may be produced from herds that also have greater feed inputs, therefore, feed costs need to be weighed against calf prices to determine optimum calving time.

Calving dates influence milk yield of beef cows and growth of calves. Milk yield of the dam is a major determinant of growth rate in beef calves but yield may be affected by a number of factors. ARS scientists in Montana evaluated the milk yield of first-calf heifers born and raised within three calving systems and the impact on growth of their calves. Heifers whose calves were born in late winter through early spring differed in their milk yield from those born in late spring (Grings et al., 2005). Precipitation pattern for the year influenced whether the milk yield for heifers calving in late spring was greater or lesser than earlier calving heifers. Calf growth rate was well related to milk yield. Understanding the impacts of calving date on amounts and patterns of milk production can aid in developing management systems to best match nutrient needs of cow-calf pairs in different calving systems.

Economic implications of alternative beef production systems. In cow-calf beef production systems, management decisions are driven by possible economic outcomes, which are based upon the balance of cow-calf performance outputs and cost of inputs. Research in many regions of the US has shown that feed costs are often the largest portion of input costs in production systems. ARS scientists from Montana and Oklahoma collaborated with researchers at Montana State University to conduct research to identify calving seasons and strategies of weaning and marketing that match the nutrient needs of the animals, reduce input costs, and optimize economic outcomes (Kruse et al., 2004). Using ARS data from livestock production studies, researchers at MSU conducted an economic study on cow-calf beef production systems utilizing different seasons of calving, weaning strategies, and retained ownership options. Cow-calf production systems selling weaned calves from late spring systems yielded higher ranch gross margins than all other systems. This was primarily due to the increase in feed costs for late winter or early spring calving systems. When steer calves were backgrounded after weaning, systems utilizing late spring calving yielded higher gross margin than those calving in late winter or early spring. Although feed and transportation costs differed among backgrounding options, no differences were found in cumulative gross margins among backgrounding options within calving season. This was primarily due to differences in the cost of weight gained by steers in the backgrounding phase and timing of sale. This research provides useful guidlines for producers struggling with the complex interactions of various production options.

"Intensive early stocking" is an effective approach to grazing management. Intensive early stocking (IES) was developed to allow native warm-season grasses to be harvested while forage quality is high early in the summer growing season. Managers stock the rangelands for only the first half of the grazing season but at twice the season-long stocking rate. ARS scientists demonstrated that grazing rangelands early with stocker cattle is advantageous in comparison to season-long grazing on tallgrass prairie near El Reno, OK, and on northern mixed prairie near Miles City, MT (Grings et al., 2002; Phillips et al., 2003). Stocker calves produced more gain per acre when managed under IES than under conventional management. EIS was generally no more profitable than conventional stocking, even though EIS reduced fixed costs and enhanced flexibility in marketing cattle in comparison to season-long grazing.

Reducing risk in decision-making for cow/calf producers and rangeland managers. A modeling approach that assesses impacts of alternative management decisions prior to field implementation would reduce decision-making risk for rangeland and livestock production system managers. ARS scientists in Wyoming and Colorado evaluated the Great Plains Framework for Agricultural Resource Management (GPFARM) model in simulating forage and cow-calf production in the Central Great Plains. The GPFARM model has functional utility for simulating forage and cow-calf production with satisfactory accuracy at semiarid-temperate sites, such as southeastern Wyoming and northeastern Colorado (Andales et al., 2005). Continued development will focus on improving plant response to environmental stresses and testing the model's functionality as a decision support tool for strategic and tactical ranch management.

A simulation model for beef cattle performance in the feedlot. Beef cattle producers lack a predictive understanding of how stocker cattle will perform in the feedlot. ARS scientists in Arkansas, cooperating with researchers from Texas A&M University, developed a model to predict stocker cattle performance in the feedlot in terms of percent retail product, marbling score, and carcass hot weight. Field tests of the model indicate that animal data gathered at the end of the grazing phase can aid in predicting the economic value of feedlot finishing (Aiken et al., 2004). Such information will be especially helpful to stocker producers who are considering retaining ownership through the feedlot phase.

Farm model to aid strategic planning in integrated crop, beef and dairy cattle operations. Farmers are asked to manage increasingly complex agricultural systems to achieve economic and environmental sustainability but they lack appropriate decision-support tools needed for the task. ARS scientists in Pennsylvania developed and released a whole-farm simulation model to aid in integrating crop, dairy and beef production systems more efficiently (Rotz et al., 2005). The new model release added beef animal production and updated the dairy animal component with new knowledge on feed intake, growth, and manure excretion. Process-based relationships were also added to predict ammonia emissions and phosphorus runoff loss from farms. The farm model was used to evaluate the economic feasibility of using automatic or robotic milking systems on dairy farms with 30 to 270 cows (Rotz et al., 2003). Given current technology and costs, the automatic systems appeared to provide long-term economic benefits only on farms with 50 to 60 cows. Such models help managers and consultants assess the economic and environmental outcomes of incorporating new technologies and strategies prior to making substantial investments.

Swathed annual forages for overwintering beef cattle. Beef production, the major livestock enterprise on the Northern Great Plains, can experience high input costs and occasionally low profitability. A multi-disciplinary team at Mandan, ND has evaluated the use of swathed annual crops as an alternative method of overwintering beef cattle. Rainfall during the project was unusually high, but costs per head per day were $0.24 lower with the swathed annual crops compared to drylot. Additional environmental and economic savings may be realized because of distribution and direct deposit of manure and feed waste on the crop field. The main challenges associated with the swathed crops were snow depth, icing of the windrow, and need for some expensive farm equipment (Tanaka et al. 2005). Use of crops and crop residue to overwinter cows requires the producer to evaluate livestock as well as crop needs. Research into alternative beef production systems will provide producers with low-cost options as well as potentially enhance environmental benefits (Karn et al. 2005).

New insights into silvopastoral tree, forage, and beef production. The complex terrain of mountainous regions creates a wide range of microsite conditions supporting diverse vegetation functional groups. Forage-livestock enterprises are well suited to these regions, but the landscape and growing conditions complicate management practices and decisions which frequently involve integrating pasture and forest resources. ARS scientists in West Virginia studied the relationship between conifer tree growth and forage production in silvopastoral systems. Both tree height and diameter increased faster on trees planted in improved pasture than in traditional forestry plantings (Garrett et al., 2004). Silvopasture sites can be established successfully by planting in summer and grazing in the following year (Neel at al., 2003). Sward productivity and nutritive value can be sustained by maintaining greater residual, post-defoliation biomass. Forage production is reduced but nutritive value, in terms of the energy–protein quotient, is improved in modest shade relative to open sites. Forage grasses adapted to full-sun systems are productive and persistent in partial shade (Belesky, 2005). However, forage production decreased linearly as the diameter of tree trunks increased. Depending on tree spacing and growth rates, forage production could drop to near zero within 20 years of tree planting (Ares et al., 2003; Burner and Brauer, 2003; Brauer et al., 2004). Growing ruminants achieve comparable average daily gains on silvopasture relative to full-sun pasture; however, reduced herbage productivity restricts stocking density so that livestock production per unit land area is less. These results provide important insights into management of silvopasture systems, which often differs substantially from traditional pasture management.

ARS locations and cooperators: Beaver, WV; Booneville, AR; Burns, OR; Cheyenne, WY; El Reno, OK; Fort Collins, CO; Las Cruces, NM; Mandan, ND; Miles City, MT; University Park, PA; Woodward, OK; Montana State University; Oregon State University; Texas A&M University.

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COMPONENT V
INTEGRATED MANAGEMENT OF WEEDS AND OTHER PESTS

There are five problem areas in this component: (A.) Invasive and Noxious Weeds; (B.) Poisonous Plants; (C.) Tall Fescue Toxicosis; (D.) Destructive Insects; and, Problem Area E: Lack of effective spatial information technologies to monitor and assess pest populations.

(A.) Problem Area: Invasive and Noxious Weeds.

Ecology and competition: Development of effective weed control and revegetation techniques requires an expansion of basic knowledge of the biology and ecology of both desirable and undesirable (weedy) plant species. Both the competitive ability of the invaders, and the invaders impacts on rangeland ecosystems depend on interactions with key plant resources. For example, early spring growth is an important characteristic to consider when developing perennial plants to compete with exotic species. *Tamarix,* or saltcedar, is one of the most deleterious, exotic invaders of riparian areas in the western U.S. due to its high water use, and negative impacts on soil salinity and native plant and animal species. However, in many eastern U.S. states and all of Canada, previous claims of invasive saltcedar were actually misidentified or non-naturalized specimens (Gaskin 2003; Gaskin and Schaal 2003). ARS scientists have also evaluated the impact of soil water availability on competition between leafy spurge and grasses (Rinella and Sheley 2005a,b,c). A model is being developed that predicts the susceptibility of rangelands to weed invasion using processes that incorporate precipitation, vegetation gaps and livestock grazing. Atmospheric CO_2 concentrations can also influence invasion. Increasing CO_2 concentrations dramatically increased the growth of cheatgrass (*Bromus tectorum*) (Ziska et al. 2005). The increase in cheatgrass growth is an important factor explaining the increase in fires on western sagebrush rangelands.

Invasive plants also interact with soil erosion and fertility. For example, significant soil erosion has occurred in areas where junipers have exceeded their natural habitat (Miller et al. 2005; Pierson et al. 2003). Invasive weeds have been shown to affect nutrient cycling and soil properties (Blank and Young, 2003; Blank and Young, 2004). Plant growth increased the soil enzymes responsible for N, S, and P mineralization (Blank, 2004) and *Lepidium latifolium* an invasive weed on wetlands and riparian areas uses increased N availability to out compete native species (Blank, 2002). Similarly, experiments in which N availability has been reduced have shown that low N inhibits invasive annual weeds more than native perennial grasses (Blumenthal et al., 2003, Monaco et al., 2003). Also, early data from a reciprocal garden experiment between locations in the U.S. and France, suggest the invasiveness of medusahead may be linked to greater phosphorus availability in US soils. This information can be used to develop ways to manipulate succession on degraded rangelands to enhance restoration efforts.

Noxious Weed Management: ARS scientists have cooperated to develop new methods to mange noxious weeds on rangelands. Leafy spurge (*Euphorbia esula*) is a highly invasive plant that infests more than 5 million acres in the US and is estimated to cause more than $144 million dollars in damage in Montana, Wyoming, North Dakota and South Dakota alone. Leafy spurge displaces native vegetation, reduces cattle grazing and wildlife habitat, and decreases rangeland plant diversity. An area-wide program (TEAM Leafy Spurge) involving federal, state and local agencies, private and public land owners were organized to develop and disseminate weed management techniques for leafy spurge across a four state area. Using a combination of biological control, grazing, burning and herbicide applications, this program has resulted in large and widespread reductions of leafy spurge, producing economic benefits estimated at more than $6.7 million (Anderson et al. 2003a, b; Prosser et al., 2002). A model is currently under development to help producers estimate the impact of leafy spurge on grass production.

ARS scientists have found that as the duration of grazing decreases and stocking density increases, sheep will graze reproductive parts of exotic and invasive leafy spurge (Euphrobia esula) more than stem and leaf portions (Taylor et al., 2005). The current season-long grazing strategies recommended to manage leafy spurge negatively impact native plant species and can promote recruitment of other exotic species. Application of 480 sheep grazing-days equivalent during a 48-hour period caused a 50% decrease in standing leafy spurge flowers relative to 480 sheep grazing-days during a 192-hour period; remaining total biomass and sheep performance was similar between the two strategies. Short-duration high-density sheep grazing is a biocontrol tool that targets the reproduction of leafy spurge while minimizing negative grazing effects on native species.

The broadcast application of herbicides on rangelands to managed invasive plants is often too expensive. Therefore other control methods are being evaluated. Biological control has high potential in weed management programs on rangelands because it can permanently reduce weed populations, does not require expensive technology, and is ecologically non-disruptive. Preliminary data from a common garden experiment provided strong evidence that invasive plants appear to evolve and lose defenses in favor of competitive traits suggesting that poor defenses may make some invaders particularly susceptible to biological control. Biocontrol agents and practices for exotic rangeland weeds such as saltcedar and leafy spurge are being developed (Kremer et al., 2004; Caesar et al., 2002; Caesar, 2003). Highly specific leaf feeding beetles (*Diorhabda* spp.) have been established in several test sites in the western US but have been variably effective at reducing saltcedar growth (Dudley and Kazmer, 2005).

Burning is another important management tool for use in controlling invasive species. Burning is an effective tool in restoring riparian areas with shallow water tables but riparian areas with deeper water tables may need a combination of fire and reseeding (Blank et al., 2003). Exposure to sagebrush smoke improved growth of some native and introduced grasses (Blank, 2001). Grazing management of rangelands impacted by invasive plants can be especially challenging. Early spring grazing following juniper cutting had no impact on recovery of existing herbaceous plant cover and density when compared to ungrazed treatments. However, early grazing was detrimental to seed production on the cut-grazed treatment when compared to the ungrazed cut treatment; a factor that may limit future site recovery (Bates, 2005). A model has been developed that predicts responses of leafy spurge and grass to management (Rinella and Sheley, 2005b, c).

Locations and Collaborators: Boise, Burns, Cheyenne, Dubois, Logan, Miles City, Reno, Sidney.

(B.) Problem area: Poisonous Plants

Plant compounds: Cyclopamine is a toxic substance found in *Veratrum californicum* or false hellebore. While this substance causes lamb malformations in sheep it may also block certain signaling pathways in certain cancers (Karhadkar et al. 2004). Individual alkaloids from lupines, poison hemlock, potatoes and Nicotiana spp. are also being tested for their toxicity (Lee et al. 2005; Wang et al. 2005). Relatively benign plants also can cause losses in some species of livestock. Switchgrass, a native perennial grass currently being evaluated as a potential biofuel, contains diosgenin which can cause death to sheep and horses grazing pure stands of switchgrass (Lee et al. 2001).

Swainsonine, a toxic alkaloid in locoweed, adversely affects fetal health and disrupts the estrus cycle in females and causes male infertility (Stegelmeier et al. 2004; Stegelmeier et al. 2005). A method to measure the toxic alkaloid, swainsonine, in plant material was developed (Gardner et al. 2001). Cooperative research found high correlations between an endophyte and swainsonine concentrations (Gardner et al. 2003) and demonstrated the endophyte is needed for swainsonine to be present (Ralphs et al. 2002a). Defoliation of locoweed did not affect its vigor, persistence or toxicity (Ralphs et al. 2002b). Research indicates that horses can be conditioned to avoid eating locoweed (Pfister et al. 2002a).

Larkspur poisoning: Poisoning by larkspurs (*Delphinium spp.*) causes numerous cattle losses in the western range states. Characterization of additional toxic larkspur species was done using electrospray mass spectrometry and/or liquid chromatography (Gardner and Pfister, 2000; Gardner et al., 2000). Genetic evaluation using DNA markers of tall larkspurs classified *D. occidentale, D. barbeyi* and *D. glaucum* as distinct species (Raphs et al., 2000; Pfister et al., 2002b; Panter et al., 2002). These results were integrated to show how knowledge of taxonomy, alkaloid concentration and other factors can be used to make informed management decisions. Competitive inhibition enzyme-linked immunosorbent assays (CI-ELISA) were developed for larkspur alkaloids (Lee et al., 2003). These assays will assist in developing rapid, sensitive and specific approaches to identify poisoned animals and help determine which plants under what growing conditions are likely to poison livestock. Alkaloid concentrations in larkspur are diluted as biomass increases during the growing season (Ralphs et al., 2002) but sheep grazing prior to cattle grazing does not appear to reduce risk for livestock producers with dense low larkspur concentrations (Pfister et al., 2001; Lauchbaugh et al., 2001; Pfister et al. 2002c; Pfister et al., 2002d).

Poisonous plant effects on livestock: Noxious weeds can also influence the ruminal dynamics of cattle. Cooperative research with South Dakota State University has identified chemicals that may cause cattle to avoid eating leafy spurge. Diterpene ingenols were also isolated from leafy spurge and one of these elicited a learned feeding aversion in cattle (Halaweish et al., 2002, 2003). Currently, rumen microbial DNA assays are being developed and cooperative work is proceeding with New Mexico State University to determine the diversity of rumen microflora when noxious weeds are digested. These results may provide means to strategically supplement cattle and increase their intake of noxious weeds like leafy spurge.

Other cooperative research with New Mexico State University studied the dose response and length of exposure effects of swainsonine on subclinical markers of intoxication and nutrient metabolism. Sheep ingesting 0.2 mg of swainsonine/kg of body weight showed minimal subclinical changes. Further, subacute ruminal, abomasal, and intravenous exposure to swainsonine had little impact on ruminal fermentation characteristics, total tract digestibility of nutrients, and nitrogen retention at exposure levels as high as 1.6 mg of swainsonine/kg of body weight. Animals may be able to graze locoweed-infested areas for short periods, as long as consumption does not regularly exceed 0.2 mg of swainsonine/kg of body weight daily (Obeidat et al., 2005). Oral exposure of withers to locoweed resulted in subclinical intoxication but did not have perceptible effects on para-aminohippuric acid serum concentrations or other pharmacokinetic parameters evaluated. Symptomatic tissue damage associated with swainsonine exposure as indicated by elevated levels of alkaline phosphatase and aspartate aminotransferase activities did not appear to have deleterious effects on the disposition of para-aminohippuric acid. Thus, use of para-aminohippuric acid as a measure of blood flow rates to aid in delineating effects of swainsonine on blood flow and nutrient flux through splanchnic tissues of ruminants appears to be an acceptable model (Strickland et al., 2005). Studies on the elimination of swainsonine from livestock found that swainsonine appeared in the serum and milk of lactating ewes and cows in a dose-dependent fashion following a single dose oral exposure. However, detectable levels of swainsonine or subclinical toxicity were not observed in the serum of nursing lambs or calves. To transfer a sufficient amount of swainsonine to lambs and calves via the milk to induce detectable levels of swainsonine (>0.025 g/mL) or subclinical toxicity in the serum, a single oral dose of swainsonine (locoweed extract) greater than 0.8 mg/kg BW to the lactating mothers must occur. The risk of swainsonine toxicity seems to be greater when nursing ruminants repeatedly select a diet containing locoweed in addition to ingesting milk contaminated with swainsonine (Taylor and Strickland, 2002).

Locations and Collaborators: Logan, Mandan; and, New Mexico State, South Dakota and Utah State Univ.

(C.) Problem Area: Tall Fescue Toxicosis

Detecting endophytes in forage grasses - Plants infected with endophytic fungi may display increased vigor and enhanced tolerance to a variety of stresses. While the beneficial effects of endophytes are desirable, the plant/fungus symbiosis results in the production of alkaloids that cause livestock toxicosis and limit the utility of these grasses in forage and pasture applications. ARS scientists developed an improved method to detect endophytes in seed and plant tissues from tall fescue and perennial and annual ryegrass (Dombrowski et al., 2005). This PCR method provides an accurate, sensitive approach for detecting the presence of the endophyte in these grasses, providing a valuable tool for researchers to assess the presence of the endophyte in available germplasm.

Bioassay of Vascular Toxicity Associated with Fescue Toxicosis. A number of alkaloids, including ergot and loline, are produced by endophyte-infected tall fescue, but is not clear which alkaloids, either in combination or singly, are directly responsible for the intoxication in livestock. Sorting out the toxins is further complicated by animals likely biotransforming many of these alkaloids to aid in elimination. ARS scientists in collaboration with University of Kentucky have validated a multi-myograph system using blood vessel rings taken from cattle as a bioassay for rapidly screening compounds for vascular activity (Klotz et al., 2005). During validation the scientists demonstrated that vascular tissue was viable for up to 72 hours after collection if stored at 2-8^{o}C in oxygenated Krebs-Henseleit media. Viability was confirmed using norepinephrine to induce contraction of the blood vessel rings before and after storage. Scientists also demonstrated that the right and left leg blood vessels that were selected for the bioassay did not react differently in the screening system. Preliminary experiments using this bioassay system indicate that the ergovaline, an ergopeptine alkaloid, is greater than 1000 fold more potent than lysergic acid. Lysergic acid does not appear to induce contractility of the vessels until one reaches supra-physiological levels (approximate 10^{-5} M concentration). Lysergic acid appears to be one of the bioconversion products of the more complex ergot alkaloids of the ergopeptine class. If these findings hold in follow-on experiments, and the conversion of ergopeptines to lysergic acid can be enhanced in the animal, then animal tolerance to endophyte-infected tall fescue might be enhanced. This bioassay provides another tool for determining the toxic components of endophyte-infected tall fescue and may provide a possible screening assay for potential prophylactic/treatment protocols for the intoxication.

Metabolism and elimination of tall fescue alkaloids in equids. Pregnant mares consuming endophyte(*Neotyphodium*)-infected tall fescue are at severe risk of developing "Equine Fescue Toxicosis" characterized by prolonged gestation, agalactia, increased foal and mare mortality, dystocia, placental aberrations, weak and dysmature foals, and altered hormone profiles. Solving the problem is limited by the lack of conclusive information concerning the identity of the toxicant(s) and their metabolism in horses. ARS scientists in collaboration with University of Kentucky are studying the biological fate of two candidate toxicants (ergovaline and lysergic acid). These researchers have compared initial exposure of naïve horses to ergovaline and lysergic acid to that following subacute exposure to measure effects on alkaloid retention and routes of elimination. They found length of exposure had little to no effect on alkaloid retention or route of exposure indicating that metabolic pathways and tissues associated with alkaloid elimination were not compromised or enhanced by prior exposure. Additionally, data indicated that approximately 60% of the ergovaline consumed was retained by the animal over a 24 hour period, whereas lysergic acid was eliminated from the animals in greater amounts (>180% of intake) than consumed. These data indicate that the more complex alkaloids such as ergovaline are likely converted to lysergic acid for elimination. (Schultz et al., 2004, 2005.) Therefore, methods to enhance this conversion, especially if lysergic acid proves to be less toxic than ergovaline, should improve horse tolerance to endophyte-infected tall fescue.

Improving management options for fescue toxicosis. Fescue toxicosis is estimated to cost the livestock industry over one billion dollars annually. Close and frequent defoliations of tall fescue with moderate to heavy grazing intensities will reduce the toxic alkaloid concentrations and the associated severity of the intoxication. Preliminary research has also demonstrated that cattle weight gains on endophyte-infected tall fescue are improved significantly when animals have a progesterone/estradiol benzoate implant, provided forage is not a limiting factor. Cattle suffering heat stress related to the fescue toxicosis can recover within 4 to 10 days, following a switch to a clean diet. This would suggest that the effects of the intoxication are not permanent and can be reversed (Aiken et al., 2004; Looper et al., 2004). These findings indicate the use of endophyte-infected tall fescue in forage-based cattle enterprises can be sustainable if the appropriate combinations of management protocols are implemented.

Scientists at the University of Arkansas in cooperation with the University of Missouri and ARS scientists have developed a cultivar of tall fescue which contains a novel endophyte fungus. This cultivar does not produce alkaloid toxins that reduce livestock performance. ARS scientists in cooperation with the North Carolina Agricultural Research Service evaluated hays from a novel endophyte introduced to Jesup tall fescue and found that the presence of the novel endophyte gave similar animal responses as Jesup when endophyte free and both better or similar to Jesup with a toxic endophyte (Burns and Fisher, 2006). Replacement of existing tall fescue pastures with this cultivar should increase the efficiency of livestock production in those areas of the USA where tall fescue is grown.

Maintaining tall fescue adaptation and persistence. Introduced forage tall fescue is adapted to a wide array of soil chemical and environmental challenges. Seed germination and seedling establishment are influenced by endophyte and depends on whether the endophyte is a product of a naturalized association or a novel non-ergogenic endophyte (Belesky and Burner, 2004). Herbage mass and allocation within developing seedlings was influence as well and would have some influence on the persistence and competitive ability of tall fescue serving as host to a modified endophyte race (Belesky et al., 2004). Introduced forage tall fescue also has the ability to tolerate soil chemical stresses (Malinowski et al., 2005a, b), which might be a factor in the adaptability of the species to a wide range of soils and growing conditions.

Locations and Collaborators: Beaver, Booneville, Corvallis, Lexington, Raleigh, Watkinsville; and, North Carolina Agric. Research Service, Univ. of Arkansas, Kentucky, and Missouri, Oregon State Univ.

(D.) Problem area: Destructive Insects

Eastern Tent Caterpillar and Mare Reproductive Loss Syndrome: Mare Reproductive Loss Syndrome resulted in an estimated $400 million loss to the Kentucky horse industry in 2001-2003. The Eastern Tent Caterpillar was identified via direct feeding studies as the causative agent and controlling these caterpillars became a priority (McDowell et al. 2003, Powell 2002, Sebastian et al. 2002). Both bifenthrin and permethrin were found to be effective as a winter treatment to prevent caterpillar emergence from egg masses while permethrin was effective as a foliage spray in pastures to control late-season caterpillars. Bidrin and emamectin injected into the trunks of cherry trees (food source for caterpillars) were also effective. (Stevens, et al. 2002; Riske 2004, Riske and Townsend, 2005) Recommendations including the removal of cherry trees from pastures and the use of pesticides have been distributed to veterinarians and horse owners so the next outbreak of Eastern Tent Caterpillars can be controlled prior to becoming a serious threat.

Grasshopper ecology and management: Grasshoppers consume an average of 21-23% of annual production across all rangeland ecosystems, causing considerable impact to the range livestock industry due to variation in available forage. Grasshopper populations fluctuate as a result of climatic and other factors, and their numbers can increase more than 10-fold during periodic outbreaks. Snakeweed grasshoppers, a North American species that feeds only on certain hosts in the Asteraceae plant family, exists as at least two genetically-distinct host plant-associated lineages that feed on different host plants in the western U.S (Sword et al., 2005a). These results suggest that both grasshopper and snakeweed management decisions must carefully consider the genetic history and host plant affiliations of grasshopper source populations. Predicting outbreaks of grasshoppers requires knowledge of how different ecological factors affect their population dynamics. Nymph-overwintering grasshopper species were found to reduce peak biomass only in a year with early summer drought conditions and survival of later hatching grass specialist pest species was not affected by these nymph overwintering grasshoppers (Branson, 2003; 2004). Bottom up factors and abiotic conditions may play a more important role in determining population growth of grasshoppers than top down factors such as avian predation (Branson, 2005a). Fire may be a useful management tool for grasshopper control but the reduction in grasshopper populations was short-lived (Branson, 2005b). Raw, unprocessed canola oil is a more effective attractant for grasshoppers than the refined oils used previously (Foster et al., 2005). Preliminary results are that grasshopper behavioral fever and hot/dry conditions are limiting efficacy and obscuring any attractive effects from the oil.

Mormon cricket ecology and management: Mormon crickets form huge migratory bands that move across range and agricultural land. Outbreaks can cause major depletions of range vegetation and losses to annual cropping systems. Despite their importance in these ecosystems research investments have been small and largely limited to remedial control practices. In particular, little is known about the movement of Mormon crickets. Using radiotelemetry, ARS scientists have demonstrated that individual Mormon crickets can be tracked over long distances (Lorch et al., 2005). The use of this technology led to the discovery that individuals can move much greater distances, more than 2 km, than previously thought (Sword, 2005, Sword et al. 2005b). Quantitative data on individual movement patterns will be used to develop predictive models of Mormon cricket migration. These models can be used to estimate the rate and direction of migratory band movement. Their implementation will assist in determining if, when, and where specific migratory bands should be controlled.

Locations and Collaborators: Miles City, Sidney.

<u>Problem Area E: Lack of effective spatial information technologies to monitor and assess pest populations.</u>

Remote Sensing: Remote sensing techniques have proven useful for detecting, monitoring and assessing a number of invasive rangeland plants. Hyperspectral remote sensing was able not only to detect saltcedar invasions but also areas where natural insect enemies had caused extensive defoliation of this pest plant (Anderson et al., 2004).

Hyperspectral remote sensing capabilities are being developed to detect yellow starthistle (Xin et al., 2005). Repeatability of hyperspectral remote sensing images is difficult and methods are being developed to improve data quality (Anderson and Peleg, 2005; Peleg et al., 2005). These accomplishments will increase the value of remote sensing in detecting invasive species on rangelands.

Locations and Cooperators: Sidney.

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