FY2016 Annual Report
National Program 215—Pasture, Forage and Rangeland Systems

Introduction

The USDA-ARS National Program for Pasture, Forage and Rangeland Systems (NP215) had another productive year in 2016 in terms of scientific output, technology transfer activities and breadth of collaborations with partners and stakeholders across the US and around the world. Scientists in NP215 continue to make extraordinary impact in numerous diverse areas of research relating to the management of the Nation's natural resources, including the over 1B acres of rangelands and pasture lands.

In FY2016, NP215 continued implementing project plans that were developed from comprehensive stakeholder input gleaned from the NP215 national stakeholder workshop in 2012. The workshop brought stakeholders and the NP215 research community together to prioritize the scope and direction of research in NP215 and to discuss current and future areas of impact for stakeholders.

The overarching goal of NP 215 is:

> *To improve food and energy security while enhancing the natural resources base by developing and transferring economically viable and environmentally protective technologies for sustainable range, pasture, forage and turf production systems that are based on fundamental applications of ecological and agronomic processes, and that are flexible to mitigate and adapt to the uncertainties of changing climate and market conditions.*

Our Nation's range, pasture, and herbage-based forage and turf landscapes serve many critical functions. Farms and ranches produce high quality, nutritious, abundant, and safe food products, as well as fiber and wood products that are the basis of income for producers and their rural communities. Rural areas provide significant ecosystems services such as clean air, water, and wildlife habitat, and are a long-term repository for biodiversity. These systems comprise about half of the land surface of the United States and represent a large and diverse mix of ecological sites, including annual grasslands of California, tundra rangelands of Alaska, hot arid deserts of the Southwest, temperate deserts of the Pacific Northwest, semiarid cold deserts of the Great Basin, prairies of the Great Plains, humid native grasslands of the South and East, and pastures and hay fields within all 50 states from Hawaii to Maine and Alaska to Florida.

The United Nations estimates that two-thirds of the world's agricultural land is pasture, forage and rangelands that can sustainably produce high quality animal products, but are unsuitable for more sustained, intensive production of grains or vegetables for human consumption. Knowledge gained about the development of sustainable land management in the United States will aid people across the globe, and ARS research will be critical to meeting the food security demands of a projected 9+ billion people by 2050. In FY2016, the importance of these global applications was demonstrated by NP215 scientist collaborations with researchers in Argentina, Australia, Belgium, Brazil, Canada, China, Colombia, Denmark, Ethiopia, France, Germany, Italy, Jordan, Kenya, Mexico, Netherlands, New Zealand, Romania, Russia, United Kingdom, and Uruguay. Many of these international interactions continue long term and productive scientific relationships.

The Nation's 30-40 million acres of turf lands are found around our homes, schools, municipal and commercial buildings, in our parks, greenbelts and recreational areas, and along our roadsides, airports and right-of-ways. These lands contribute to our well-being in many ways, including beautifying our towns and cities; enhancing property values; and providing vital environmental services such as erosion prevention, nutrient cycling, carbon sequestration and aquifer replenishment. Turfgrass and related industries contribute an estimated $40 billion a year to the U.S. economy.

Pastures, forages and rangelands are the primary forage base for U.S. livestock grazing industries and are used by more than 60 million cattle and more than 8 million sheep and goats. Forage livestock systems contribute more than $100 billion in farm sales annually to the U.S. economy. The estimated value of alfalfa and other hay production is $13 billion, and is the third most valuable crop to U.S. agriculture, behind only corn and soybeans. In addition, hay exports from all U.S. ports has increased 34% during the 2002-2011 period to nearly 4M metric tons per year. The publicly owned rangelands in the western U.S. are also critically important, providing forage on 260 million acres for three million beef cattle and sheep raised on over 30,000 primarily family owned and operated ranches. Nearly 70% of dietary protein and 40% of dietary calories for the U.S. population are of animal origin, and forage resources are crucial for sustained efficient production of food animal products.

The ecosystem services provided by these lands are of increasing importance. Watersheds in upland range and pasture regions are essential sources of clean water for urban areas, irrigated agriculture, and recreation. These lands provide forage and habitat for numerous wildlife species, including 20 million deer, one-half-million pronghorn antelope, 400,000 elk, 55,000 feral horses and burros, and hundreds of additional animal and bird species. An array of additional demands are also placed on these natural resources, including mining, oil and natural gas production, camping, hiking, fishing, hunting, and other recreational activities. For example, Bureau of Land Management rangelands, primarily in the western U.S., supported over 1.5M hunters and over 40M visitors in 2011. Meeting these many demands requires an improved understanding of how basic ecological processes are affected by grazing livestock production, drought, climate change, forage management and harvest, and other conservation practices.

Of particular significance is the continued close working relationship between NP215 scientists and technical staff with the Natural Resource Conservation Service. The NRCS provides technical support to the management of ~1 billion acres of private grazing lands. ARS scientific support in the development of conservation practices deployed by the NRCS, and the quantitative techniques employed in evaluating their effects, is critically important to the management of these natural resources.

Harvested and conserved forages provide a dietary resource for continuity of livestock production that is especially important during periods of cold or drought when nutrient rich plants are not available. Harvested and conserved forages also provide an important source of roughage and nutrients for dairy cattle in animal feeding operations. To meet this demand, nearly 200 million tons of forage crops are harvested each year from 73 million acres in the U.S., which is 24% of the cropland - providing about half the forage requirements of dairy cattle. The remainder, along with rangeland and pasture, supplies the forage needs of beef cattle, sheep, goats, horses, and other livestock. Increased forage and food animal production efficiencies are needed to ensure the competitiveness and sustainability of food animal producers and to improve domestic and international food security.

During FY 2016, 96 full-time scientists working at 22 locations across the U.S. actively engaged in 26 ARS-led and 189 cooperative research projects in NP215. ARS-led projects were approved through the ARS Office of Scientific Quality Review in 2012, making FY2016 the fourth year of implementation of these five-year projects. The gross fiscal year 2016 funding for NP215 was $42.8 million.

New additions to the NP215 team in 2016 were:

- **Dr. Deborah Samac** was selected to be the new Research Leader of the Plant Science Research Unit in St. Paul, MN. Her research is in the area of molecular markers for disease resistance in alfalfa, diversity of alfalfa pathogens, alfalfa biotechnology, and characterization of microbial communities associated with alfalfa roots.
- The Plant Science Research Unit in St. Paul, MN hosted visiting scientist **Dr. Yuanyuan Cao**, an Associate Professor in Microbiology at Anhui Agricultural University, in Hefei, Anhui in China. Her research with ARS focused on phenotyping alfalfa root architecture and characterizing diversity in symbiotic bacteria in alfalfa root nodules.
- The Forage Seed and Cereal Research Laboratory, Corvallis, OR, welcomed three new scientists in 2016: **Dr. Ryan Hayes** is the new Research Leader at FSCRL. He is working on development of rust resistance germplasm in cool season grasses. **Dr. John Henning**'s expertise is in genetics and breeding; he will provide bioinformatics support to ongoing projects in Corvallis. **Dr. Barb Gilmore** is a postdoctoral research associate studying biotic stress of cool season grasses.
- **Dr. Tucker Burch,** Research Agricultural Engineer, joined the U.S. Dairy Forage Research Center, Marshfield, WI. His field of expertise is civil engineering. **Dr. Kristan Reed** has also joined the USDFRC as a postdoctoral research associate. She is studying reactive nitrogen in dairy production systems.
- **Dr. Lisa Kucek** joined the U.S. Dairy Forage Research Center, Madison, WI as a postdoctoral research associate. She is studying breeding of winter annual legume organic cover crops.
- **Dr. David Hoover** joined the Rangeland Resources and Systems Research Unit in Cheyenne, WY. David will be working on ecohydrological issues in semiarid rangelands as affected by management and topoedaphic influences.
- The Northern Great Plains Research Laboratory in Mandan ND hosted visiting scientist **Dr. Julie Ryschawy** of the French National Institute for Agricultural Research (INRA), Toulouse, France, to study integrated crop-livestock systems.
- The Grazinglands Research Laboratory in El Reno, OK welcomed two new postdoctoral research associates in 2016: **Dr. Pradeep Wagle** is an ecologist studying evapotranspiration monitoring with eddy covariance systems. **Dr. Tanka Kandel** is a soil scientist monitoring greenhouse gas emissions using static chambers under different crop, tillage, fertilizer, and grazing systems. **Dr. Pradeep Adhikari** is an agronomist studying crop modeling with Decision Support System for Agrotechnology Transfer (DSSAT) to evaluate soil and water management strategies under changing climate conditions.

The following scientists retired from the ranks of NP215:

- **Dr. Robert Blank** is now on phased retirement from the Great Basin Rangelands Research Unit in Reno, NV. He is finalizing his research on cheatgrass interactions on soils in the Great Basin.
- **Dr. Bill Jokela,** Research Soil Scientist, retired from the U.S. Dairy Forage Research Center, Marshfield, WI.

- **Dr. Matt Sanderson** of the Northern Great Plains Research Laboratory, Mandan, ND, retired after serving six years as Research Leader.

The distinguished record of service of these scientists is recognized world-wide, and they will be missed in NP215.

The following scientists in NP 215 received prominent awards in 2016:

- **Drs. Mark Weltz** and **Jason Nesbit,** Great Basin Rangelands Research Unit, Reno, NV and **Dr. Ken Spaeth,** USDA-NRCS, Ft. Worth, TX, were invited to Almaty, Kazakhstan to provide a 5 day workshop on assessing risks to rangeland health and sustainability. Training was provide in use and application of the Rangeland Hydrology and Erosion Model and the KINEROS2 watershed assessment tool to 40 faculty members of Kazakh National Agrarian University to assess soil erosion and its potential to degrade rangelands. The team was awarded Honorary Professorship and full professor status at Kazakh National Agrarian University and 2 medals related to conservation and excellence in teaching.
- **Dr. Peter Vadas** of the U.S. Dairy Forage Research Center, Marshfield, WI, received a Superior Paper Award from Transactions of ASABE for his manuscript "*New Model for Runoff, Sediment, and P Losses from Outdoor Cattle Lots.*" Dr. Vadas was also named an Outstanding Associate Editor by the Soil Science Society of America.
- **Dr. Wayne Coblentz** of the U.S. Dairy Forage Research Center, Marshfield, WI, received an Editor's Choice Award from the Journal of Dairy Science for his paper, "*Growth Performance and Sorting Characteristics of Corn Silage/Alfalfa Haylage Diets with or without Forage Dilution Offered to Replacement Dairy Heifers.*"
- **Dr. Michael Casler** of the U.S. Dairy Forage Research Center, Madison, WI received the Medallion Award from American Forage and Grassland Conference, the highest recognition given by AFGC, for outstanding contributions on behalf of forages and grasslands and the American Forage and Grassland Council, and national recognition for work in research, teaching, extension, production, or industrial development.
- **Dr. Lauren Porensky** of the Rangeland Resources and Systems Research Unit in Cheyenne WY, received the U.S. Forest Service National Grassland Council Research and Technology Award Honorable Mention for work on Thunder Basin National Grassland.
- **Dr. David Toledo** of the Northern Great Plains Research Laboratory, Mandan, ND, received the Outstanding Young Range Management Professional Award from the Society of Range Management.

The quality and impact of NP 215 research was further evidenced in 2016 by following:

- Over 171 refereed journal articles published;
- 1 new patent received
- 1 new patent application and 6 new invention disclosures submitted;
- 4 current cooperative research and development agreements, and 10 new material transfer agreement with stakeholders;
- Administration or development of 6 collaborative web sites for partners in academia, other research organizations or non-government organizations, and stakeholders.

NP 215 Accomplishments for FY2016

This section summarizes 19 significant and high impact research results that address the priorities of the 4 specific components of the FY 2013 – 2018 action plan for the NP 215. Each section summarizes accomplishments of individual research projects in NP 215. Of particular note are the many high impact accomplishments that address key problems facing management of the Nation's grazing lands. Units in the NP215 program have been nimble in directing research to develop conservation practices and pasture/forage management systems that solve critical problems, including controlling wildfire and erosion, enhancing habitat values for critical species including sage grouse, controlling invasive species such as cheatgrass and juniper, and development of ecologically based techniques for quantitatively assessing and monitoring land. Many of the programs summarized for FY 2016 include significant domestic and international collaborations with both industry and academia. These collaborations provide extraordinary opportunities to leverage funding and scientific expertise for USDA-ARS research by rapidly disseminating technology, which enhances the impact of ARS research programs.

Additionally, internal collaborations remain a significant emphasis for ARS research locations. Through these collaborations, scientists gain from each other's findings and better coordinate research methods and protocols. In FY16, progress was made in developing the National Wind Erosion Research Network, led by ARS but incorporating the efforts of researchers across USDA and other federal agencies. The Network also ties into the emerging Long-Term Agro-Ecosystem Research (LTAR) network being developed by ARS crop and grazing land scientists. In addition to the benefits these networks afford to ARS scientists, stakeholders also benefit through more coordinated and consistent data and information for their management analysis and planning.

Component 1. Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services

Grazing management strategies to prevent wildfires in western rangelands. Exotic annual grasses, such as cheatgrass, are now present on nearly 100 million acres of western U.S. Rangeland. Invasion by cheatgrass increased the amount of highly flammable, fine fuels in infested areas, which in turn, increased the frequency and size of wildfires. These wildfires are not only a threat to human safety, they also reduce livestock forage and degrade wildlife habitat. Unfortunately, the same wildfires also kill native plants and allow further invasion by cheatgrass. Mitigation efforts focused on reseeding or replanting native plants after a wildfire have had only limited success. ARS scientists in Burns, Oregon have developed strategies that effectively reduce the fine fuel loads, thus reducing wildfire frequency and heat intensity. These strategies provide ways to retain the desired native plants and reduce their loss when fires do occur. The scientists developed a model and research framework for using pre-fire fuel-load management (including livestock grazing) to decrease the mortality of desired native plants during wildfires and reduce the need for post-fire seeding practices, which are often ineffective. This work provides ranchers and public land managers with strategies for preemptive fuels management that can prevent loss of native forages.

Establishment of desirable forage species is more successful following cheatgrass weed control. Cheatgrass (*Bromus tectorum*) invasion has significantly altered native plant communities throughout the Intermountain West, and rehabilitation of cheatgrass-infested rangelands is a daunting task for land managers. The establishment of long-lived perennial grasses is key to suppressing cheatgrass spread and allowing plant succession to occur. ARS scientists in Reno, Nevada, implemented study plots in northern Nevada to test various herbicides to control cheatgrass and establish desirable plant species for wildlife and grazing resources. The application of herbicides reduced cheatgrass densities from an average of 210.6/m^2 down to 7.2/m^2, and at the same time, perennial grass densities, through release of residual plants and drill seeding of desirable species, increased from 0.6/m^2 to 10.7/m^2. This study shows that cheatgrass control using appropriate herbicides is critical in successful rehabilitation of rangelands, and when done properly, rangeland managers in the Great Basin will have greater rehabilitation success and potentially save millions of dollars in unsuccessful rehabilitation efforts.

Global warming increases cheatgrass invasion in Great Plains rangeland. Cheatgrass is one of the most problematic invasive plant species in U.S. rangelands, but has historically been less prevalent in the Great Plains. ARS researchers in Fort Collins, Colorado, and Beltsville, Maryland, with collaborators from the University of Wyoming, discovered that experimental warming, such as would occur with rising temperatures due to climate change, increases cheatgrass biomass and seed production by 400% in mixed-grass rangeland near Cheyenne, Wyoming. In contrast, elevated CO_2 had little effect on cheatgrass, likely due to nitrogen limitation. These findings provide producers and public land managers in the mixed-grass prairie—the largest remaining grassland in North America—information forewarning of the possible consequences of rising climatic temperatures on cheatgrass invasion.

Soil erosion threatens the sustainability of rangelands. Concentrated flow erosion processes are distinguished from splash and sheet flow processes in their enhanced ability to mobilize and transport large amounts of soil, water, and dissolved elements off-site, impacting soil health and sustainability of the site. A team of ARS scientists in Reno, Nevada, in association with ARS scientists in Tucson, Arizona and Boise, Idaho, have developed a new risk assessment tool to assess potential soil loss. This new tool allows land managers to evaluate plant communities and conservation practices to reduce risk, manage erosion and assess the sustainability of the site as compared to the historic plant community. The tool utilizes the Rangeland Hydrology and Erosion Model (RHEM), and provides managers with a simple and accurate means to rapidly assess management options and establish priorities for determining which areas need conservation.

Innovative approaches for remotely monitoring land surface conditions. Improved remote sensing methodologies and data acquisition technologies are needed to accurately assess and map rangeland vegetation and monitor rangeland health. By developing analyses procedures and conducting ground verification of remotely sensed estimates of canopy greenness (a proxy measure for plant phenology (seasonal changes) and production) from multiple data sources, including tower cameras (i.e., phenocams), UAV-based digital imagery, and satellite sensors (Landsat and MODIS), ARS scientists in Las Cruces, New Mexico have demonstrated that inexpensive phenocams provide valuable data in near real-time. These efforts have led to the ongoing development of an LTAR cross-site multi-scale phenology data network. Additionally, the National Coordinating Office of the National Phenology Network has utilized this information in their effort to integrate phenological observations collected at different scales. These phenocam technologies increase speed and accuracy of gathering information about the landscape and enhance our ability to inform land managers, who use the information to make management decisions such as adjustments to the timing and duration of livestock grazing.

Holistic grazing system increases soil carbon and nitrogen. ARS scientists in Reno, Nevada, in collaboration with a range consultant, have completed a study on the effect of two grazing management systems (traditional vs. holistic), on soil properties on a New Mexico ranch. The traditional system is year-round grazing with a stocking rate of one cow per fifty-six acres. The holistic system divides the land into many smaller pastures, with cattle grazing each for only three to five days. Following grazing, the pastures are allowed to remain ungrazed for a rest period of one hundred days, which allows the grazed plants to recover and regrow. The holistic grazing system allows a heavier stocking rate, in this case one cow per thirty-five acres. For each grazing system, soils were sampled by depth and by microsite (i.e. bare ground, grass, and shrub). Results showed that even with the heavier stocking rate, rangelands managed using holistic principles had significantly greater total soil nitrogen and total soil carbon than traditionally grazed rangelands and a decreased proportion of bare ground and increased forage production.

Tools and techniques for multi-scale inventory, monitoring, and assessment. Standardized approaches for monitoring rangelands are needed to allow land managers and public land agencies to collect and share data that address numerous rangeland management and policy needs. ARS scientists in Las Cruces New Mexico led and supported the development, testing and implementation of core monitoring indicators and methods and scalable sampling designs within the Bureau of Land Management (BLM's) Assessment, Inventory, and Monitoring (AIM) program (including BLM's national guidance and local support for monitoring Greater Sage-grouse habitat). This included integration of BLM's monitoring efforts with the existing Natural Resources Conservation Service (NRCS) and United States Forest Service (USFS) monitoring programs. ARS scientists also led the development of novel techniques for analyzing rangeland monitoring data relative to land potential to produce results that directly support management decision making. The resulting standardized inventory, monitoring, and assessment techniques and tools (available via landscapetoolbox.org) are providing managers and policy makers with information needed by U.S. agencies and international partners to manage resources at local to continental scales over millions of acres of rangelands.

Ecohydrologic framework for Ecological Site Descriptions. Ecological sites and their descriptions (ESDs) are the primary basis by which rangeland management agencies evaluate ecosystem health, develop management objectives, target conservation practices, and communicate regarding ecosystem responses to management. However, ESDs seldom include ecohydrologic relationships that strongly regulate overall ecosystem health and responses to various disturbances. ARS scientists in Boise Idaho, in cooperation with other ARS scientists and Natural Resources Conservation Service personnel from across the U.S., developed a framework and methodology for integration of key ecohydrologic data and relationships within the ESD structure. The ecohydrological framework and methodology was adapted to the Rangeland Hydrology and Erosion Model (RHEM) to take into account water dynamics, improving the accuracy of the model and enhancing the development and management of ESDs. The integration of this new framework on ecohydrologic relationships expands the ecological foundation of the overall ESD concept for management of U.S. rangelands while improving communication between private land owners and federal land managers across multiple disciplines in the field of rangeland management.

Northern mixed-grass prairie can bounce back from heavy grazing, but recovery is slow. Sustainable rangeland management hinges on a solid understanding of how grazing management decisions affect plant communities over the short- and long-term. For many rangelands, current conceptual models suggest that heavy grazing can cause irreversible shifts in vegetation composition, but few studies have experimentally tested this idea. ARS researchers at Fort Collins, Colorado and Cheyenne, Wyoming found that, as expected, 33 years of heavy grazing caused desirable cool-season grasses to decline while warm-season grasses increased. Contrary to expectations, reversing management from heavy grazing to light or no grazing allowed cool-season grasses to recover, indicating that northern mixed-grass prairie is more resilient to grazing than current models predict. However, results suggest that it takes more than a decade of light grazing for a heavily grazed plant community to revert to light-grazing conditions, and this recovery timeline is economically burdensome for most producers. Researchers can enable better management planning on semiarid rangelands by using long-term data to add critical rate-of-change information to conceptual models, which will improve tools that help land managers develop long-term management plans.

Prediction of climate-driven vegetation state changes. Directional decreases or increases in precipitation are predicted for aridlands in the future. ARS scientists in Las Cruces, New Mexico have collected long-term data from the Jornada Experimental Range that included drought and wet periods. These data were used to predict the response of perennial grasses on sites dominated by different shrub species (mesquite, creosotebush, and tarbush) under a future drier, or wetter, climate. Production was linearly related to rainfall during drought and no-trend years. However, during an extended wet period, a nonlinear increase in grass production occurred. The fastest grass response occurred in mesquite-dominated sites, intermediate responses in tarbush-dominated sites, and slowest responses in creosote-dominated sites. These site-specific responses were related to soil texture and plant available water. Mechanistic models are being used to predict state changes from shrub- to grass-dominated under alternative land use-climate scenarios. This regional understanding will help producers manage grazing land resources during times of climate variability and change.

A native slender wheatgrass with improved rangeland stand establishment characteristics. Vast areas of semi-arid rangelands in the western U.S., particularly in the Great Basin, are severely disturbed. These regions experience more frequent wildfire and are becoming increasingly eroded, leading to the site being more heavily infested with troublesome weeds such as cheatgrass and medusahead rye. In such areas of limited annual precipitation, native grasses are more difficult to establish, less productive and persistent, and less defoliation-tolerant under severe water stress than their introduced counterparts. To conserve native habitat and reduce fire danger, it is critical to develop native grasses that can be seeded onto these harsh range sites that are competitive against invasive weeds, easy to establish, and persistent, with increased seed yield. Slender wheatgrass is a native, self-pollinating, short-lived, early serial, perennial species that colonizes degraded landscapes. Because of its abundant rhizomes (underground plant stems that aids establishment and improves drought tolerance), ARS scientists at Logan, Utah, developed an improved alternative to current slender wheatgrass cultivars, releasing Charleston Peak slender wheatgrass germplasm. Charleston Peak is currently the only slender wheatgrass plant material that originates in the Great Basin, and displays potential as an improved material for conservation (erosion control) and re-vegetation (reclamation) plantings on arid and semi-arid rangelands for the Great Basin and Intermountain Regions of western U.S. Charleston Peak germplasm is adapted to elevations ranging from 4,500 ft. to 12,000 ft., prefers loams and sandy loams, and can tolerate high salinity ranges.

Native Thurber's needlegrass increases rangeland biodiversity. As a result of large-scale planting of non-native grasses (i.e., crested wheatgrass) in the early part of the 19th century, many western U.S. landscapes have lost biodiversity. There is a need to increase the genetic diversity of such regions during landscape revegetation after disturbances (e.g., wildfire and human disturbance) by seeding native grass and legume species. For instance, native Thurber's needlegrass is a densely tufted bunchgrass (12 to 24 inches tall) that provides valuable forage for livestock and wildlife. In contrast to many non-native plantings, this grass is typically found in association with a diverse plant community including juniper, sagebrush, saltbush, horsebrush, bitterbrush, winterfat, Sandberg bluegrass, Indian ricegrass, bluebunch wheatgrass and thickspike wheatgrass. However, seed for this species is not commercially available, and therefore, ARS scientists at Logan, Utah, developed and released Princeton Thurber's needlegrass germplasm for revegetation of degraded sites. This will lead to the development of commercially available seed sources and provide a means for establishing native and more diverse revegetation efforts.

Component 2: Develop Improved Pasture Technologies and Management Systems

Increasing species richness improves pasture yield and carbon sequestration. Pasture management options are needed that both increase forage production and provide ecosystem services such as increased soil carbon sequestration. Over the course of a nine year study, ARS researchers in University Park, Pennsylvania evaluated whether increasing the number of plant species sown in a pasture might accomplish these management objectives. Researchers found that a five-species mixture of forages produced 31% greater yield than a two-species mixture. Yield benefits from the five-species mixture were greatest in years with high rainfall and were greater than average the last two years of the study, suggesting that the effects were long-lived. The five-species mixture also sequestered three times as much soil organic carbon as the two-species mixture. Increasing the number of sown species can have multiple, long-term benefits on temperate pastures, including both forage production and ecosystem services such as soil carbon storage and improved soil health. Furthermore, the practice could be easily adopted by most pasture land managers in the region.

Fall oats improve sustainability of dairy production. Dairy producers in the north-central U.S. often need stored forages to maintain livestock through the winter. Fall-grown oat is an excellent candidate because it has good yield potential as a late-season crop, provides an opportunity during summer to spread manure, and aggressively takes up nitrogen in the soil to help reduce loss to the environment. Fall oats can also be used for managed grazing. Research was needed to determine soil fertility requirements and management for oats as stored feed, and to optimize grazing management for improved cow performance. ARS researchers at Marshfield, Wisconsin, found that using nitrogen fertilizers increased oat yields for stored feed by 50% or more, and that dairy manure applied in summer provided adequate nitrogen. It was further determined that, for heifers in central Wisconsin, grazing of oats established in August should begin in late September; delaying grazing until mid-October consistently decreased heifer growth, particularly if rapidly maturing oat types were used. This improved fall-oat management information provides dairy producers with additional options to produce quality animal feed, stored or grazed; and to reduce the environmental risk of nitrogen leaching to groundwater.

Sterile, perennial sorghum species hybrid released. Cold-tolerant, noninvasive, perennial forage sorghums are needed for increased hay production. ARS researchers at College Station, Texas, working with Texas A&M University scientists, collected and evaluated a naturally occurring sorghum type. Molecular studies revealed the grass to be a natural hybrid between *S. bicolor* and *S. halepense*. The genotype produces a limited number of seed heads in early spring and late fall only, and the few seed produced are sterile. Since flowering is very limited, the plant produces leaves throughout the growing season, which makes it a very desirable high-biomass forage grass for hay production and at least two cuttings can be harvested each growing season. Since its seeds are sterile and its rhizomes exhibit limited spreading, it is not an invasive species. This natural hybrid was released as germplasm in FY 2016; it should significantly benefit cattle producers in the southern Great Plains.

Trailhead II, an improved native basin wildrye germinates rapidly for improved stand establishment. Many areas of the western U.S. have been severely degraded by human disturbance, wildfires, and the invasion of weedy annual plant species (e.g., cheatgrass, medusahead rye). Thus, there is a need to identify and cultivate plant materials that establish and persist on degraded landscapes. Relatively tall (3 to 6 feet) basin wildrye grass is ideal for providing wind protection in winter calving pastures, holds its nutrient value well at maturity (7-8% protein), and can withstand heavy grazing and trampling in its dormant state. Moreover, as a bunch type grass, basin wildrye is well adapted to stabilizing disturbed soils, is drought tolerant, possesses a fibrous root system, and has adequate seedling vigor in areas receiving 8 to 20 inches of annual precipitation. These characteristics make it a desirable plant material for reclamation. ARS scientists at Logan, Utah, developed and released Trailhead II basin wildrye, which exhibits improved stand establishment and rapid emergence. The release of Trailhead II provides an alternative that may enhance the success of conservation and re-vegetation plantings in the Intermountain West and Northern Great Plains areas of the United States.

Component 3: Improved Harvested Forage Systems for Livestock, Bioenergy and Bioproducts

Bacterial stem blight disease of alfalfa is an increasing threat to forage production. Economic damage of alfalfa fields by late spring and early fall frosts has increased in the past several years and in some locations, increased sensitivity to frost was associated with herbicide application. ARS researchers in Saint Paul, Minnesota found that damaged alfalfa was infected by the bacterial stem blight pathogen, which has the ability to increase the range of temperatures at which frost damage will occur. The genome of the pathogen was sequenced and comparisons with other bacterial genomes showed that it is closely related to bacteria infecting pears and beets. Methods were developed for identifying alfalfa plants resistant to this pathogen, and cultivars with moderate numbers of resistant plants have been identified. These results will be valuable for developing cultivars with high levels of resistance to the disease for integrated disease management and sustainable forage production.

Molecular markers for Verticillium wilt resistance in alfalfa. Verticillium wilt (VW) is an alfalfa disease that reduces forage yields up to 50%. Current breeding strategies rely greatly on phenotypic recurrent selection that is slow and inefficient for genetic improvement. An ARS scientist in Prosser, Washington, in collaboration with Alforex Seeds, S&W Seed, Forage Genetics International and the Noble Foundation, identified 11 molecular (genomic or DNA) markers associated with VW resistance in two alfalfa populations. The markers identified in this study can be used for improving resistance to VW in alfalfa; these markers and associated germplasm for disease resistance will facilitate the rapid development of new alfalfa cultivars with improved VW resistance.

Unique perennial sorghum germplasm developed. *Sorghum propinquum* is a species that is critical in the development of perennial sorghum germplasm to be used for both forage and bioenergy purposes. Perenniality in sorghum is achieved from belowground rhizomes that survive low temperatures. Unfortunately, spreading rhizomes are usually associated with invasiveness in the weedy, rhizomatous species Johnsongrass (*S. halepense*). *Sorghum propinquum* produces fewer and less invasive rhizomes than Johnsongrass, which minimizes the risk of invasiveness. However, most sorghum hybrids that have been developed using this species as a parent have lacked the desired level of cold tolerance. ARS researchers at College Station, Texas, working with Texas A&M University scientists, successfully doubled the chromosomes in diploid *S. propinquum* to improve winter survival traits and suppress the rhizome production that causes the plant to be invasive. Seven unique tetraploid plants were recovered, which is a significant step in breeding winter-hardy perennial sorghum germplasm with high potential as new forage and bioenergy crops with minimal risk of invasiveness from seed or rhizomes.

Effective, new diagnostic tool for root-knot nematodes. Nematodes are microscopic worms that occur everywhere around us, but especially in the soil. Some nematodes infect plants through the roots and cause billions of dollars in crop losses worldwide each year. Root-knot nematodes are an important example. Root-knot nematodes damage many kinds of plants, including carrots, causing the roots to be deformed and interfering with nutrient uptake. Identifying these nematodes in the soil can be nearly impossible, but an ARS scientist at Beltsville, Maryland, in collaboration with scientists from Denmark, has developed a new DNA test to detect the northern root knot nematode. This new diagnostic test is very sensitive, highly specific, and able to detect this species directly in the soil. This research provides an important tool for accurately determining which fields are infested, and the level of infestation, allowing growers to make informed management decisions before carrot cultivation.

Germplasm and molecular markers for improving alfalfa drought tolerance identified. Enhancing drought resistance and water use efficiency of alfalfa varieties is key to meeting the challenges of finite water resources. An ARS researcher in Prosser, Washington, conducted a replicated trial in both greenhouse and field and identified 27 alfalfa varieties with a higher level of drought resistance than the known drought resistant control. A laboratory study on marker-trait association identified 20 and 15 genetic loci associated with drought resistance index and relative water content, respectively. Comparisons of target sequences flanking the resistance loci against the reference genome of *M. truncatula* (model legume- barrelclover) revealed multiple chromosomal locations. Markers associated with salt tolerance have also been identified and located on chromosomes 1, 2, and 4. These markers will be useful in marker-assisted breeding of new alfalfa varieties with drought resistance and enhanced water use efficiency.

Rapid selection of root system architecture that promotes enhanced alfalfa forage yields. Selection for yield in alfalfa has focused on aboveground plant traits, largely ignoring the potential contribution of the root system to improve yield through enhanced water and nutrient acquisition. Previous research found that alfalfa plants with a highly branched root system supported greater forage yields than plants with a typical root system; however, selection required a minimum of 20 weeks to identify plants with the branching root phenotype. ARS researchers in Saint Paul, Minnesota developed a method to identify plants with a strong taproot or strong branch roots after only 2 weeks of growth, with the number and length of tertiary roots the key measurement for distinguishing root types. Plants could be identified consistently even with mild drought stress, nutrient stress, and with nodulation by symbiotic bacteria. Several candidate genes were identified that were associated with the branching root phenotype. These results will facilitate ‘root breeding’ approaches aimed at modifying root system architecture to increase the absorptive capacity of roots for water and nutrients to increase alfalfa productivity, persistence, and resilience to environmental stresses.

First-of-its-kind searchable tannin database. Condensed tannins are natural protein-binding substances present in some forage species; they have been found to protect forage protein from degradation during both silage fermentation and rumen digestion. One research goal is to decipher what chemical characteristics and concentrations of condensed tannins will be optimal for improving protein utilization and milk production of dairy cattle. ARS researchers at Madison, Wisconsin have created a database with data from the scientific literature called the Dairy Forage Research Center Condensed Tannin NMR Database. This instrument allows scientists to search for information about condensed tannins by structure, molecular formula, and more. Citations for all literature references used in this database are also provided. The database is available, free of charge, from the ARS website. This database is a valuable resource for scientists around the world working in the growing field of condensed tannin research.

Component 4: Turf Improvement

Golf course putting greens that require fewer inputs. Increasing water restrictions, concerns over pesticide use and economic constraints are causing golf course managers to reduce inputs of fertilizer, water and labor. Warm-season (C4 photosynthetic pathway) grasses use less water, have fewer summer diseases and survive better during summer heat, so there is interest in using improved warm-season grasses on golf course putting greens. A trial was established in 2013 at eleven locations across the southern U.S. to evaluate three warm-season grass species (bermudagrass, zoysia, and seashore paspalum) for persistence, winter tolerance, disease incidence and playing surface quality. Results indicate that several bermudagrass varieties may have potential for use on golf course putting greens. The seashore paspalum entries have performed very well in the southern locations, while suffering severe winter damage in northern locations. Several of the zoysia entries have performed well but do not have the playing surface characteristics (green speeds necessary) needed under these management conditions. These results will be used to guide future planting of golf greens that have a lower environmental impact.

Discovery of novel plant endophytes for improved stress tolerance. Endophytes are microorganisms that live symbiotically within plants and may improve plant tolerance to abiotic and biotic stresses. ARS researchers in Corvallis, Oregon isolated and identified 111 fungal endophytes comprising 39 genera and 133 different bacterial endophytes comprising 37 different genera/species, of which 94 were unique isolates. The endophytes were collected from eight different grass species growing in saline environments and sandy soils along the Oregon Coast. Fourteen of the bacterial isolates possessed ACC deaminase activity, an enzyme associated with improved plant growth under stress. These newly discovered endophytes have the potential to improve the health and productivity of grasses and other crop species grown in marginal or stressful conditions.