National Program 215 Pastures, Forage and Rangeland Systems
National Program Annual Report: FY2013

Introduction

The USDA-ARS National Program for Pasture, Forage and Rangeland Systems (NP215) had another productive and dynamic year in 2013. Scientists in NP215 continue to make extraordinary impact in numerous diverse areas of research relating to food security, ecosystem services and rural development.

In FY2013, NP215 initiated project plans that were developed from comprehensive stakeholder input gleaned from the NP215 national stakeholder workshop. 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. These efforts are documented online at: http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=215 and include: the ***Retrospective Review Panel Executive Summary*** and the ***FY2013-FY2018 Action Plan*** for NP215 which went into effect on October 1, 2012.

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 the more 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.

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. These 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. 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. 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. 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 land management practices.

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 confined animal feeding operations. To meet this demand, nearly 200 million tons of forage crops are harvested each year from 73 million acres in the U.S., which is 24% of the cropland - 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 2013, 99 full-time scientists working at 23 locations across the U.S. actively engaged in more than 248 ARS-led and cooperative research projects in NP215. ARS-lead projects were approved through the ARS Office of Scientific Quality Review in 2012, making this the first year of implementation of these five-year projects. The gross fiscal year 2013 funding for NP215 was $42 million.

New additions to the NP215 team in 2013 are:

- **Dawn Browning**, Las Cruces, NM, joined the NP215 team at the Jornada Experimental Range – Range Research Management Unit after serving as a post-doc at the location. She is a Ph.D. graduate from the University of Arizona and is now focused on management technologies for conservation of western rangelands.
- **Jason Karl**, Las Cruces, NM, joined the NP215 team at the Jornada Experimental Range – Range Research Management Unit. Jason had been serving as a post-doc at the location. He is a Ph.D.

graduate from Michigan State University and is now focused on management technologies for conservation of western rangelands.

- **Lauren Porensky,** Cheyenne, WY, joined the NP215 team at the High Plains Grasslands research Station. Lauren is a rangeland ecologist interested in synergies and trade-offs between conservation and production in working landscapes. Her scientific background includes landscape ecology, plant ecology, rangeland management, GIS and remote sensing, and restoration ecology. She received her PhD from the University of California, Davis in 2012.
- **David Toledo**, Mandan, ND, joined the NP215 team at the Northern Plains Research Laboratory. Previously David had been located at the ARS Jornada Experimental Range where he worked on the development and application of indicators for monitoring soil and vegetation attributes and assessment of rangeland health.

The following scientists retired from the ranks in NP215:

- **Terry Booth**, High Plains Grasslands Research Station, Fort Collins, CO.
- **David Burner**, Dale Bumpers Small Farms Research Unit, Booneville, AR
- **Greg Lewis**, Range Sheep Production Efficiency Research Unit, Dubois, ID
- **Jack Morgan**, High Plains Grasslands Research Station, Fort Collins, CO.
- **Carroll Vance**, Plant Science Research Unit, St. Paul, MN
- **Ken Vogel**, Grain, Forage and Bioenergy Research Unit, Lincoln, NE.

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 2013:

- **Brandon Bestelmeyer, Jeff Herrick and Kris Havstad**, Las Cruces, NM, were recognized with a **Secretary of Agriculture Honor Award** for 2013 as members of the Interagency Ecological Site Implementation Team.
- **Justin Derner**, Cheyenne, WY received the *Kling Anderson Lectureship Award* from Kansas State University, which was established to enhance training in Range and Forage Management at Kansas State University by providing the opportunity for students and faculty to benefit from interaction with outstanding scholars.
- **Ben Green**, Logan UT, received a *Special Achievement Award* at the 9th International Symposium on Poisonous Plants (ISOPP9) in Hohhot, Inner Mongolia, China for his work on genomics and gene marker investigations in beef cattle and their sensitivity to neuro-toxic poisonous plants.
- **Stacey Gunter**, Woodward, OK, received the *2013 Animal Management Award* from the American Society of Animal Science.
- **Stuart Hardegree**, Boise, ID; **Tom Monaco**, Logan, UT; and **Roger Sheley**, Burns, OR; received the ARS Superior Technology Transfer Award for "Ecologically-based invasive plant management of invasive annual grasses".
- **Douglas Johnson**, received the 2013 W.R. Chapline Research Award from the Society for Range Management.
- **Jack Staub**, was recognized with a 2013 Outstanding Researcher Award from the American Society for Horticultural Science.

- **Stephen Lee**, Logan, UT, received a *Special Achievement Award* at the 9th International Symposium on Poisonous Plants in Hohhot Inner Mongolia, China for his research on the chemical elucidation of toxins from plants affecting livestock in Brazil, Australia and the United States.
- **Dan Pote** and **Steve Haller**, Booneville, AR, were recognized by ARS with a *2012 ARS Superior Technology Transfer Award* for having designed, developed, and patented an innovative tractor-drawn machine known as the "Poultry Litter Subsurfer." which can transport 5 tons of dry poultry litter directly from a poultry house and rapidly apply it under the soil surface; resulting in improved nutrient-use efficiency and fewer environmental problems by decreasing nutrient losses.
- **David Toledo**, Mandan, ND received the 2013 Texas A&M University Association of Former Students *Distinguished Graduate Student Award for Excellence in Research* for his "outstanding academic record and contributions in teaching and research".
- **Ken Vogel**, Lincoln, NE, was elected to the USDA-ARS Hall of Fame.

The quality and impact of NP 215 research was further evidenced in 2013 by following:

- Over 240 refereed journal articles published
- Application for one new patent
- Sixteen new cooperative research and development agreements with stakeholders
- Fifty new scientific technologies developed, and
- Administration or development of 20 web sites for academia or stakeholders.

In 2013 NP 215 scientists participated in research collaborations with scientists in: Argentina, Australia, Brazil, Canada, China, Czech Republic, Ethiopia, France, Germany, Greece, India, Japan, Mongolia, Namibia, New Zealand, Panama, Russia, Spain, Sweden, United Kingdom and Uruguay.

NP 215 Accomplishments for FY2013

This section summarizes significant and high impact research results that address specific components of the FY 2013 – 2018 action plan for the NP 215. Each section summarizes accomplishments of individual research projects in NP 215. Many of the programs summarized for FY 2013 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.

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

Problem Statement A: Developing economic livestock grazing systems for rangelands that meet global food security objectives while being adaptable to changing climate and varying environmental conditions and preserve the natural resources integrity.

Analysis of toxic pyrrolizidine alkaloid in contaminated forages. Pyrrolizidine alkaloid (PA) - containing plants have global distribution, and they often poison animals and humans by contaminating pastures, feeds, food, herbal products, and medicinal products. Common plants containing PAs in the North America include over 25 species of *Senecio*, which are responsible for recent poisonings in cattle in Arizona. Hounds tongue (*Cynoglossum officinale*) often contaminates hay and poisons horses and calves. In humans, common comfrey (*Symphytum officinale*) is a concern and is common in health foods stores as an herbal product. *Echium* and *Heliotropium* species are a problem in Europe, Australia and other countries, and in the Middle East the most recent concern has been contamination of cereal grains with seed of *Ageratum* species which have been responsible for multiple human deaths. Honey and pollen are also a concern for human health in areas where bees have access to these PA containing plants. Toxicity is characterized by liver failure and several PAs are also carcinogenic as confirmed by ARS scientists in Logan, UT. This research also explains a disease called "Unidentified Liver Disease" which is common in poor populations in the northwest region of Tigray, Ethiopia, where it is suspected that the disease is related to natural toxins in food. In cooperation with the Centers for Disease Control and Prevention, ARS scientists analyzed samples collected and screened from the Tigray region of Ethiopia, including millet, teff, sorghum, maize, sesame, honey and an alcoholic drink called tella. PAs were detected in all the grains tested and in tella, as well as in a tea made from some of these grains. Contaminated flour, tea and tella were thought to be the primary contributors to liver disease in adults and children in this region and these products are now being evaluated accordingly to prevent further dangerous toxin exposure. Because PA-containing plants are worldwide in distribution and impact, this research is important to national and international animal and human health organizations in mitigating and preventing exposure to toxic pyrrolyzidine alkaloids some of which are potent carcinogens.

Effect of weather on growth of beef cattle in the Northern Great Plains. Weather and climate are known to affect forage quantity and quality and animal stress, yet predictions of climate effects on livestock production are hindered by limited analyses comparing long-term climate and cattle production data. ARS researchers at Miles City, MT, reported relationships between weather and calf weaning

weight from 76-year records. As expected, calves grew faster with long, cool growing seasons. However, precipitation during late winter (Feb 6-22 – late gestation) was associated with significantly reduced calf weaning weights, possibly as a result of maternal negative energy balance or some yet unexplained factors (imprinting, etc). This suggests that additional feed or shelter for late gestation cows in late winter might be beneficial to cattlemen even with normal calving rates and calf birth weights. Additional analyses indicate that, as expected, high temperatures during the first two weeks of summer were negatively related to calf growth. However, long cool grazing seasons – which typically produced the best calf weaning weights – tended to start earlier in the year. The conventional wisdom is that an earlier spring means a hotter growing season and earlier plant maturity (reduced forage quality). ARS data suggest that earlier springs provided more cool growing-degree days before hot summer temperatures arrived, potentially refuting the supposition that earlier green-up leads to earlier plant maturity and lower forage quality. This work facilitates forecasting of climate effects on beef production and has led to collaborative research examining weather relationships with cow and steer performance with ARS researchers in Cheyenne, WY, and Mandan, ND.

Identification of cytotoxic and potentially carcinogenic dehydro-pyrrolizidine alkaloids in human and animal food/feed. The pyrrolizidine alkaloid (PA) riddelliine has been listed as a potential human carcinogen. ARS researchers in Logan, UT used cell culture models to determine that several other PAs (lasiocarpine, seneciophyline, senecionine, and heliotrine) were significantly more cytotoxic than riddelliine. Toxicity appears to be alkaloid-specific with little relationship to the base type or class of side chain. As the mechanisms of carcinogenesis and toxicity are probably the same, it is likely that the highly cytotoxic PAs present a larger carcinogenic risk than riddelliine, the only PA currently identified as a potential human carcinogen. Identification of PAs that are cytotoxic and potentially carcinogenic is essential to the identification and development of methods of analysis for PAs in animal feed, human food, and animal or human herbal products that will be used to prevent poisoning and lower the risk associated with these potential carcinogens.

Diagnosis of pine needle and juniper induced abortions in the U.S. and Spain. In the western U.S., pregnant cows grazing on ponderosa pine needles commonly have an increased rate of spontaneous abortion. These abortions are a significant economic loss to cattlemen. Serum samples from aborted fetuses and their dams from both the U.S. and Spain were compared for metabolites of isocupressic acid (ICA), the abortion-causing toxin in pine needles. ARS scientists in Logan, UT identified common juniper as the cause of plant-induced abortion in the Rioja mountain region of Spain. The additional cause of cattle abortions from common juniper in addition to the ponderosa pines is important information for cattle producers, as both are common in the western U.S. In fact, junipers inhabit much of the U.S. and these findings can now be used to prevent previously undiagnosed spontaneous abortion incidents in regions where junipers are available to pregnant cows.

Problem Statement B: Need for management strategies and practices that enhance and conserve rangeland ecosystems to provide multiple ecosystem services including forages for livestock, soil conservation, water quality, control of invasive species, recreation and wildlife habitat conservation under changing environmental conditions.

Revegetation and restoration options for crested wheatgrass stands on western rangelands. Crested wheatgrass is often used in rangeland vegetation restoration and rehabilitation projects because of its

high rate of establishment compared to native perennial bunchgrasses. However, once established, reintroduction of native plant species into these crested wheatgrass stands has been largely unsuccessful, limiting their value for many wildlife species. ARS researchers at Burns, OR, demonstrated that crested wheatgrass stands could be diversified by planting sagebrush seedlings. Results indicate that control of crested wheatgrass was not needed for successful establishment of sagebrush, and did increase the growth of sagebrush. This research represents the first published success in re-introduction of native plant stock into crested wheatgrass communities. Reestablishment of sagebrush in crested wheatgrass communities will increase their value to sagebrush-associated threatened and endangered wildlife species, including the sage-grouse.

Weather variability and adaptive restoration management for rangelands. Temperature extremes, drought and other weather phenomena in the western U.S. make rangeland restoration an extremely risky endeavor. Successful restoration requires a management approach that adapts to variations in weather to successfully establish a desired plant community. ARS researchers in Boise, ID, developed a procedure for quantifying how historical weather patterns affected seed germination of common grasses and shrubs, then created a conceptual model to use this information in an adaptive management framework for future rangeland restoration efforts. This methodology can be used by land managers to design more effective restoration plans for millions of hectares of rangelands in the western U.S. that have been invaded by introduced annual weeds.

Influence of endophyte genotype on toxic swainsonine concentrations in different populations of locoweeds. Locoism is a toxic syndrome of livestock caused by the ingestion of a subset of legumes known as locoweeds. The disease is characterized by motor and sensory nerve damage resulting in peculiarities of gait, impairment of vision, extreme excitement, emaciation, and ultimately paralysis and death. Locoweeds contain the toxic indolizidine alkaloid swainsonine, which is produced by the endophytic fungi *Undifilum* species. The distribution and severity of swainsonine-produced lesions are species-specific. Horses, goats, cattle and sheep are the most sensitive to swainsonine poisoning while rodents and deer are relatively resistant. Previously ARS scientists in Logan, UT, reported that swainsonine concentrations differ between populations of legumes. A study was conducted to determine if the genotype of the plant, endophyte, or an interaction of the two might be responsible for the differences in swainsonine concentration in these legume populations. Legume plants derived from seeds collected at 2 locations were grown in a common environment, and a plant genotype by endophyte cross inoculation was performed. Results showed that the genotype of the endophyte is responsible for the differences in swainsonine concentrations observed in the two populations. As a result, better predictions of swainsonine concentration can now be provided to producers, reducing the relative risk of animals grazing on locoweeds. In related work ARS scientists developed sensitive models to compare swainsonine-induced toxicity with those of other toxic alkaloids for various animal species. This information will be used to better define the risk of poisoning and to determine the role swainsonine plays in other plants that contain swainsonine along with mixtures of other toxic alkaloids.

Problem Statement C: Need for greater fundamental understanding of ecological processes and interactions so science-based management practices, technologies, and germplasm can be improved to meet production, conservation and restoration objectives under changing climatic conditions.

Evolution of a competitive advantage (weediness) in invasive mullein. Rapid evolution may help invasive plants/weeds succeed in their new range, but it is unclear which traits evolve and how common such evolution is. Scientists from ARS in Fort Collins, CO, in cooperation with scientists from Colorado State University, discovered that common mullein, a Eurasian plant that is invasive in much of the United States, has evolved several traits typical of weedy and invasive species that bolster their competitive advantage. These traits include low root-to-shoot ratio, rapid growth, and rapid responsiveness to high water availability. U.S. mullein populations also developed enhanced resistant to a generalist insect herbivore. These results will help scientists and managers understand the role of evolution in invasion, and develop management strategies, such as increased competition from desired species, to combat species with such new evolved competitive traits.

Degraded Great Basin rangelands can be rehabilitated with herbicides. Rangelands of the Great Basin are difficult to rehabilitate due to invasive species competition and extreme aridity. In cooperation with stakeholders, including the livestock industry and the mining industry, ARS scientists in Reno, NV, tested cheatgrass control methods, various plant materials, and post-rehabilitation practices to provide resource managers and private land owners improved technologies to rehabilitate rangelands. ARS techniques have resulted in 98% control of cheatgrass on research plots. Moreover, such control has improved the establishment of desirable plant species benefitting forage value, wildlife habitat, and plant community structure. The Nevada Department of Wildlife has documented a 400% increase in the local mule deer populations in these study areas.

Developing improved plant materials for the Western U.S. rangelands. The invasion of weedy annual grasses following disturbance (grazing, wildfires, or human) is increasing on western rangelands. More annual grasses contribute to greater wildfire frequency, which destroys rangeland diversity, increases soil erosion, decreases air quality, and degrades wildlife and livestock habitat and forage, costing the U.S. agricultural economy billions of dollars. Currently there is a lack of perennial plant materials available that will successfully establish, persist, and compete against invasive annual grasses. To meet these demands, scientists in Logan, UT, developed and released improved plant cultivars of Indian ricegrass, Snake River wheatgrass, basin wildrye, bottlebrush squirreltail, western wheatgrass, Siberian wheatgrass, crested wheatgrass, alfalfa, basalt milkvetch, western prairie clover, and forage kochia. These plant materials have consistently demonstrated improved ability to establish, persist, and reduce the invasion of weedy annual grasses on range sites that experience frequent drought, hot temperatures, disturbance, and frequent wildfires. These plant materials provide additional options for public and private land managers in their fight to restore western rangelands to a stable productive ecosystem. Seed is now available commercially for most of these plant materials.

Rangeland restoration to reduce losses to livestock from poisonous plants. In many areas in the western U.S., rangeland ecosystems have been compromised, enabling poisonous plants to flourish and causing increased animal losses. ARS researchers at Logan, UT, established seeding and demonstration plots using improved rangeland grasses and forbs to show that restoration of rangelands to a healthy ecosystem will reduce or prevent animal losses from poisonous plants. Replicated seeding plots and larger demonstration plots were established on the Channeled Scablands in eastern Washington State where lupine-induced “crooked calf syndrome” is endemic and occasional catastrophic losses of baby calves occur. Evaluation of replicated plots and demonstration plots indicated that varieties of wheat grasses including Hycrest and Siberian, mixed with palatable forbs such as forage Kochia, will successfully establish and persist in this harsh environment, improving the forage base for cattle and

wildlife grazing while decreasing the threat of poisonous lupine. This research is important to ranchers because it will lead to improved forage quality, biomass and reduced losses from lupine-induced crooked calf syndrome.

Innovative approaches for remotely monitoring land surface conditions in arid rangelands. Monitoring the condition of rangelands in real time or on a schedule that facilitates optimum land management systems is very challenging. Better methods are needed to integrate remotely sensed data from multiple sources in order to inform and support land management decision-making. ARS scientists in Las Cruces, NM, developed multiband observational capabilities for monitoring rangeland surface conditions from tower and Unmanned Aircraft System (UAS) cameras and satellite systems. Field and satellite observations were linked in order to monitor plant phenology in real time. Time-series UAS imagery was used to develop a protocol for accurately mapping rangeland vegetation. These technologies have direct application for real-time assessment of rangeland health and monitoring vegetation type and phenology to improve rangeland management and ecology and responses to drought and other environmental factors.

A grazing strategy to reduce impact of lupine induced crooked calf syndrome on western rangelands. Lupine-derived crooked calf syndrome is a result of complete fetal inactivity, which results in severe skeletal deformations. ARS scientists in Logan, UT, determined that intermittent grazing of lupine could potentially mitigate or substantially reduce the impact of lupine as a primary cause of crooked calf syndrome. In this study pregnant cows were fed lupine in a "ten day on - 5 day off" regiment for 30 days and then compared with cows fed lupine daily for 30 days. Cows fed lupine for 30 days uninterrupted gave birth to severely deformed calves. Cows fed lupine on the intermittent regiment produced calves that were marginally affected (i.e. slight contractures which resolved spontaneously) or normal calves. This study confirms that removing cattle from lupine exposure, even for a short period, allows calves to regain normal fetal movement and prevents the most severe birth defects. This method has been implemented by cattle ranchers in Washington State with great success, allowing producers to utilize these productive high risk pastures and still reduce the impact from lupine.

Component 2: Develop Improved Pasture Technologies and Management Systems

Problem Statement D: Need for pasture-based livestock production systems that meet producer, environmental, and food security objectives and are adaptable to changing environmental and climatic conditions.

Antibiotic production by a soil bacterium inhibits the growth of certain plant pathogens. Strain SBW25 of the bacterium *Pseudomonas fluorescens* has been extensively studied for its plant growth promoting properties and its ability to protect certain crops from disease. The basis of this protection was not understood and consequently, the disease-reducing properties could not be extensively applied to crop production. Scientists at ARS in Corvallis, OR, and Oregon State University, isolated and identified the antibiotic, L-furanomycin from cultures of this bacterium and demonstrated that this antibiotic inhibited the growth of a pathogen of tomatoes, as well as the bacterium that causes bacterial soft rot of corn. This research suggests that antibiotic production by SBW25 impacts the interaction of microbial populations that affect soil productivity by reducing the populations of certain crop pathogens.

This is the first report of furanomycin production by a *Pseudomonas* bacterium and may lead to significant advances in crop protection and production.

Condensed tannins reduce ruminal protein degradation. Although alfalfa and other legumes are valued for their high crude protein concentrations, this key nutritional resource is often used inefficiently by dairy cows. Condensed tannins, which are found naturally in birdsfoot trefoil but not in alfalfa, may improve the efficiency of protein use by partially shifting the digestion of protein from the rumen to the gastrointestinal tract of cattle. ARS researchers at Marshfield and Madison, WI, evaluated 24 alfalfa and birdsfoot trefoil hays and silages to estimate the amount of protein degradation in the rumen. Results indicate that protein degradation decreased by 3.2 to 4.6 percentage units of crude protein for each percentage unit of condensed tannin in the forage. In this study, condensed tannins modestly reduced the proportion of protein degraded in the rumen, which should improve protein-use efficiency of dairy cattle. Gains in protein use-efficiency are desirable because they reduce both the need for costly protein supplements for cows, and the loss of ammonia from manure that causes nitrogen pollution of waterways and respiratory problems in humans and livestock.

Understanding genetic diversity of native range plants across the landscape. There is an increasing desire among public and private land managers to use plant materials that are genetically similar to native (local) communities when revegetating western rangelands after disturbance. However, little is known regarding the patterns of genetic diversity of these plant materials across a landscape scale. Using molecular genetics techniques, ARS scientists in Logan, UT, characterized the patterns of genetic diversity in Idaho and Roemer's fescue, bluebunch wheatgrass, Snake River wheatgrass, slickspot peppergrass, Utah sweetvetch, mannagrass, basalt milkvetch, western prairie clover, small burnet, and orchardgrass. This work defined the differences between self- and cross-pollinating species and led to the development of improved plant materials that are genetically similar to local communities. This research was also used by the U.S. Fish and Wildlife Service (USFWS) in deciding not to list slickspot peppergrass as an endangered species. The techniques have been adopted by APHIS, Bio security Australia, and Oregon Dept. of Agriculture as an official testing protocol.

Problem Statement E: Need for management strategies and practices that enhance and conserve pasture agro-ecosystems to provide multiple ecosystem services under changing environmental and climatic conditions.

Innovative approaches for multi-scale and remote monitoring and assessing land surface conditions. Methods are needed to integrate remotely-sensed data from multiple sources in order to inform and support land management decisions. ARS scientists in Las Cruces, NM have developed multiband observational capabilities for monitoring rangeland surface condition from tower and Unmanned Aircraft System (UAS) cameras and satellite systems. Field and satellite observations were linked to monitor plant growth and development (phenology) in real time. Time series UAS imagery was used to develop a protocol for accurately mapping rangeland vegetation and changes over time. These technologies have direct application for assessing rangeland health and monitoring vegetation type and phenology. In related research, standardized approaches for monitoring rangelands are needed to allow data-sharing among agencies and to address policy needs. ARS scientists led development of rangeland monitoring indicators, field methods, and sampling design techniques that are now being applied to over 200 million acres of BLM and private land (NRCS-NRI) in the United States. ARS created web-based and GIS tools to support monitoring programs (design, data collection, and analysis) and developed near real-time smartphone and tablet-based data collection protocols. The inventory, monitoring, and

assessment techniques and tools developed by ARS scientists are producing consistent and interpretable data that provide managers and policy makers with information necessary to manage resources at local to national scales.

Problem Statement F: Need for science-based understanding of how soils, plants, animals, climate and human activities interact to affect pasture ecosystem structure and function at multiple scales over time to improve the effectiveness of land management under changing environmental conditions.

Improved genetic selection technology for complex grass genomes. Genetic selection programs to improve valuable traits of forage grasses with complex genomes (polyploids) have been hindered by a lack of technologies to effectively target specific genetic markers and associated gametes. In response to this critical limitation, ARS researchers at El Reno, OK have developed a "gamete-selection" approach for tall fescue and rye grass that now provides forage breeders with technologies similar to those so effectively used to increase the yield and adaptability of corn and other commodity crops. This technology has the capacity to revolutionize grass breeding by identifying elite germplasm through the development of dihaploid selection lines for use in subsequent generations, thus increasing the rate of genetic progress several-fold over conventional breeding strategies. This technology may also be used to evaluate the specific interaction of tall fescue with both toxic and non-toxic fungal endophytes. It has been well established that there is a very precise interaction and careful balance between the fungal endophyte and the nuclear genome of the individual plant. If the interaction is not good, the fungal endophyte stunts the growth and development of the plant. If the endophyte-nuclear genome interaction is complementary, the plant thrives. This technology would enable more precise evaluation of the relationship between specific genotypes and fungal endophytes in order to promote those that are highly resilient and productive, but not toxic to grazing animals. Additionally, the gamete-selection approach is inexpensive and low input. It is now being disseminated to industry and is providing excellent achievement in identifying and generating superior tall fescue materials with industry collaborators.
Rapid DNA-based paternity testing assay for alfalfa will speed rate of alfalfa improvement. Alfalfa is the fourth most widely grown crop following corn, soybeans, and wheat in the U.S. with over 20 million acres harvested in 2012. In alfalfa variety development programs, the pollen donors of plants being evaluated are mostly unknown. This lack of paternal identity leads to slower genetic improvement from alfalfa breeding programs. ARS researchers in Madison, WI collaborated with an industry stakeholder to develop a low-cost, rapid DNA-based paternity testing laboratory assay for alfalfa, including necessary computational software. This new technology will double the amount of genetic information available to alfalfa breeders allowing them to target and select specific genetic lines and significantly increase the yield and adaptability of existing and developing alfalfa varieties.

Novel molecular tools developed for grass breeding. Until recently, molecular genetics tools (i.e., maps, markers, etc.) were limited for many grass species. The development of DNA maps and associated gene markers is critical for the continued development of improved plant materials better adapted to establishment, persistence, and tolerance of drought, increased salinity, and freezing. ARS scientists in Logan, UT, developed DNA maps and markers in alfalfa, basin and creeping wildrye, thickspike and Snake River wheatgrass, bluebunch wheatgrass, and orchardgrass. Sequencing and mapping of expressed gene sequences from perennial grasses and alfalfa have been completed to characterize genes associated with seed retention, rhizome development, seed germination, self-

incompatibility, forage quality, forage production, heavy metal uptake, winter survival (orchardgrass), and flowering habit (orchardgrass; late versus early). These new genomic resources and their comparative genetic analyses with related high-value crop species, such as wheat, will enable rapid improvement of perennial plant materials for pasture and rangelands and identify sources of disease resistance for wheat improvement.

Improved bioenergy type switchgrass cultivar with high biomass yield tested and increased for use in the northern U.S. Switchgrass cultivars for the northern half of the U.S. have been limited to upland ecotype switchgrass cultivars because traditional lowland cultivars have poor winter survival in the region. However, lowland switchgrass cultivars could produce greater biomass yields if they had better winter survival. A new lowland type switchgrass cultivar 'Liberty' was released in 2013. Liberty was developed by ARS researchers at Lincoln, NE by crossing northern upland and southern lowland plants followed by three generations of breeding selection for improved winter survival, high biomass yield, and low stem lignin concentration. Over a three year period in trials in NE, WI, and IL, Liberty had excellent winter survival and in eastern NE and northern IL had biomass yields that were two tons per acre greater than the best available upland cultivars. The experimental strain is in the release process and has been planted in a Foundation seed increase field. It will be the first bioenergy type cultivar for the Midwest and the northern Great Plains and will likely be adapted to the Northeast states as well. When processed in a biorefinery, the increased biomass yield will result in an additional 160 gallons of ethanol per acre, which could fuel an economy car for an additional 5000 miles per year.

Improved germination and stand establishment in forage kochia benefits the livestock industry. Forage kochia is an introduced high quality and nutritious, semi-shrub that has been seeded on western U.S. rangelands for fall and winter forage. However, its widespread acceptance has been reduced by its poor seedling germination and subsequently reduced stands. ARS scientists in Logan, UT, showed that use of two subspecies of forage kochia *B. prostrate* (*grisea* and *virescens*), along with age of seed, and planting date all affected forage kochia seed germination in the field. At 45 days after planting, when germination was at or near maximum, current year's harvested seed of subspecies *grisea* had field germination of 85%. This was higher than subspecies *virescens*, and significantly higher than year-old seed of both subspecies, which germinated at less than 15% during the same planting dates of January through April. Thus, planting in January or February using current year's harvested seed of subspecies *grisea* provided the best forage kochia germination, and increased the likelihood of a successful stand. These results were disseminated to livestock producers through several regional meetings in Montana, Wyoming, and Utah during the winter of 2013. The use of forage kochia during the fall and winter grazing periods reduces overall animal feeding costs by up to 25% on some ranches through reductions in stored forage and extension of the grazing season.

Improved smooth bromegrass strain increases beef cattle gains on pastures. Improved cool-season grasses are needed in the Midwest and Northern Great Plains to improve stagnant pasture beef cattle gains per acre and beef enterprise profitability. ARS scientists in Lincoln, NE, in collaboration with University of Nebraska, used a 3-year grazing trial with beef yearlings to evaluate an improved smooth bromegrass strain developed for increased forage yield and digestibility. Cattle grazing the improved bromegrass had 3-year average daily gains of 3.1 lbs per head per day during spring grazing. The 3-year average body weight gain of 349 lbs per acre during the spring grazing season was 12% greater than that for the widely used smooth bromegrass parent cultivar, demonstrating that the genetic improvements in smooth bromegrass can have significant economic value when used in well managed pastures. The

smooth bromegrass experimental strain is in seed increase for potential release as a new cultivar and will be available for use to meet the demand for improved cool-season pastures in the Midwest and Northern Plains.

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

Problem Statement G: Need for improved plant materials for harvested forage and biomass production systems based on forage legumes and grasses that will increase the efficiency of livestock and bioenergy production systems while enhancing the environment.

Novel alfalfa management options contributes to improved ethanol potential. In an alfalfa biomass energy production system, alfalfa hay can be separated into cellulose-rich stems to produce liquid fuel (ethanol) and leaves to produce a valuable high protein livestock feed. Maximizing yield of leaf protein and stem cell wall sugars is essential for optimum economic return of such a biofuel production system. ARS scientists in Saint Paul, MN and Madison, WI found that potential ethanol yield was greater from stems harvested at the late flower stage compared to stems harvested at the early bud stage, while leaf crude protein yields were similar between the two harvest management schemes. The two non-lodging biomass-type alfalfa cultivars evaluated had greater potential ethanol yield than the high-forage-quality cultivars at the Wisconsin field site but the high quality cultivars had greater leaf crude protein yield than the non-lodging types at the Minnesota site. Using new biomass type alfalfas together with modified cutting management strategies will increase the profitability of alfalfa biomass production systems by reducing costs as much as 19%.

Problem Statement H: **Need for improved harvested forage and biomass production systems that increase economic and energy efficiency while enhancing the environment to meet national energy and food security goals.**

Perennial peanut protects protein from degradation during ensiling. Ensiling is a popular method of preserving forage through natural fermentation, especially in humid regions where drying options to produce high quality hay might be limited. Ruminant animals such as dairy cows have limited ability to use plant protein that is broken down during harvest and storage. It costs farmers an estimated $100 million annually to supplement livestock feed with protein to make up for this deficiency. However, alfalfa does not grow well in warm, humid climates, and southern farmers often pay to ship alfalfa hay from cooler regions. Previous research had indicated that perennial peanut forage show improved protein use efficiency when fed to lambs as haylage (ensiled). ARS scientists in Madison, WI, had previously demonstrated that in red clover, reaction of special phenolic compounds with an endogenous polyphenol oxidase (PPO) enzyme prevents protein degradation when the forage is preserved by ensiling. ARS scientists and collaborators then demonstrated that this same mechanism is present in the perennial peanut. This discovery demonstrated that perennial peanut could be a high quality, cost effective alternative forage legume for southern farmers.

Component 4: Turf Improvement

Problem Statement J: Need for improved germplasm and management practices that are adapted to biotic and abiotic stresses and meet the objectives of turf producers and users under changing climatic and environmental conditions.

Elevated salinity of soils greatly limits alfalfa production. Identifying and characterizing genes that control the complex trait of salt tolerance in alfalfa will accelerate conventional breeding programs and increase production efficiency, sustainability and value of this most widely grown forage crop in the United States. ARS scientists in Beltsville, MD, performed next generation sequencing to determine the activities of genes in alfalfa cultivars that contrasted in salt tolerance. The findings revealed a broad spectrum of genes affected by salt stress. More than 60,000 tentative consensus sequences were obtained and analyzed. Bioinformatics analysis showed that the expression of 1,165 genes was significantly altered under salt stress. About 40% of differentially expressed genes were assigned to known gene ontology categories that describe gene products in terms of their associated biological processes and molecular functions. Knowledge on genes and global gene expression data obtained in this work will speed the development of new salt-tolerant cultivars and the molecular markers identified will be used for genetic mapping of the salinity trait and for marker-assisted selection in breeding programs.

Nitrogen supply from alfalfa is robust. Alfalfa provides an excellent environment for its natural symbiont, rhizobial bacteria, which return the favor by capturing nitrogen from the air for use by the plant. Over time, this process enriches the soil with nitrogen, providing fertilizer for later crop rotations. However, it is not known how this nitrogen supply varies with crop and soil management. An ARS scientist in Saint Paul, MN, and colleagues at the University of Minnesota found that the residual nitrogen supply was not affected either by livestock manure application to the alfalfa before it was killed, or by using no-tillage instead of complete mixing of alfalfa residue with the soil. It was also discovered that approximately 50% of the time, alfalfa provides residual nitrogen adequate for both the first and second subsequent crops of corn, saving the farmer about $160 per acre and reducing the amount of fossil fuel needed to produce corn. In some cases, the amount of nitrogen needed for highest yield of the second corn crop varied widely, but in only 10% of the cases did it need the same dose of fertilizer as required by continuous corn. These findings make the prediction of nitrogen more reliable, and will result in markedly reduced N fertilizer costs for farmers by reducing excessive fertilizer nitrogen application to corn grown after alfalfa.

Controlling coccidiosis in small ruminants to improve performance on intensively grazed pastures. Coccidiosis is one of the most economically devastating parasitic diseases of small ruminants and other livestock. This protozoan infection of the gastrointestinal tract is difficult to treat and can cause diarrhea, dehydration, loss of appetite, weight loss, and even death of young animals. *Sericea lespedeza* (SL), a legume forage, has been reported to control gastrointestinal parasites in small ruminants when fed as pellets, but no data existed on the control of coccidiosis in lambs. ARS scientists in Booneville, AR, and collaborators determined that feeding SL pellets effectively controlled coccidiosis and reduced the need for pharmaceutical treatment of the disease. This information is important to organic and conventional small ruminant producers, extension agents, and scientists and may have further impact on other livestock species, reducing death and chronic slow growth of young animals.

Determination of appropriate production practices of bioenergy feedstock grasses for the Southeast.

Two high-yielding perennial grasses have shown promise as biomass feedstocks in the Southeast. However, specific cultivars and production practices need to be determined to guide growers. ARS researchers at Tifton, GA, grew napiergrass (also called elephantgrass) in a non-irrigated study with either poultry litter or inorganic fertilizer. In general, nitrogen removal exceeded the amount applied, suggesting that higher fertilizer application rates are necessary than those currently recommended. Total soil carbon increased by over 3000 kg ha^{-1} among the three treatments, indicating that use of napiergrass as a biomass feedstock would be either carbon-neutral or carbon-positive relative to petroleum-based alternatives. In a related study, ARS scientists grew different breeding lines of energycane (high-yielding high-fiber biomass feedstock derived from sugarcane) to evaluate conversion to ethanol over time. A laboratory procedure converted the biomass from nine different energycane breeding lines to ethanol. Ethanol yield from higher fiber energycanes was more stable over multiple harvests because they contain fewer free sugars. These higher fiber energycanes also produced higher yields in Tifton, GA compared to sugarcane types. Information from these two studies will help direct the bioenergy industry and growers on types and methods of high-yielding biomass grasses for the Southeast.