USDA

United States Department of Agriculture

Agricultural Research Service

2018 ANNUAL REPORT ON SCIENCE

RESEARCH TO DEVELOP AND TRANSFER SOLUTIONS TO AGRICULTURAL PROBLEMS

www.ars.usda.gov

ABSTRACT

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This publication is the Agricultural Research Service's 2018 annual report on science, composed of numerical research outputs for the agency, accomplishments and impacts for each goal in the ARS 2012-2017 Strategic Plan, and ARS' performance plan for 2019.

Additional copies of this Report on Science can be downloaded from www.ars.usda.gov.

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INTRODUCTION

The Agricultural Research Service (ARS) is the U.S. Department of Agriculture's (USDA) chief in-house scientific research agency. Each day, more than 2,000 ARS scientists at more than 90 research locations, including overseas laboratories, discover real-world solutions to America's agricultural challenges.

Our unique capacity to conduct research that has an impact on the food we eat, the water we drink, and the air we breathe makes ARS one of the world's premier scientific organizations and a recognized champion of integrated research targeting national and regional agricultural priorities.

ARS' mission is to deliver scientific solutions to national and global agricultural challenges, with a vision of global leadership in agricultural discoveries through scientific excellence.

ARS' Strategic Plan for FY 2012-2017 describes the Agency's research, program management, administrative management, and civil rights and diversity goals. It also crosswalks ARS' priorities to those of the Department and of the Research, Education, and Economics Mission Area.

ARS organizes its research activities into 15 National Programs that are part of one of four broad Strategic Goal Areas:

- Nutrition, Food Safety and Quality;
- Natural Resources and Sustainable Agricultural Systems;
- Crop Production and Protection; and
- Animal Production and Protection.

The specific research goals for each of the four Strategic Goal Areas are developed after consultation with customers, stakeholders, and scientists and are described in each National Program's Action Plan, which form the basis for the research component of ARS' Strategic Plan. A full description of ARS' 5-year National Program Cycle, based on Relevance, Quality, Performance, and Impact, can be found in Appendix 1.

This Annual Report on ARS science describes progress made in Fiscal Year (FY) 2018 on the research goals described in the Strategic Plan in sections that address the Agency as a whole and for the specific Strategic Goal Areas. It also delineates the Agency's research performance plan for FY 2019-2021.

ARS ANNUAL REPORT ON SCIENCE

The outcomes and impacts of agricultural research occur on a continuum that begins when new knowledge is captured in scientific publications and databases. Some of that knowledge can be directly transferred into use by means of trade journal publications and outreach activities. Other knowledge requires additional research, often collaboratively with industry and other partners, to develop products. Some of these products are released by ARS into the public domain and some require intellectual property protection and licenses as incentives for utilization through commercialization. These types of research outputs can be measured quantitatively and are listed under Research Outputs below. The ARS Section of the USDA Annual Report on Technology Transfer more fully describes the Agency's technology transfer accomplishments.

Any measure of successful ARS research would have to include its positive impacts on U.S. and global agriculture, a safer and more nutritious food supply for the nation and the world, and reduced environmental impact from food production. Outcomes and impacts of ARS research realized in FY 2018 are documented for each ARS research goal.

In this document, ARS has integrated its performance plan, which describes specific research targets for the next 3 years, with its annual report, which describes what was accomplished for last year's research targets and why those accomplishments are important.

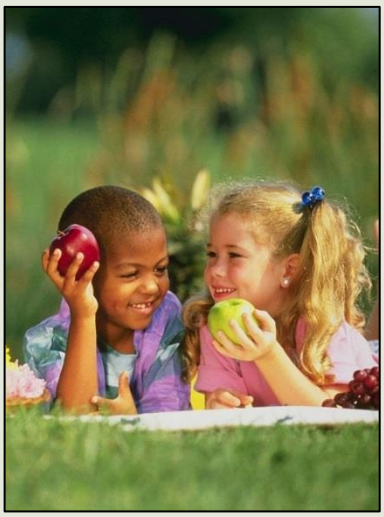
ARS Research Outputs in FY 2018

Scientific Knowledge	4,138	Peer-reviewed journal articles
Knowledge Transfer	68	Trade journal publications
	118	New Material Transfer Research Agreements
	476	New Cooperative Research and Development Agreements
	108	Patent applications filed (21 new patents issued)
	40	New licenses (426 active licenses total)
Preparing the Next Generation	82,091	Students participating in ARS outreach events (includes workshops and career fairs)
	2,100	Students and interns
	450	Postdoctoral scholars

Progress on Emerging Priorities in FY 2018

Agriculture is dynamic, driven by environmental, biological, economic, social, and technological change. New capabilities are realized and new threats emerge. In FY 2018, ARS initiated or continued progress on the following emerging priorities.

ARS SYNERGIES



In FY 2015, ARS accelerated its pursuit of innovation to propel U.S. agriculture into the future. We wanted to develop a new way of thinking about how we do our science, something that could be a catalyst for breakthrough innovation. An aspirational goal was collectively set – *Transforming Agriculture to Deliver a 20 Percent Increase in Quality Food Availability at 20 Percent Lower Environmental Impact by 2025*. This Grand Challenge recognizes the many pressing issues facing U.S. agriculture and that these issues are inextricably linked. In the minds of farmers, consumers, and citizens, having sufficient food to meet a growing population, ensuring it is of wholesome quality, and addressing agriculture's substantial environmental footprint are inseparable needs. To address them holistically, ARS research leadership designed an innovative mechanism to foster research collaborations that cut across disciplines, projects, and locations, enabling synergistic, system-level solutions to complex agriculture problems.

The ARS Synergies (formerly Grand Challenge) initiatives launched by the Office of National Programs recognize two trends in the scientific enterprise. The first trend is convergence among many disciplines in solving system wide challenges. Often called "wicked" problems, some of the thorniest problems in agricultural science are hard to define, undergo change during the process of research, and have multiple targets or problem points. An example is the goal to increase the benefits of consuming dairy products, improve dairy product quality, and reduce the environmental impacts of production. The Dairy Agriculture for People and the Planet project is designed to address these questions across human nutrition, animal production and environmental services disciplines and aims to integrate a wide variety of data in one coherent project for the first time.

Another example is the Solving the Citrus Greening Problem Project, which is set to enable the recovery or re-invention of sustainable citrus production in the presence of citrus greening. The project team draws upon frontier technologies of vector population management, pathogen control, disease symptom mitigation, delivery systems for inputs, and new germplasm to find ways of controlling this critical and rapidly spreading invasive disease. Moving forward, these ARS Synergies will focus on cross-disciplinary team building to achieve broader and higher impact goals.

A second trend that has typically been outside the reach of ARS until now, has been the entrepreneurial opportunity to follow a high-risk/high impact breakthrough insight by developing and testing an idea that may lie at the fringe of individual expertise. The recent renaissance in prize competitions, and success of platforms such as "Innocentive" led ARS to launch ARSX, a place for allowing agricultural scientists pursue their unconventional ideas.

ANTIMICROBIAL RESISTANCE

Antimicrobial resistance (AMR) has been an area of focus during the past two decades for USDA, which plays a dual role in protecting animal agriculture and public health. Growing concern regarding antimicrobial resistance led to development of the *USDA Antimicrobial Resistance (AMR) Action Plan* and Executive Order 13676, *Combating Antibiotic-Resistant Bacteria*. The *National Action Plan for Combating Antibiotic Resistant Bacteria* was published on March 27, 2015 and identified the following goals:

1. Accelerate basic and applied research and development;
2. Slow the emergence of resistant bacteria and prevent the spread of resistant infections;
3. Strengthen national "One Health" surveillance efforts;
4. Advance development and use of rapid and innovative diagnostic tests; and
5. Improve international collaboration and capacities.

The following accomplishments addressing antimicrobial resistance were realized in 2018.

- ARS determined the efficacy of the plant *Nigella sativa* (black cumin), as a potential substitute for conventional antibiotics currently used in swine production. The work established that feeding black cumin dramatically improved growth efficiency of the pigs and helped them resist colonization by the bacterium, *Escherichia coli*, which is particularly pathogenic for young pigs. These results provide important information on a potential new feed additive that can help pig farmers improve the health and well-being of their young animals. Ultimately, these results will help pig farmers find new ways to safely and economically produce high quality and wholesome pork products at less cost.

- ARS found that gut bacteria in pigs fed carbadox, an antibiotic not used in humans but widely used in U.S. pig farms, behaved differently than the gut bacteria in non-medicated pigs. The differences indicated that the gut bacteria were not behaving typically and that phages, viruses that kill bacteria, were being induced in the gut microbiota. In this case, the phage genetic material had antibiotic resistance genes that could transfer resistance to antibiotics that are important in human medicine. Understanding the potential collateral effects of antibiotics will provide information to practitioners to help limit the negative consequences of antibiotic therapy.

- ARS scientists used advanced technologies (metagenomic analysis) to evaluate the antibiotic resistance genes present in the feces of pre-weaned dairy calves and lactating dairy cows from 12 farms. They showed that feces of pre-weaned dairy calves have a significantly different bacteria than lactating cows and that the antibiotic resistance genes in the bacteria were significantly different between the adults and calves. This shows that dairy animals are colonized with antibiotic resistant bacteria at a very young age and indicates that more information is needed to determine the factors that affect this early colonization to determine mitigation approaches dairy operations could use to potentially decrease the abundance of antibiotic resistance in these animals.

- Irradiation effectively reduces foodborne pathogens and spoilage microorganisms on fresh produce. However, limited research is available regarding its effect on antibiotic-resistant bacteria, or on the genes that convey that resistance. In collaboration with Virginia Tech, ARS scientists inoculated lettuce leaves with a compost slurry containing multi-drug resistant pathogens. The lettuce was washed with a mild sanitizer, irradiated, and stored for

14 days at 4° C. Irradiation reduced pathogens by 99.9 percent, no significant regrowth was seen during storage and no differences in antibiotic resistance genes were observed between irradiated and control lettuce over time. These results show that irradiation effectively reduces antibiotic resistant bacteria on romaine lettuce. This information can be used to help design use protocols for irradiation as it is applied to fresh and fresh-cut produce, improving food safety.

CLIMATE CHANGE

The vision of the USDA Climate Change Science Plan is empowering farmers, foresters, ranchers, land owners, resource managers, policy-makers, and Federal agencies with science-based knowledge for managing the risks, challenges, and opportunities of climate change, including positioning them to reduce atmospheric greenhouse gas (GHG) emissions and enhance carbon sequestration. ARS has a broad portfolio of research that supports Departmental goals for resilient crop and livestock production systems adapted to changing climate patterns and dynamics.

In FY 2018, ARS scientists:

1. Led the research, development, and appropriate application of advanced technologies and management systems that reduce agricultural emissions of nitrous oxide, carbon dioxide, and methane;
2. Developed and enhanced technologies and management systems that increase the sequestration of atmospheric carbon in agricultural agroecosystems, resulting in the storage of more carbon in soils, biomass, and biobased products;
3. Improved management systems that build soil health and climate resiliency, which help landowners strategically adapt to weather extremes and changing climatic conditions; and
4. Provided approaches to improve environmental system measurement and monitoring, which together provide the scientific and agricultural stakeholder communities with better data. These data are being used to enhance the ability to quantify and inventory GHG emissions and carbon storage at local to national scales.

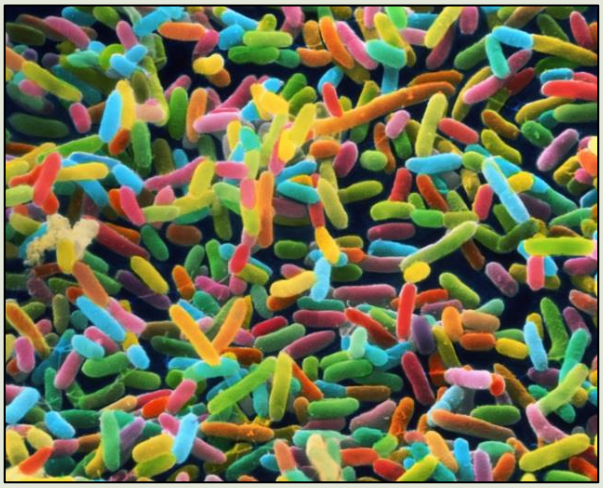
Nitrous oxide (N_2O) emissions significantly contribute to global warming and emissions have increased worldwide over the past few decades. N_2O is emitted from agricultural settings, notably from cattle manure and fertilized soils. N_2O losses from fertilizer are considered to be agriculture's overall largest contributor to global warming; in addition, these losses are concerning because nitrogen that would otherwise be available for plants is lost via the emissions. ARS researchers at Auburn, Alabama, identified and developed microbial inoculants that reduce N_2O losses from nitrogen fertilizers and improve plant production and plant nutrient efficiency. These microbial inoculants have been patented and are available to producers for reducing N_2O emissions and providing these other beneficial outcomes in production agriculture.

Two of the most important aspects of the global climate are increases of atmospheric carbon dioxide (CO_2) and temperature. ARS scientists in Fort Collins, Colorado; Cheyenne, Wyoming; and Woodward, Oklahoma, conducted a 7-year field experiment to study how increasing atmospheric CO_2 and temperature (both alone and in combination), affected the forage for livestock in the northern prairie. Forage production increased by an average of 38 percent over the 7 years, but forage quality decreased when both CO_2 and temperature were increased. For example, digestibility of western wheatgrass dropped from 63 percent to 61 percent, and crude protein content also decreased from 8 percent

to 7 percent. While not large, these changes could influence management decisions by ranchers because rates at which individual cattle gain weight during the growing season are expected to decrease. ARS research indicates that strategies to reverse this loss in weight gain include increasing stocking rates, patch burning, fertilization at low rates, and legume interseeding.

Soil organic carbon (SOC) must be maintained or increased to ensure crop productivity and soil health. But SOC levels in the Pacific Northwest dryland production region has greatly declined in the past few decades because of intensive tillage, low biomass inputs, fallow production, and straw burning. In the early 1980s, ARS researchers in Pendleton, Oregon, measured SOC in crop fields to a depth of 60 inches, and repeated their measurements in the early 2000s. They found that cropping with winter wheat and peas increased deep SOC the most, while enrolling fields in the Conservation Reserve Program and cropping with winter wheat and reduced tillage also increased deep SOC. These results can be used to encourage producers to use deep-rooted legumes such as peas as rotation crops, and to reduce the use of tillage and fallow for sustainable wheat production.

MICROBIOME



Microbiomes are the "*dark matter*" in the universe of life. A microbiome is a community of microorganisms (bacteria, viruses, and fungi) that live on or in people, plants, animals, soil, oceans, and the atmosphere. Microbiomes promote the healthy functioning of diverse ecosystems, and affect human and animal health, crop and soil health, climate change, and other complex systems. By contrast, dysfunctional microbiomes are associated with human chronic diseases such as obesity, diabetes, and asthma; reductions in agricultural productivity; and local ecological disruptions such as the hypoxic zone in the Gulf of Mexico. ARS is taking a systems approach to understanding and harnessing microbiomes for the benefit of agriculture and human nutrition.

ARS scientists achieved the following noteworthy research results in FY 2018:

- Honey bees are responsible for more than $15 billion per year in added crop value via pollination. Yet the health of the U.S. honey bee industry is in jeopardy because colony mortality each winter now exceeds 40 percent. ARS researchers demonstrated that the honeybee gut microbiome is a major determinant of worker bee health. Pollen age and quality are major determinants of gut microbiome flora. A worker bee diet of aged pollen allows opportunistic bacteria to become established resulting in poor bee health. In addition, exposure to antibiotics eliminates bee gut bacteria and compromises bee immune system function, therefore enhancing susceptibility to infection by pathogens. Finally, elevated atmospheric CO_2 reduces pollen protein concentrations, also impacting bee health.

- Understanding the microbiomes of different agricultural environments, including those of soils, waterways, and even manures, is critical to enable optimization of those systems for improved agricultural production. The understanding of these microbiomes also contributes to approaches that can reduce the risk that may arise from environmental exposures to harmful microorganisms that may be present in those environments. ARS research on soil microbiomes is developing an understanding of the management practices that enhance soil microbial communities for improved water retention and infiltration, soil organic matter production, erosion stability, and

greenhouse gas production reduction. ARS researchers have observed complexity shifts in soil microbiomes due to the implementation of organic production, cover crop introduction, and tillage practice changes, and these are being examined for their influence on increased agricultural productivity and sustainability. ARS scientists are also investigating the role of environmental microbiomes on the increase of—or reduction of—the prevalence of microbes with antimicrobial resistance (AMR) genes.

- Extreme weather conditions, including rising average temperatures and drought, increasingly threaten U.S. agriculture. Root endophytic microbes are known to play an important role in determining host fitness under drought stress. Thus, ARS analyzed the bacterial communities in the roots of 18 species of grass (Poaceae), including wheat, corn, sorghum, barley, oat, miscanthus, rye and pearl millet that display varying degrees of drought tolerance. These studies showed that drought is a powerful architect of root metabolic activity and root microbiome diversity in all species examined and promotes a dramatic increase in the abundance of select Actinobacteria in the roots of all hosts studied. Inoculation experiments with isolated cultures demonstrated that increased root colonization during drought positively impacts plant growth. The discovery of this drought-induced enrichment and associated shifts in metabolite exchange between plant and microbe and fitness reveal a potential blueprint for manipulating plant microbiomes for improved crop fitness.

- Normal bacteria in the human intestine make multiple forms of vitamin K. In a study of 80 adults, consumption of a diet rich in whole grains for six weeks resulted in a reduction in vitamin K compared with a refined grain diet but the individual vitamin K levels varied more than 80-fold from person to person. That variation correlated with presence of several bacterial species, indicating specific bacteria are required to make vitamin K to obtain this specific benefit from whole grains. In another nutritional study, ARS scientists examined a family of chemicals called polyphenols from pomegranate peel to alter the intestinal microbiota. Currently, pomegranate peel is an agricultural waste product with high cost of disposal. Feeding the pomegranate polyphenols to mice significantly altered the proportions of the normal intestinal bacteria and greatly reduced colonization with a model organism equivalent to enteropathogenic *E. coli.* If the same effect is observed in humans, this suggests that pomegranate peels that are otherwise discarded could become a high value coproduct.

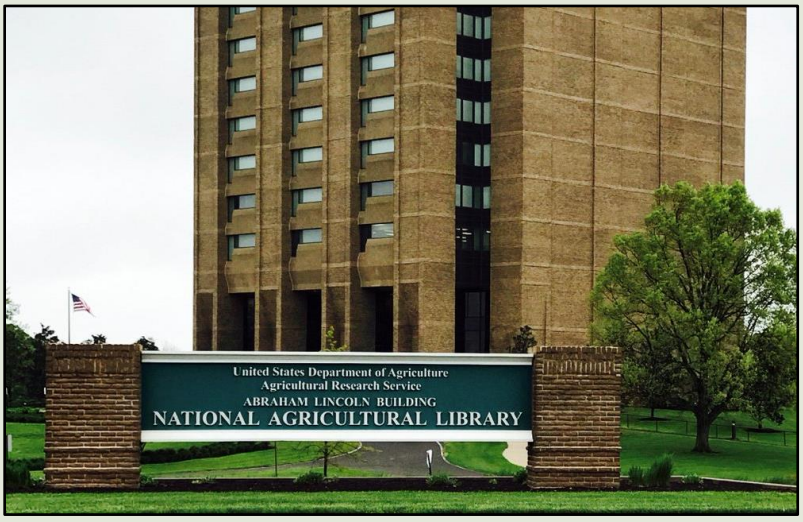
Agricultural Resources and Research Tools

ARS maintains a number of key resources supporting global agricultural research—and global agriculture itself. These resources include unique and invaluable collections of plant and animal germplasm, including heritage and pre-agricultural species and wild relatives of crops from all over the world. These provide the seed stock and clones for agricultural research, preserve agricultural genetic diversity, and are a critical reserve of the world's agricultural plants and animals. Likewise, ARS maintains one of the largest public collections of microorganisms in the world, including pathogens and microorganisms instrumental to the growth of healthy plants and animals.

ARS is also a trusted source of key, publicly accessible data. ARS databases include food composition databases that are the standard reference for producers, researchers, and nutritionists; databases of plant and animal genomic and phenotypic information; and long-term environmental databases on soils, watersheds, and climate.

ARS also maintains publicly available scientific models and software that are used by scientists and end users to model crop and farm production and management, water resources use and management, pest management, plant and animal growth, and research calculations.

NAL SPOTLIGHT – 2018 ACCOMPLISHMENTS



The National Agricultural Library (NAL) is one of four national libraries of the United States and houses one of the world's largest collections devoted to agriculture and related sciences. NAL maintains collections of agricultural books and journals, and has applied library science to the digital world, creating an Ag Data Commons and public information sites on a variety of agricultural and research topics.

The following are major accomplishments that the NAL achieved in FY 2018:

Life Cycle Assessment (LCA) Commons: In FY 2018, NAL implemented and documented repository management and data stewardship best management practices based on the Open Archival Information System (OAIS) reference model. NAL completed development and deployed the openLCA Collaboration Server data collection, publication, and search application. Consequently, NAL has reduced LCA Commons product operating costs by 60 percent and reduced the time required for publishing a complex data set from months to days. NAL also led the development of the Global LCA Data Access (GLAD) application, which provides distributed access to national level data sets around the world. The GLAD prototype launched at a European Commission event in April 2018. Lastly, NAL continued to lead the Federal LCA Commons interagency coordination activity, which has expanded to

include the U.S. Forest Service and the Federal Highway Administration, in addition to DOE, EPA, DOD, and NIST. In FY 2019, NAL will develop a continuous integration and deployment environment for the LCA Commons product. With an automated testing and deployment environment, the LCA Commons application will be ready for cloud migration per departmental requirements. The current website at www.lcacommons.gov will also be redesigned to be more agency-neutral to reflect that the LCA Commons is an interagency collaboration.

NAL Mass Digitization: In FY 2018, NAL digitized and created citation information for 14,954 items (713,548 pages), bringing total number of digitized items to 147,875 (6,761,642 pages). NAL continues a large-scale digitization project to digitize agricultural literature and provide public online access. During FY 2018, NAL digitization continued to focus on historic USDA-issued publications, nursery and seed trade catalogs, and topic-specific content to support NAL online exhibits and information. In addition, NAL continued contributing rare and historical titles to the Biodiversity Heritage Library. Until all mass-digitized publications are migrated to NAL web services, public access is available at https://archive.org/details/usdanationalagriculturallibrary

NAL Digital Collections: In FY 2018, the National Agricultural Library's Digital Collections (NALDC) consisted of more than 30,000 historical documents and reports across 10 major collections. Building on upgrades developed for PubAg, NAL modified database, search, and user-interface technology to support an upgrade that was deployed in FY 2018. NAL migrated the upgraded metadata records for items in three collections (Organic Roots, Historical Dietary Guidance, and the Animal Welfare Act History) to the new NALDC location named NALDC Beta. Work also began on migrating the other remaining digital sub-collections to the new interface infrastructure. The National Agricultural Library's Digital Collections can be found at: https://naldc.nal.usda.gov/.

OTHER AGRICULTURAL RESOURCES AND RESEARCH TOOLS – 2018 HIGHLIGHTS

The following is just a subset of the major tools and resources that ARS researchers developed in FY 2018:

ARS researchers in Columbia, Missouri, have developed a low-cost robotic system to directly observe roots in soil and measure the growth rate response under both optimal and water-deficit conditions. The robot, referred to as "RootBot," was designed for use in a controlled environment and to enable roots to develop normally in the dark and in soil. This technology has broad applications for use in multiple crops and with varying soil treatments, including water deficit stress. The platform facilitates the rapid assessment of root traits, which will support breeding efforts to improve drought tolerance in all major crops.

ARS scientists in St. Paul, Minnesota developed a system that can separate nitrate from contaminated water and concentrate it for re-use as fertilizer. It is DC powered and runs on solar panels, so it is suitable for remote locations. A feasibility test was successfully conducted on a contaminated trout stream that has a nitrate concentration in excess of 20 ppm. The system was able to remove an average of 42 percent of the nitrate from water passing through it, concentrating it in a tank that ultimately reached a concentration exceeding 500 ppm, which was subsequently used elsewhere as fertilizer. This approach could be used to recover nitrate from streams, contaminated wells, ponds, and lakes.

ARS scientists from Reno, Nevada; Tucson, Arizona; and Boise, Idaho collaborated with University of Nevada Reno and the Desert Research Institute in the development of modeling technologies to successfully predict rangeland runoff, soil erosion, and salinity transport at the hillslope scale.

One of the major hindrances to understanding poultry diseases is the lack of commercially available immunological reagents specific for poultry, like antibodies. In 1 year, ARS scientists in Beltsville, Maryland, developed 74 different

mouse hybridoma cell lines which secrete monoclonal antibodies. These antibodies are currently being tested by commercial companies for fitness of purpose and inclusion in various immunological assays. Having these antibodies commercially available to the greater scientific community will greatly advance poultry infectious disease and health research worldwide.

A new fully annotated reference genome assembly for Hereford cattle has been released. Although the sequence was released last year, it has been annotated using new data indicating gene content and expression, significantly improving the utility of the tool for beef cattle genomics research. This annotated assembly is now the globally accepted reference for genomic studies in cattle.

In partnership with a broad suite of collaborators, ARS scientists released several new and/or updated tools and databases, including:

- The Root Zone Water Quality Model (RZWQM2, Version 4.0), which has been downloaded from the ARS website about 15 times per month from 28 different countries;
- Grass-Cast, which is a new tool that uses year-to-date climate data and seasonal temperature and precipitation outlooks to predict forage production for rangelands at the county level;
- The Agricultural Conservation Planning Framework (ACPF), an ArcGIS-based software program for watershed planning towards improvement of agricultural water quality;
- The Rangeland Hydrology and Erosion Model (RHEM), for predicting rangeland runoff, soil erosion, and salinity transport at the hillslope scale; and
- The Northeast Grazing Guide, an outreach tool for the Northeast Pasture Consortium that provides detailed information on forage, pasture, grazing, and livestock management for forage-livestock systems in the northeastern United States. The website provides a central resource site for ARS research summaries and outreach materials that support farmers and agribusiness involved in forage-livestock production systems and facilitates interaction among farmers, researchers, extension, and private industry, and has over 10,000 page views per year.

International Collaborations

In recognition that agriculture, and agricultural research, is now a global enterprise, ARS' Office of International Research Programs is working to enhance the productivity, effectiveness, and impact of ARS National Programs through mutually beneficial international research activities. The United States directly benefits from international collaboration in agricultural research through access to new ideas and technologies, global germplasm collections, crucial international foreign research sites, enhancement to domestic research, and increased trade. Many agricultural problems such as emerging and re-emerging plant and animal diseases; control of invasive species through discovery and importation of biological control agents; scientific collections, including genetic resources preservation; and the need to increase productivity to ensure adequate supplies of agricultural products, increasingly cross national borders and provide a strong incentive for greater international cooperation. International agricultural research cooperation addresses global food security by providing solutions to current and future agricultural productivity and sustainability challenges. By sharing knowledge and technology through close cooperation with national and international research institutions based in other countries, ARS collaborations enhance international relationships, increases institutional research capacity, and speeds technology development.

In 2018, ARS participated in 2,305 foreign research collaborations with 115 countries (shaded in blue):

Figure 1 - ARS collaborated with scientists in the blue-shaded regions. Click on a region name to view a table listing the number of collaborations with each country in that region.

GOAL AREA 1: NUTRITION, FOOD SAFETY, AND QUALITY

The Nutrition, Food Safety, and Quality research and information area exists to lead and coordinate ARS research and information dissemination to define the role of food and its components in optimizing health for all Americans; develop tests and processes that keep the food supply safe; reduce and control pathogens and toxins in agricultural products; and improve the economic viability and competitiveness of American agriculture by enhancing the quality and utilization of agricultural products for the benefit of producers and consumers.

Goal 1.1 – Enable Americans to Make Health-Promoting, Science-Based Dietary Choices

NATIONAL PROGRAM 107 - HUMAN NUTRITION

To improve the nutrition and health of the American people, ARS conducts research on the quality of the American diet and on related health behaviors. Distinctive aspects of this research include an emphasis on a food-based approach to improving health; the core capability to sustain long-term research in areas deemed of high priority for the Nation's health; the availability of state-of-the-science equipment and facilities for human research across the lifecycle; and the conduct of multidisciplinary research to improve the nutritional value of the American diet and food supply. The mission of the Human Nutrition Program is to define the role of food and its components in optimizing health throughout the life cycle for all Americans by conducting high national priority research. This research emphasizes study of essential nutrients and nonessential, health-promoting components in foods; evaluating the nutritional value of diets eaten by people in America; determining how consumption of specific foods or food components can enhance health; and developing strategies to improve food choices and lifestyle factors. Increasingly, research focuses on addressing over-consumption and caloric imbalance with incorporation of cutting-edge genomic and metabolomic technologies to carry out research. Research addresses four overarching components: nutrition monitoring, the scientific basis for dietary recommendations, obesity prevention, and life stage nutrition and metabolism. Information dissemination programs operated by the National Agricultural Library address general and specific human nutrition issues and audiences and

include general Web portals such as www.nutrition.gov as well as the targeted Web sites of the Food and Nutrition Information Center.

PERFORMANCE MEASURE FOR GOAL 1.1

Monitor nutrient composition of food supply and consumption by Americans while conducting research on life stage nutrition and metabolism. Strengthen the scientific basis for dietary guidance for health promotion and disease prevention and develop strategies for prevention of obesity and related diseases.

FY 2018 PERFORMANCE REPORT FOR GOAL 1.1

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will survey, release data on, and analyze national food consumption patterns of Americans**.**

- ARS scientists in Beltsville, Maryland, released two large batches of information from What We Eat in America. These data are from part of a greater dataset that is the only nationally representative evaluation of what Americans eat. These data inform many nutrition policies and help researchers identify what nutrients are under- or over-consumed by Americans.

Indicator 2: During 2018, ARS will develop new methods, conduct food composition analyses, and compile databases for known, emerging, and new classes of nutrients and for branded food items.

- ARS scientists in Beltsville, Maryland, collaborated with U.S. Pharmacopeia to develop a new set of guidelines for selecting the best methods to detect impurities in unsafe or otherwise unwholesome foods and botanical supplements. These guidelines will help other researchers to establish procedures that will ensure the quality of their products.

Indicator 3: During 2018, ARS will identify dietary and lifestyle intervention strategies to prevent obesity and promote healthy food choices and eating behaviors.

- In a study conducted by ARS researchers in Boston, Massachusetts, previously inactive people in their 70s and 80s improved their ability to move and function by walking at a moderate speed for at least 48 minutes per week. Influencing older adults to walk at least 1 hour per week may reduce healthcare costs and improve the quality of life for millions.
- ARS researchers in Grand Forks, North Dakota, demonstrated that individuals must expend more than 1,500 calories/week through exercise to have meaningful losses in weight and fat.

Indicator 4: During 2018, ARS will determine the functions, bioavailability, interactions, and requirements for known, emerging, and new classes of nutrients across the lifecycle.

- ARS scientists in Houston, Texas, developed a new approach for testing gut health that is faster and less expensive than traditional methods for assessing gut health. This new method will enhance the ability of healthcare workers to identify cases of gut inflammation, a cause of growth stunting in some children in rural Africa.

Indicator 5: During 2018, ARS will publish new findings on metabolic processes that are affected by nutrient intake.

- ARS scientists found that the recently discovered hormone asprosin triggers appetite stimulation, weight gain, and increased body fat. Obese humans and mice have elevated levels of asprosin in the bloodstream; blocking it

in mice reduced appetite and weight. These findings suggest that controlling asprosin levels in the bloodstream could be an effective treatment of obesity and type 2 diabetes.

- A study conducted by ARS scientists in Beltsville, Maryland, indicates that the daily consumption of at least 1.5 ounces of walnut halves, but not ground nuts, alters gut bacteria associated with decreased risk of colon cancer and heart disease.

- ARS scientists in Davis, California, conducted the first ever controlled study to investigate the benefits of the Dietary Guidelines for Americans (DGA). While their results demonstrate that the DGA improved blood pressure in overweight and obese women, the team observed no improvements in insulin, glucose, or lipids in the absence of weight loss. Currently, only limited health benefits can be attributed to following the DGA.

Indicator 6: During 2018, ARS will discover genetic or epigenetic factors that influence physiologic responses to diet or changes in gene expression in response to dietary intake.

- While the APOA2 gene is known to play an important role in cardiovascular health, ARS researchers in Boston, Massachusetts, demonstrated that this gene also influences an individual's propensity to gain weight. The research team found that individuals with a given variant of the APOA2 gene who also eat high levels of red meat, poultry, cheese, and butter are more likely to gain weight than individuals without that variant, suggesting only genetically predisposed people would experience weight gain on diets containing high animal fat and protein.

- Research conducted by ARS scientists in Houston, Texas, showed that a naturally occurring genetic variant can increase the concentration of iron in mouse milk by 35 percent. These findings may inform strategies for stimulating the increased production of iron in breast milk, helping to reduce the prevalence of iron deficiency in infants.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 1.1

During FY 2019, ARS will:

1. Collect and release data on national food consumption patterns of Americans and the chemical composition of those foods.
2. Identify dietary and lifestyle intervention strategies to prevent obesity and promote healthy food choices and eating behaviors.
3. Publish new findings on metabolic processes that are affected by nutrient intake.
4. Determine the functions, bioavailability, interactions, and requirements for known, emerging, and new classes of nutrients across the lifecycle.

During FY 2020, ARS will:

1. Collect and release data on national food consumption patterns of Americans and the chemical composition of those foods.
2. Identify dietary and lifestyle intervention strategies to prevent obesity and promote healthy food choices and eating behaviors.
3. Publish new findings on metabolic processes that are affected by nutrient intake.
4. Determine the functions, bioavailability, interactions, and requirements for known, emerging, and new classes of nutrients across the lifecycle.

During FY 2021, ARS will:

1. Collect and release data on national food consumption patterns of Americans and the chemical composition of those foods.
2. Identify dietary and lifestyle intervention strategies to prevent obesity and promote healthy food choices and eating behaviors.
3. Publish new findings on metabolic processes that are affected by nutrient intake.
4. Determine the functions, bioavailability, interactions, and requirements for known, emerging, and new classes of nutrients across the lifecycle.

Goal 1.2 – Protect Food from Pathogens, Toxins, and Chemical Contamination during Production, Processing, and Preparation

NATIONAL PROGRAM 108 – FOOD SAFETY

The safety of the food supply continues to be a highly visible public health issue and a national priority for the Federal government. The continued priority is partly due to the diverse and complex system of production, processing, and distribution of food in the United States and the increasing global distribution. Outbreaks of foodborne illness are seen as a major cause of morbidity and mortality and economic costs, both nationally and internationally. The full extent of the disease burden is still unknown, even with recent CDC estimates. Foodborne illnesses can be caused by microbial pathogens, parasites, viruses, and an array of foodborne contaminants such as chemicals or toxins. The cause of every outbreak is still unknown, but persistent outbreaks of major commodity-specific foods that may directly affect public health, regulations, industry, and trade require our immediate attention.

ARS has developed an integrated approach to food safety, that is, food production is seen as a continuous process from production through harvesting and processing to retail and the consumer. Pre- and post-harvest are not separated, but considered an integrated production system of safe and quality food. Interventions and controls that are applied to one phase will ultimately affect the other segments of food production and processing. Food safety research has also changed during the past decade, having moved past simple surveillance/prevalence studies to asking more complex questions. Consequently, researchers are required to think creatively to solve problems, which means considering alternate perspectives, exploiting new opportunities and technologies, and crossing conventional boundaries. Multidisciplinary collaborations, especially between Centers/Institutes nationally and internationally are an absolute necessity.

ARS provides the intramural infrastructure and expertise to address short- and long-term needs in food safety. Because of the infrastructure, ARS is uniquely poised to respond quickly to emerging and critical food safety issues. ARS also collaborates closely with Federal regulatory agencies as well as industry, professional, and international stakeholders to assist in addressing their specific food safety needs.

PERFORMANCE MEASURE FOR GOAL 1.2

Develop new technologies that assist ARS customers in detecting, identifying, and controlling foodborne diseases associated with the consumption of animal products that affect human health.

FY 2018 PERFORMANCE REPORT FOR GOAL 1.2

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will determine how population systems in animals, plants, or the environment, or any combination of these influence the safety of food. ARS will determine the conditions under which microorganisms exist. ARS will determine how microorganisms may in turn influence the conditions prevailing in the environment. ARS will ensure that these technologies can be utilized by regulatory agencies, producers, and/or processors to help assure safe food products.

- ARS researchers in Athens, Georgia, demonstrated a correlation between certain breeds of poultry and their likelihood of infection by *S. Entiridis*, a bacterium that poses a food safety risk to humans. Additionally, the breed less likely to carry *S. Entiridis* had an increased likelihood of infection in birds raised in conventional cages compared to those raised in colony units enriched with perches and nesting areas. This new knowledge informs multiple strategies for mitigating egg contamination.

Indicator 2: During 2018, ARS will develop an understanding of bacterial, viral, and fungal pathogenicity through a systems biology approach. ARS will utilize this data for pathogen intervention and control, modeling, and providing data for the development of risk assessments by regulatory agencies. ARS will ensure that these technologies can be utilized by regulatory agencies, producers, and/or processors to help assure safe food products.

- ARS researchers in New Orleans, Louisiana, demonstrated that increased atmospheric carbon dioxide levels can lead to an increase in aflatoxin production. The research also developed a better understanding of how genes within the aflatoxin-producing fungus are affected by elevated carbon dioxide levels. This new knowledge will help modelers predict levels of aflatoxins produced under various environmental conditions and provide insight on how remediation efforts will be influenced by future global environmental conditions.

- ARS researchers in Ames, Iowa, identified genes in Shiga toxin-producing *E. coli* strains that could influence their persistent colonization in cattle that spread the toxin much more readily than other cattle. The proteins encoded by these genes could be developed into blocking therapies that prevent the colonization of these easily spread strains in cattle, ultimately mitigating meat contamination by these bacteria that causes intestinal disease in humans.

Indicator 3: During 2018, ARS will develop innovative methods and advanced technology systems that rapidly and accurately detect, identify, and differentiate the most critical and economically important foodborne bacterial, viral, and protozoan pathogens. ARS will ensure that these technologies can be utilized by regulatory agencies and/or producers to help assure safe food products.

- ARS scientists in collaboration with researchers at Purdue University developed a new artificial intelligence (AI) system capable of detecting bacteria not already present in a reference database. This functional prototype of an AI-based emerging pathogen detection system demonstrates the tremendous potential of AI technology in agricultural biosafety.

Indicator 4: During 2018, ARS will develop intervention and control strategies that will help to significantly decrease or eliminate pathogens in food animals and their derived products (eggs/milk), seafood, and plant crops (produce/grains/tree nuts) during critical periods of production and processing. ARS will develop and subsequently combine new/innovative processing technologies using the intelligent hurdle concept. ARS will ensure that these technologies can be utilized by producers and/or processors to help assure safe food products.

- ARS scientists in Albany, California, developed an effective and energy-saving new technology to simultaneously dry and decontaminate wet whole almonds, helping to prevent future industry recalls and outbreaks of human illness due to *Salmonella* contamination.

- ARS scientists in Wyndmoor, Pennsylvania, developed an effective protocol for reducing levels of the toxic inorganic arsenic that can be found in rice. This new approach is quicker and more effective than previous efforts to reduce inorganic arsenic in cooked rice.

- ARS researchers in Albany, California, showed that a box liner enhanced the bactericidal effects of a sulfur dioxide pad in table grape shipping containers. This new knowledge will reduce contamination in table grapes purchased by consumers at food stores.
- ARS researchers in Wyndmoor, Pennsylvania, collaborated with an industry partner to scale up ARS' previously patented radio frequency pasteurization (RFP) process for producing safer eggs with exceptional quality. New breakthroughs in the scaling up of this technology reduce the overall cost of each RFP and will facilitate the commercialization and widespread use of the process.

Indicator 5: During 2018, ARS will develop bioinformatic databases and tools, and predictive user-friendly models to understand pathogen behavior and acquisition of virulence characteristics under various stress conditions. ARS will determine the key risk factors of human pathogens in foods, and evaluate systems interventions for their impact, which will enable regulatory/action agencies to make critical food safety decisions that impact public health.

- ARS researchers have contributed to the development of ComBase, an online tool to help industry and regulatory agencies describe and predict microorganism survival and growth under a variety of food-related conditions. This tool assists users in predicting and improving the microbiological safety of foods.

Indicator 6: During 2018, ARS will develop innovative methods and advanced technology systems that rapidly and accurately detect and identify veterinary drugs, chemical residues, heavy metals, persistent organic pollutants, and biological toxins derived from bacteria, fungi, and plants. ARS will evaluate contaminant toxicity and mechanism of action. ARS will provide data which will enable regulatory/action agencies to make critical food safety decisions that impact public health.

- Zilpaterol is an additive that enhances the efficiency of feed conversion and causes cattle to increase in size, but it is approved for use in only certain countries. The rapid and sensitive detection of it in live animals or in animal tissues is of critical concern to regulatory and trade officials worldwide. ARS scientists in Fargo, North Dakota, optimized a technique for the rapid screening of zilpaterol in animal urine and tissues. This new approach has the potential to be adapted for field use and for the rapid detection of numerous other chemical residues of importance to animal agriculture.

- Researchers in Albany, California, have developed a new assay that can detect even the lowest concentrations of the toxin abrin, a potential bioterror weapon that is similar to ricin. Easy, cost-effective, and increasingly rapid methods of abrin detection are critically necessary during incidences of deliberate or suspected food adulteration.
- ARS researchers in Beltsville, Maryland, developed a new imaging system that rapidly detects and measures contaminants in food. The system can directly and rapidly analyze a sample powder in only 10 minutes, whereas conventional instruments would take hours to perform the same analysis.

- ARS scientists in Peoria, Illinois, developed a new method for detecting very low levels of a highly toxic toxin produced by a fungus that infects oats, wheat, barley, rye, maize, and rice. Unlike routine tests for this toxin, this new method is capable of detecting multiple forms of the toxin. This method is important for ensuring food safety and supporting the export of U.S. grain commodities.

- ARS scientists in Wyndmoor, Pennsylvania, developed and validated a fast, efficient, high-throughput analytical method for the routine monitoring of pesticides in meat and poultry products. The USDA Food Safety Inspection Service is now implementing this method for routine monitoring of contaminants. This new method is expected to improve regulatory monitoring, reduce the cost of sample analysis, increase sample throughput, and provide reliable data for more contaminants of concern.

Indicator 7: During 2018, ARS will develop approaches to understand the development, persistence, and transmission of antimicrobial resistant (AMR) genetic elements that result in antimicrobial resistant foodborne pathogens. ARS will develop and validate assays to rapidly detect and assess AMR pathogens. ARS will develop and evaluate alternatives to antibiotics to reduce the development of AMR in foodborne pathogens.

- Research conducted by ARS scientists in Clay Center, Nebraska, suggests that raising beef cattle without any antibiotics would not reduce levels of antimicrobial resistance compared to conventional production.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 1.2

During FY 2019, ARS will:

1. Determine how population systems in the food continuum influence the safety of the food supply.
2. Develop innovative methods and advanced technology systems that rapidly, accurately, and cost effectively detect, identify, and differentiate foodborne pathogens, chemical residues, and biological toxins in foods.
3. Develop intervention and control strategies that decrease or eliminate contaminants in the food supply to make it safer for consumers.
4. Develop bioinformatic tools to understand acquisition of virulence characteristics. Develop databases and predictive models to understand pathogen behavior and provide data for the development of risk assessments.
5. Develop approaches to understand antimicrobial resistance and evaluate alternatives to antibiotic use.

During FY 2020, ARS will:

1. Determine how population systems in the food continuum influence the safety of the food supply.
2. Develop innovative methods and advanced technology systems that rapidly, accurately, and cost effectively detect, identify, and differentiate foodborne pathogens, chemical residues, and biological toxins in foods.
3. Develop intervention and control strategies that decrease or eliminate contaminants in the food supply to make it safer for consumers.
4. Develop bioinformatic tools to understand acquisition of virulence characteristics. Develop databases, and predictive models to understand pathogen behavior and provide data for the development of risk assessments.
5. Develop approaches to understand antimicrobial resistance and evaluate alternatives to antibiotic use.

During FY 2021, ARS will:

1. Determine how population systems in the food continuum influence the safety of the food supply.
2. Develop innovative methods and advanced technology systems that rapidly, accurately, and cost effectively detect, identify, and differentiate foodborne pathogens, chemical residues, and biological toxins in foods.
3. Develop intervention and control strategies that decrease or eliminate contaminants in the food supply to make it safer for consumers.
4. Utilize molecular biology and bioinformatic tools to understand specific phenotypic characteristics such as the acquisition of virulence, pathogenicity, and antimicrobial resistance. Develop and evaluate methods/alternatives that reduce these characteristics.

Goal 1.3 - Improve Postharvest Quality and Develop New Uses of Agricultural Products

NATIONAL PROGRAM 306 – QUALITY AND UTILIZATION OF AGRICULTURAL PRODUCTS

This research will increase our knowledge and develop technologies to better measure or enhance the quality of crop and animal products after harvest. Similarly, the marketability and value of commodities can be increased by ensuring that value-added food products (such as fresh-cut or minimally processed produce) retain sensory quality, nutritional value, and are free from food safety hazards. The research in this National Program will also generate new information on health promoting components of foods and assess their effects on important human diseases and obesity, in cooperation with the Human Nutrition National Program (NP 107) and other partners. In addition to food quality and safety, consumers have expressed concern over rising food prices which can be attributed to multiple factors. A significant factor in the cost of food production can be attributed to food waste or rot. Estimates indicate that approximately 27 percent of food produced in the United States is lost as waste among retailers, food service businesses, and consumers. Additional losses occur during food harvesting, storage, and distribution. The magnitude of the loss is even greater when resources spent on growing food such as fuel, water, fertilizer, chemicals, land-use, and human resources are considered. NP 306 research will develop technologies that improve quality, extend product shelf life, reduce waste, and decrease costs.

ARS conducts research on the development of nonfood, nonfuel biobased products from agricultural commodities and byproducts. Interest in biobased products has increased as consumers and governments have sought more environmentally friendly products that provide alternatives to petroleum and which do not contribute to greenhouse gases. Thus, biobased products can reduce our dependency on petroleum and provide a more sustainable technology for the future. Biobased products that were once too expensive to commercialize may now be affordable. There is some public concern that biobased products could contribute to the rising cost of food in the United States. This program seeks opportunities to develop biobased products from agricultural feedstocks that do not compete with food, in cooperation with other ARS national programs and partners. ARS also supports quality and processing research on crop fiber, such as cotton, and from animal hides, such as leather and wool. Stakeholders who produce fibers and hides constitute an important segment of our rural economy. These industries are severely impacted by energy and production costs and have lost market share to foreign competition. Technologies that improve fiber quality, reduce the energy consumption of processing equipment, and develop new products are needed to help the fiber industry to compete in a global market.

PERFORMANCE MEASURE FOR GOAL 1.3

Develop methods and technologies to better define, measure, preserve or enhance quality and improve utilization of food crops, animals and agricultural fibers, as well as non-food, non-fuel biobased products and sustainable technologies/processes.

FY 2018 PERFORMANCE REPORT FOR GOAL 1.3

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will enable commercially-viable post-harvest technologies for non-food biobased products and for value-added non-food processing.

- ARS researchers in Manhattan, Kansas, collaborated on research that developed a new method for detecting Zika virus in whole, intact *Aedes aegypti* mosquitoes with a prediction accuracy of 99.3 percent. This test is 18 times faster and 110 times cheaper than previous methods for screening Zika. A proposal based on this work has been submitted to the Department of Defense to develop a portable, handheld, cell phone-based technique for rapid surveillance of Zika, dengue, and malaria control programs.

- ARS researchers in New Orleans, Louisiana, collaborated in the development of a new drug that desensitizes peanut allergy in allergic individuals. Once it becomes available for public use, it will be the first treatment available in the world for individuals with peanut allergy.

- Compared to newly generated virgin plastic, recycled plastic often exhibits a significant loss in stiffness, strength, and heat resistance. ARS scientists in Albany, California, collaborated with the California Almond Industry to improve the heat stability and stiffness of recycled plastic by adding a residue from almond shells, an inexpensive, abundant waste byproduct from the U.S. almond industry. This eliminates the need for expensive petroleum-based additives to recycled plastic.

- ARS scientists in Albany, California, developed a novel, inexpensive process for making single-use food containers from renewable plant fiber composites that degrade quickly when composted. The containers are molded in only a few seconds and compost more readily than paper products. This research improves the sustainability of the single-use food container industry and provides a new degradable, sustainable coproduct from food waste and nonfood feedstocks.

- Tunicamycin is a powerful alternative to the traditional class of broad spectrum antibiotics, but its toxicity to humans has prevented its use for therapeutic applications. ARS researchers in Peoria, Illinois, have now modified tunicamycin into non-toxic derivatives that can be added to penicillin-based drugs to increase their efficacy by 32 to 64 times. This significant discovery now allows older-type antibiotics to once again be effective and is an important step toward combating drug resistance.

- ARS scientists in Peoria, Illinois, and Lincoln, Nebraska, developed the first insect repellent that is effective for use against biting stable flies and biting face flies. Biting flies cost the cattle industry more than $2.4 billion annually, and this new product is being tested by U.S. cattle farmers and ranchers as a sustainable, natural technology to address these serious issues.

- ARS researchers in Albany, California, and their collaborators determined the protein structure of the Ber e 2 Brazil nut allergen. The structure of this protein had remained elusive for more than a decade and will now be used to help the medical industry develop treatments to Ber e 2 allergenicity.

Indicator 2: During 2018, ARS will develop new or improved methods to measure, predict, enhance, or reduce impacts to food marketability, nutritional quality, new bioactives and functional foods, and/or food processing technologies.

- ARS scientists in East Grand Forks, Minnesota, conducted the National Fry Processing Trial in collaboration with potato industry representatives and publicly funded plant breeders. The trial identified several potato varieties with both excellent processing characteristics as well as ultra-low acrylamide levels, a potentially toxic byproduct that often forms when potatoes are fried. These varieties will be evaluated in more detailed industry trials and eventually replace current varieties used by the potato industry.

- ARS researchers showed that broccoli microgreens —a seedling stage of broccoli that children and adults will eat more readily than mature broccoli— contain four times more of a compound beneficial to human health compared to broccoli crowns. The team identified ways to further fortify the microgreens and enhance their visual quality and shelf life. These findings are now being adopted in commercial microgreen production systems.

- ARS researchers in New Orleans, Louisiana, demonstrated that sweet sorghum syrup contains twice as much protein as other syrups, increased antioxidant activity, and beneficial levels of potassium, magnesium, and iron. These results were transferred to key stakeholders, who now use them to promote sweet sorghum syrup as a sweetener.

- ARS researchers in Albany, California, developed a method for transforming mushroom-stalk waste into a new vegetarian ingredient with a high level of vitamin D. This colorless, tasteless, edible powder applied as a film coating to fruit bars and fresh-cut melons has been shown to help preserve quality and safety and increase shelf life.

- ARS researchers in Fort Pierce, Florida, identified annatto and paprika to be compatible with fruit waxes and desirable for enhancing the brightness and intensity of the peel color in early season harvested citrus. These additives can replace "Citrus Red No 2," a traditionally used postharvest colorant that was recently identified as a group 2B carcinogen by the European Union.
- The "Falling Number" test is a procedure used by the USDA Agricultural Marketing Service to determine the quality, marketability, and price of a particular wheat grain based on its potential for starch breakdown. Despite the wide use of this procedure, it is unreliable at high altitudes. ARS scientists in Beltsville, Maryland, have developed a correction equation for the Falling Number test that will now be used widely throughout the United States to ensure the high quality of wheat that goes to market.

- ARS scientists in Wenatchee, Washington, collaborated with industry partners to develop a procedure for identifying fruit lots that are at high or low risk for developing scald, a brown discoloration within the peel of the fruit. Such information can improve warehouse marketing plans for the fruit industry.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 1.3

During FY 2019, ARS will:

1. Enable commercially-viable post-harvest technologies for non-food biobased products for new uses and for value-added processing.
2. Develop new or improved methods to measure, predict, enhance or reduce impacts to food marketability, nutritional quality, develop new uses, and/or food processing technologies.

During FY 2020, ARS will:

1. Enable commercially-viable post-harvest technologies for non-food biobased products, for new uses and for value-added processing.
2. Develop new or improved methods to measure, predict, enhance or reduce impacts to food marketability, nutritional quality, develop new uses, and/or food processing technologies.

During FY 2021, ARS will:

1. Enable commercially-viable post-harvest technologies for non-food biobased products, for new uses and for value-added processing.
2. Develop new or improved methods to measure, predict, enhance or reduce impacts to food marketability, nutritional quality, develop new uses, and/or food processing technologies
3. Develop bioconversion technologies to enable sustainable commercial production of products into biofuels and high-value by-products.

GOAL AREA 2: NATURAL RESOURCES AND SUSTAINABLE AGRICULTURAL SYSTEMS

We conduct research that *explains* the nature and function of agricultural systems and their physical, chemical, and biological components. With that explanatory power, we develop abilities to *predict* how agricultural systems may respond to different environments or management scenarios. Once we can make predictions with confidence, we turn that knowledge into *decision support* tools and methods for:

- Improving the efficiency and effectiveness of management practices for agricultural systems and working lands to enhance ecosystem goods and services, including the sustainable production of agricultural commodities;
- Managing soil, water, air, and biological resources for society's benefits, including reductions in environmental impact, under different climatic regimes and environmental conditions;
- Providing agricultural products and co-products as renewable, bio-based alternatives to petroleum as inputs to manufacturing and generating energy;
- Developing new, valuable, environmentally sound uses for agricultural and industrial byproducts.

Major priorities for ARS research on interactions among land, water, atmosphere, and diverse biological communities include remediation and use of degraded water for production of a wide range of crops; protection and enhancement of ecosystem goods and services arising from our natural resources; adaptation of agricultural production systems to climate change, and mitigation of agricultural greenhouse gas emissions; development of diverse energy crops and agronomic practices for efficient and sustainable production, optimized for different geographic regions and climatic conditions throughout the U.S.; identification of safe uses of agricultural wastes and byproducts in generating energy/fuel and value-added biochemical products and fertilizers; creation and evaluation of conservation practices and land management decision-support tools arising from ARS' long-term agricultural research conducted in the agency's unique, critical infrastructure of instrumented watersheds and rangelands; development of widely accessible databases to support analyses of agriculture, land management, and the environment; and creation of a broad-based data and information access portal at the National Agricultural Library to enable life-cycle analyses and development/validation of sustainability indices for agricultural production and delivery systems.

Goal 2.1 – Integrated, Effective, and Safe Water Resource Management

NATIONAL PROGRAM 211 – WATER AVAILABILITY AND WATERSHED MANAGEMENT

Fresh water is essential to maintaining both agricultural and industrial production, ecosystem integrity, and human health. As the nation was established and expanded, it flourished in part because of its abundant and readily available water and other natural resources. As the 21st century unfolds, agriculture faces new and intensifying water challenges—increasing demands for water from our cities, farms, and aquatic ecosystems; increasing reliance on irrigated agriculture for stable crop and animal production and farm income; and changing water supplies due to groundwater depletion in some areas, climate variability and change, and the need to tap alternative water sources. These challenges are not insurmountable, and agricultural lands can play an important role in meeting them. Advances in agricultural water management can provide important and unique contributions to the complex problem of water management at regional and national scales. As new and emerging technologies widen the range of options for future water management, science can develop and provide the tools needed by managers and planners to accurately predict the outcomes of proposed water management decisions at farm to national scales. The factual basis for decision-making includes an understanding of these new technologies, their effectiveness as well as potential unintended consequences, and a strategy for getting water users and agencies to adopt the technologies determined to be most effective. Thus the Nation has the opportunity to apply and use science and technology to protect, sustain, enhance, and manage our water resources, improving human and ecological health while continuing to build a strong and growing economy.

PERFORMANCE MEASURE FOR GOAL 2.1

Develop technology and practices to promote improvement of integrated, effective, and safe water resource management.

FY 2018 PERFORMANCE REPORT FOR GOAL 2.1

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will develop new or improved guidelines, technologies, and/or knowledge to increase the effectiveness of agricultural water management.

- ARS scientists in Kimberly, Idaho, developed a new cell phone -based system to continuously monitor grapevine stress in real time to help grape growers manage irrigation, ultimately conserving water use and improving grape quality. The information system was installed in three commercial vineyards in southwestern Idaho.
- ARS scientists in Bushland, Texas, collaborated with Texas A&M researchers to develop a new sensor that can aid in the early detection of wheat streak mosaic virus. If a wheat plant is infected with the virus early in the season, it will yield little to nothing, and wheat crops with high levels of infection should not continue to be

irrigated. Early detection of the virus with this new sensor will help wheat farmers reduce water waste and associated pumping costs.

- ARS scientists in Boise, Idaho, developed and implemented a new software for improving streamflow estimates in real-time. Accurate estimation of streamflow is critical for water resource management and flood control, and this new tool improves the accuracy of streamflow estimates without the previously required increases in manpower.

- ARS scientists in Fort Collins, Colorado, showed that strategically irrigating maize plants immediately prior to flowering and limiting irrigation during other parts of the plant's life cycle resulted in a water savings of 15 to 17 percent with little adverse effects on yield. Importantly, these late-vegetative deficit applications of water prevented dramatic yield losses if a water shortage occurred at the end of the season.

- ARS scientists in Stoneville, Mississippi, developed a low-cost sensing device to measure plant height, canopy temperature, and canopy multispectral reflectance. The scientists are working to improve coordination between their new sensing device and global positioning system information with the goal of demonstrating how affordable open-source components can be used to develop more refined monitoring systems to collect agricultural field data.

Indicator 2: During 2018, ARS will develop new or improved guidelines, technologies, and/or knowledge to reduce erosion and sedimentation from agricultural lands and/or improve water quality.

- ARS researchers in Saint Paul, Minnesota, demonstrated that setting a 6-meter boundary around the edges of turfgrass fields results in a 43 percent reduction in chemical runoff into neighboring areas. Expanding the buffer area between turfgrass and adjacent properties will help groundskeepers design chemical application strategies that maximize environmental stewardship.

- ARS researchers in Oxford, Mississippi, demonstrated that vegetated drainage ditches in combination with a vegetated sediment pond can reduce sediment and nutrient runoff from crop fields. These study results provide regulatory agencies and farming stakeholders with a practical way to combine conservation practices to improve and sustain water quality and overall environmental quality.

- A 4-year study conducted by ARS scientists in Columbia, Missouri, showed that streambanks contributed an average of 83 percent of the stream sediment and accounted for 57 percent of total phosphorus exported from two watersheds in northeastern Missouri. These results, along with earlier studies showing that streambanks contributed 23 percent of the total nitrogen exported, clearly demonstrate the effect that bank erosion has on stream water quality. This study indicates that methods to control streambank erosion would improve water quality in this region.

- ARS researchers in West Lafayette, Indiana, constructed a phosphorus-removal structure to filter dissolved phosphorus from the drainage water of pots to help limit phosphorus runoff and protect nearby watersheds. Even a year after installing and operating the phosphorus-removal structure in a horticultural greenhouse operation, the structure continues to remove nearly 100 percent of phosphorus and copper from runoff.

- ARS researchers in Oxford, Mississippi, collaborated with University of Mississippi researchers to develop a nondestructive field mapping tool to assess soil compaction. Soil compaction can reduce crop yields, and this new tool will help with the assessment and delineation of compacted soils that is needed to define tillage protocols, fertilizer application, and irrigation schedules within a soil management plan.

- ARS scientists in Columbia, Missouri, investigated the movement of a single application of the pesticide atrazine from a treated field to the water flowing within a cave adjacent to the field. Results showed that atrazine and two of its metabolites were present in every water sample over an 18-month period and levels remained elevated 15 months after application. This study demonstrates the effect of atrazine leaching into karst aquifers and the need to implement management practices tailored to karst terrain.

- Biochar, a carbon-rich soil amendment, can be useful for trapping agrochemicals. However, ARS researchers in Saint Paul, Minnesota, demonstrated that biochar absorption capacities change over time after its addition to soil, which will affect the environmental fate of applied pesticides and thus the possibilities for long-term control of pests. This information will inform farmers, policymakers, and researchers in improving future soil amendment strategies.

- In cooperation with the USDA Natural Resources Conservation Service and Kansas State University, ARS in 2016 released a decision support software to help dam safety engineers predict potential dam breaches. In FY 2018, 10 countries across the world requested the software and incorporated it into their educational and design analysis toolboxes. ARS and collaborators are currently exploring options to use the software in early flood warning systems.
- ARS scientists participate in the Real-time Conservation Effects Assessment Project (CEAP), a congressionally-mandated multiagency effort to evaluate the effects of current and past USDA conservation programs and potential future policies. CEAP uses a system of models and detailed climate, soils, landcover, and cropland management data to help farmers better time pesticide and fertilizer applications to prevent losses in runoff.

Indicator 3: During 2018, ARS will develop new or improved knowledge, tools, technologies, guidelines, and/or conservation practices to better protect water resources, improve the overall effectiveness of USDA conservation programs, and/or improve watershed management and ecosystem services in agricultural landscapes.

- A study conducted by ARS researchers in Ames, Iowa, shows that antibiotics and bacteria with antibiotic resistance genes can run off via drainage water from tile-drained farm fields amended with swine manure. These findings provide new scientific understanding of the effect of antibiotics in agriculture on resistance in human pathogens.

- An ARS scientist in Riverside, California, developed an integrated salinity mapping system that produces reliable, reproducible, and accurate maps of soil salinity. This new tool overcomes the previous technical challenge of adequately depicting the highly variable nature of soil salinity and will help producers to optimize localized crop production.

- ARS researchers in Oxford, Mississippi, provided new detailed insights into the soil properties that predispose soil to greater likelihood of erosion. These findings have been incorporated into a new prediction tool for agricultural erosion that the USDA is now using for conservation planning purposes.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 2.1

During FY 2019, ARS will:

1. Develop new or improved guidelines, technologies, and/or knowledge to increase the effectiveness of agricultural water management and improve drought resilience.
2. Develop new or improved guidelines, technologies, and/or knowledge to reduce erosion and sedimentation from agricultural lands and/or improve water quality.
3. Develop new or improved knowledge, tools, technologies, guidelines, and/or conservation practices to better protect water resources, improve the overall effectiveness of USDA conservation

During FY 2020, ARS will:

1. Develop new or improved guidelines, technologies, and/or knowledge to increase the effectiveness of agricultural water management and improve drought resilience.
2. Develop new or improved guidelines, technologies, and/or knowledge to reduce erosion and sedimentation from agricultural lands and/or improve water quality.
3. Develop new or improved knowledge, tools, technologies, guidelines, and/or conservation practices to better protect water resources, improve the overall effectiveness of USDA conservation

During FY 2021, ARS will:

1. Develop new or improved guidelines, tools, technologies, and/or knowledge to increase the effectiveness of agricultural water management and improve drought resilience.
2. Develop new or improved guidelines, technologies, and/or knowledge to reduce erosion and sedimentation from agricultural lands and/or improve water quality.
3. Develop new or improved knowledge, tools, technologies, guidelines, and/or conservation practices to better protect water resources, improve the overall effectiveness of USDA conservation

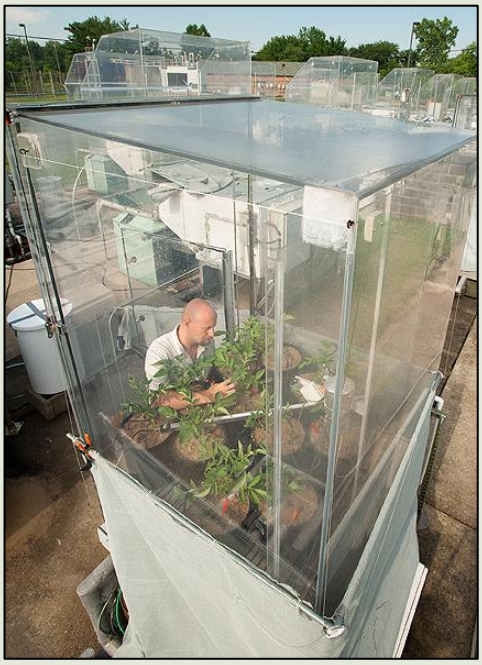
programs, and/or improve watershed management and ecosystem services in agricultural landscapes.

programs, and/or improve watershed management and ecosystem services in agricultural landscapes.

programs, and/or improve watershed management and ecosystem services in agricultural landscapes.

Goal 2.2 – Improve Air and Soil Quality and the Efficient Utilization of Byproducts for Enhanced Sustainability

NATIONAL PROGRAM 212 – SOILS AND AIR



Agricultural systems function within the soil-atmosphere continuum. Mass and energy exchange processes occur within this continuum and agriculture can significantly affect the processes. Emissions from agriculture to the atmosphere affect air quality and increase atmospheric greenhouse gas (GHG) concentrations. While GHG emissions are largely a result of the natural cycling of carbon (C) and nitrogen (N), these emissions also contribute to climate change.

A changing climate impacts agriculture, range and pasture systems, and soils through alterations of precipitation and temperature patterns. Increased atmospheric carbon dioxide (CO_2) concentration has an enhanced fertilization effect on plants, particularly weeds. Combining these impacts of changing climate can alter habitats, thus changing the distribution of pathogens, weeds, and invasive species, resulting in increased threats to agricultural production and increasing the cost of production. The impacts of climate change clearly create challenges to agriculture and soil, water, and air resources, and yet may also offer new opportunities for agricultural production and enhancement of soil quality.

Soils are a crucial boundary resource between agriculture and the atmosphere. Soils in agricultural systems must be managed to meet rising global demands for food, feed, fiber, fuel, and ecosystem services while maintaining soil productivity and limiting undesirable interactions between soils and the atmosphere. Enhancement of soil productivity is a focus of ARS research and together with crop improvement research offers promise for meeting future global agricultural demands.

The variability of the atmosphere, soils, and plants, and the complexity of interactions among these systems require collaborations by ARS scientists conducting NP 212 research. Formal and informal Cross Location Research (CLR) projects including the Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet), the Resilient Economical Agricultural Practices project (REAP; formerly called the Renewable Energy Assessment Project), the Long-Term Agroecosystem Research (LTAR) Network, and field campaigns focused on air quality are successful examples. Synthesis and integration of information, including sources outside NP 212 research projects, increases the utility and impact of ARS research for producers, land managers, and policy-makers. Efficient assimilation of data from NP 212 projects into existing and future collaborative data bases enhances synthesis and integration analyses and expands research opportunities.

PERFORMANCE MEASURE FOR GOAL 2.2

Improve quality of atmosphere and soil resources; understand effects of climate change through development of knowledge and technologies.

FY 2018 PERFORMANCE REPORT FOR GOAL 2.2

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will develop management practices and decision tools to improve quality and resilience of agricultural soils, protect air quality, improve production amidst climate variability, and reduce net GHG emissions.

- ARS scientists from Beltsville, Maryland, tested a new method—an environmental index—for identifying fields with that might have a high risk of contributing nutrient runoff to the Choptank River watershed. This new Soil Vulnerability Index (SVI) was more accurate at estimating surface runoff of organic nitrogen into the watershed than the older method, the Soil and Water Assessment Tool (SWAT). However, the SVI was less accurate than the SWAT method for identifying nitrate pollution caused by leaching into ground water. These methods can therefore be used in combination to better estimate the potential for nutrient losses into either surface water or ground water.

Indicator 2: During 2018, ARS will manage odor and reduce atmospheric emissions from animal production facilities, including increased efficiency of recovery and utilization of manure nutrients, biogas, and other byproducts.

- ARS researchers in Florence, South Carolina, developed a new system to collect and reuse ammonia that is removed from waste generated in poultry barns. This system can decrease ammonia levels in the air by 46 percent and can reduce ammonia amounts in the poultry litter by 45 percent. The use of the system also had an additional benefit in that it led to a 47 percent reduction of bird mortality. This system therefore offers poultry producers a way to simultaneously reduce ammonia problems in poultry barns and improve the health of their birds.
- In a collaboration with scientists from Iowa State University, ARS researchers in Bushland, Texas, found that applying ground soybean hulls to the floors of swine pens resulted in a 36 to 80 percent reduction in the chemicals that cause swine odors. The cost was relatively inexpensive, with treatment cost of $2.62 per marketed pig. This new approach gives swine producers a new and low-cost way to reduce odors.

Indicator 3: During 2018, ARS will develop management practices that promote soil biological components and improve agricultural system productivity resulting in validated and quantitative positive impacts on agro-ecosystem function.

- ARS researchers in Auburn, Alabama, discovered specific combinations of soil microorganisms which, when applied with to soils along with fertilizer, reduce agricultural emissions of nitrous oxide, a greenhouse gas. Because of the growing interest in placing economic value for ecosystem services—in this case, reducing the production of greenhouse gas emissions—use of this patented microbial inoculant could also provide an added income stream to the producer.

- ARS scientists in Lubbock, Texas, and Morris, Minnesota, developed a simplified, single method that provides a powerful index related to soil health. It is both easy to use and is also adaptable to many climatic zones and cropping systems. The new assay will enable producers and land owners to assess soil health inexpensively and then adopt cropping practices that improve their soil's health and productivity.

Indicator 4: During 2018, ARS will reduce the abundance, movement, and environmental impact of pathogens in manure and Pharmaceutically Active Compounds (PACs), and assess the presence, distribution, and impact of antibiotic resistant bacteria and antibiotic resistance genes in manures, soils, and surrounding environments.

- ARS researchers in Lincoln, Nebraska, investigated levels of antibiotic resistance in bacteria on 13 organic farms in Nebraska that use only manure as fertilizer—manure from cattle that had never received antibiotics during their lifetimes. Although they found bacteria in those manures that were resistant to two classes of antibiotics, these same resistance genes were detected more frequently in nearby natural prairie soils compared to the soils on the organic farms. This information suggests that farming practices that use manure in organic operations do

not lead to an increase in long-term antibiotic resistance in the soil. This information will inform U.S. policy positions around antibiotic use in U.S. agricultural products, especially organic products.

- In collaboration with Colorado State University researchers, ARS scientists from Clay Center, Nebraska, and Bowling Green, Kentucky, investigated the prevalence of antibiotic resistant bacteria in beef cattle raised without any antibiotics. They found that levels of antibiotic resistance genes in some—but not all bacterial species—were significantly lower in beef cattle raised without antibiotics. This study showed that optimized antibiotic stewardship can reduce the prevalence of bacteria with antibiotic resistance in these food animal production systems.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 2.2

Note that the research undertaken in Goal 2.4 in 2016 and earlier will be combined into a revised Goal 2.2 starting in 2017. The revised goal statement will be "Improve Air and Soil Quality and the Efficient Utilization of Byproducts for Enhanced Sustainability." The following indicators reflect that change.

During FY 2019, ARS will:

1. Develop management practices and decision tools to improve quality and resilience of agricultural soils, protect air quality, improve production amidst climate variability, and reduce net GHG emissions.
2. Manage odor and reduce atmospheric emissions from animal production facilities, including increased efficiency of recovery and utilization of manure nutrients, biogas, and other byproducts.
3. Develop management practices that promote soil biological components and improve agricultural system productivity resulting in validated and quantitative positive impacts on agro-ecosystem function.
4. Reduce the abundance, movement, and environmental impact of pathogens in manure and Pharmaceutically Active Compounds (PACs), and assess the presence, distribution, and impact of antibiotic resistant bacteria and antibiotic resistance genes in manures, soils, and surrounding environments.

During FY 2020, ARS will:

1. Develop management practices and decision tools to improve quality and resilience of agricultural soils, protect air quality, improve production amidst climate variability, and reduce net GHG emissions.
2. Manage odor and reduce atmospheric emissions from animal production facilities, including increased efficiency of recovery and utilization of manure nutrients, biogas, and other byproducts.
3. Develop management practices that promote soil biological components and improve agricultural system productivity resulting in validated and quantitative positive impacts on agro-ecosystem function.
4. Reduce the abundance, movement, and environmental impact of pathogens in manure and Pharmaceutically Active Compounds (PACs), and assess the presence, distribution, and impact of antibiotic resistant bacteria and antibiotic resistance genes in manures, soils, and surrounding environments.

During FY 2021, ARS will:

1. Develop management practices and decision tools to improve quality and resilience of agricultural soils, protect air quality, improve production amidst climate variability, and reduce net GHG emissions.
2. Manage odor and reduce atmospheric emissions from animal production facilities, including increased efficiency of recovery and utilization of manure nutrients, biogas, and other byproducts.
3. Develop management practices that promote soil biological components and improve agricultural system productivity resulting in validated and quantitative positive impacts on agro-ecosystem function.
4. Reduce the abundance, movement, and environmental impact of pathogens in manure and Pharmaceutically Active Compounds (PACs), and assess the presence, distribution, and impact of antibiotic resistant bacteria and antibiotic resistance genes in manures, soils, and surrounding environments.

Goal 2.3 - Develop and Transfer Economically Viable and Environmentally Sustainable Production and Conservation Practices, Technologies, Plant Materials and Integrated Management Strategies, Based on Fundamental Knowledge of Ecological Processes, that Conserve and Enhance the Nation's Diverse Natural Resources Found on its Range, Pasture, Hay, and Turf Lands

NATIONAL PROGRAM 215 - RANGELAND, PASTURE & FORAGES

This program develops and integrates improved management practices, germplasm, and land-use strategies to optimize productivity, economic viability, and environmental enhancement in managing vegetation, livestock, and natural resources on private and public grass and forage lands. Research activities include: enhancing conservation and restoration of ecosystems and agroecosystems through improvements based on the application of ecological principles; improving management of fire, invasive weeds, grazing, climate change, and other agents of change; developing grazing-based livestock systems that reduce risk and increase profitability in existing and emerging markets; developing improved grass and forage legume germplasm for livestock, conservation, turf, and bioenergy and bioproduct systems; improving the sustainability of turf management; and improving decision-support systems, including improving inventory, monitoring, and assessment tools.

PERFORMANCE MEASURE FOR GOAL 2.3

Develop and transfer economically viable and environmentally sustainable production and conservation practices, technologies, plant materials, and integrated management strategies based on fundamental knowledge of ecological processes that conserve and enhance the Nation's diverse natural resources found on its range, pasture, hay, and turf lands.

FY 2018 PERFORMANCE REPORT FOR GOAL 2.3

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will provide improved germplasm and cultivars that can be released for pasture, harvested forages, turf, biofuels, rangeland restoration, and conservation.

- A team of scientists across ARS have developed a new approach for rapidly and accurately estimating the concentration of sugars in switchgrass, making it cheaper and easier to calculate ethanol yields from switchgrass samples. These calibrations will have multiple uses in breeding, genetics, and management research and could be used by biorefineries to predict ethanol yield of switchgrass biomass.

- Perennial forage grasses are critical input to the meat and dairy industry, and grasses that flower and mature in sync with legumes in grass-legume mixed pastures are highly desirable and improve the overall nutrient value of the forage throughout the grazing season. ARS researchers in Logan, Utah, have identified late-flowering genes in orchardgrass and developed molecular tools to rapidly screen for this characteristic across many types of orchardgrass. Ultimately, this helps grass breeders develop grasses that can improve the timing, availability, and nutritional quality of grass-legume pastures.

Indicator 2: During 2018, ARS will provide forage, pasture, and rangeland management technologies and strategies that reduce inputs while improving livestock performance and sustaining the environment.

- ARS scientists in University Park, Pennsylvania, compared the effects of corn meal and liquid molasses in the diet of grazing, lactating dairy cows. Results suggest that molasses can replace corn meal on an equivalent basis without negatively affecting milk yield and composition. The research also found that the use of molasses as a supplement slightly improved nitrogen use efficiency and increased the beneficial fatty acids found in milk. This information offers farmers who operate grass-fed dairy farms a more economical supplement for their cows that has other potential benefits as well.

- ARS researchers in Sidney and Miles City, Montana, in collaboration with the Natural Resources Conservation Service, identified successful practices for controlling invasive Russian olive populations and for returning native species to degraded areas. They found that tree shearing followed by immediate herbicide application resulted in 96 percent Russian olive mortality. Subsequent revegetation resulted in increased native species diversity and cover; however, this 5-year study did not show whether or how often the treatment might need to be repeated. Restoration of these lands with native species can result in increased livestock forage and native biodiversity and decreased soil erosion.
- ARS scientists in Miles City, Montana, in collaboration with the Montana Department of Environmental Quality and coal mining industry representatives, found that applying glyphosate in the fall immediately after the emergence of downy brome substantially reduced this invasive weed and increased native grass and forb establishment success rates. Downy brome is an invasive annual grass that rapidly takes over native rangelands and lands disturbed by mining, making restoration difficult. The strategic application of herbicides timed to the emergence of downy brome improves efforts to remediate brome infestation, restoring the diversity and productivity of the rangeland.

- When several grass seed producers in northern California were experiencing the extensive die-off of orchardgrass, a grass commonly planted for forage, hay, or silage, ARS researchers in Corvallis, Oregon, successfully detected the presence of Cocksfoot mottle virus in all samples collected from these fields. Demonstrating the spread of this disease that had previously been known to occur only in Oregon is an important first step in effectively managing the disease in affected regions, and is leading to the development of management guidance on how to stop the spreading of the disease.

- ARS scientists in Miles City, Montana, investigated whether symbiotic mycorrhizal associations increased biomass in more than 150 Great Plains grassland species. Findings indicate that many plant species may have difficulty becoming established in areas with degraded soil biology, while plants that are less dependent on mycorrhizal associations may become more easily established in areas with degraded soil biology. Knowledge of the relationships between plants and the soil microogranisms present at a given site will facilitate rangeland restoration efforts.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 2.5

During FY 2019, ARS will:

1. Provide improved germplasm and cultivars that can be released for pasture, harvested forages, turf, biofuels, rangeland restoration, and conservation.
2. Provide forage, pasture, and rangeland management technologies and strategies that reduce inputs while improving livestock performance and sustaining the environment.
3. Develop methods to assess soil microbial and total soil ecosystem complexity in rangelands, pasture, hay, and turf lands to understand and manage soil systems for improved production, while at the same time conserving the soils for future resource needs.

During FY 2020, ARS will:

1. Provide tools and management practices for livestock producers and rangeland managers that enhance sustainable production and increase landscape resilience.
2. Develop and provide new genomic, transcriptome, proteomic, and metabolomic tools to support cultivar development of forage grasses, turfgrasses, and legumes, and to determine implications for plant production, fitness, and forage and turf utilization under different and varying environmental conditions.
3. Develop methods to critically evaluate rangeland management and restoration practices and complementary technologies that can be used to improve the establishment of desirable plants at sites in need of restoration.
4. Develop management practices that use forage crops to improve soil health, water quality, plant productivity, and economic return.

During FY 2021, ARS will:

1. Develop fundamental knowledge in plant physiology, phytobiome, nutrient cycling, and water and soil physical and biochemical sciences for pastures and forage crops, rangelands and turf covered regions.
2. Use genomic and genetic selection technologies to explore and manipulate grass and other forage plants to improve their utility in turf, pastures, and rangeland settings.
3. Develop technologies to monitor aspects of turf-covered regions, pastures and forage croplands, and rangelands and use those data to improve modeling to aid in decision support of management decisions.
4. Develop management technologies that balance landscape production and maintenance of ecosystem services, including support of livestock and wildlife, reduction or reversal of environmental degradation (invasive species, maintenance of habitat), and support of other beneficial uses of the landscape.

Goal 2.4 – Develop Integrated Solutions for Agriculture Enabling Greater Productivity, Profitability, and Natural Resource Enhancement

NATIONAL PROGRAM 216 – SUSTAINABLE AGRICULTURAL SYSTEMS RESEARCH

The National Research Council report titled *Toward Sustainable Agricultural Systems in the 21st Century* provides a foundation for the Sustainable Agricultural Systems Research program. The report identifies four goals that define sustainable agriculture:

- Satisfy human food, feed, and fiber needs, and contribute to biofuel needs;
- Sustain the economic viability of agriculture;
- Enhance environmental quality and the resource base; and
- Enhance the quality of life for farmers, farm workers, and society as a whole.

Simultaneously achieving these goals requires a systems approach based on a framework that defines production as a function of the interactions of genetics with environment and management (GxExM). The expansion of the traditional GxE interaction to include M highlights opportunities for management to enhance performance of genetic resources under varying environmental conditions. Feedback from producers and stakeholders about GxExM is universally favorable as this is how they "view the world." Additionally, products delivered to consumers are viewed as a function of (GxExM)xP where P is post-processing and represents socioeconomic factors that include price and consumer preferences, such as nutritional value and food safety.

PERFORMANCE MEASURE FOR GOAL 2.4

Develop integrated solutions to solve challenges related to agricultural system productivity, profitability, energy efficiency, and natural resource stewardship.

FY 2018 PERFORMANCE REPORT FOR GOAL 2.4

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will develop integrated solutions to increase agricultural system productivity, profitability, and natural resource stewardship with metrics to describe the sustainability of the solutions.

- In a long-term crop rotation study, ARS researchers in Mandan, North Dakota, showed that crop productivity and economic returns increased by $25 to $38 per acre with increasing crop diversity, whereas economic risk decreased. In most cases, increasing crop diversity also resulted in higher soil organic carbon levels.
- ARS researchers in Tifton, Georgia, found that strip tillage in conjunction with winter cover crop planting and poultry litter application improved plant nitrogen availability by more than 24 lb/acre/yr in sandy landscapes of the southeastern Coastal Plain. Compared to conventional tillage practices, strip tillage resulted in a 5 percent greater increase in total soil nitrogen content and a 17 lb/acre decrease in nitrogen leached from soils.

- ARS researchers in Corvallis, Oregon, in collaboration with researchers from Oregon State University, published the *Pacific Northwest (PNW) Biochar Atlas*, a suite of decision-support tools designed to alleviate uncertainty regarding the use of biochar on farms. The atlas includes tools to identify soil deficiencies, pair biochar types best suited to treat a particular deficiency, and a cost-benefit calculator. The website hosting the atlas had nearly 20,000 page visits in the first 6 months, with visitors from 75 countries.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 2.6

During FY 2019, ARS will:

1. Develop integrated solutions to increase agricultural system productivity, profitability, and natural resource stewardship with metrics to describe the sustainability of the solutions.

During FY 2020, ARS will:

1. Develop new options for alternative crops to be used in rotations with existing crops for greater production resilience, efficiency, and economic return.
2. Develop strategies to increase efficiency of water and nutrient use that enable reduced input costs and losses to the environment.
3. Develop strategies for increased resilience of production systems to extreme weather events.
4. Develop sustainability metrics appropriate for assessing trends of the long term viability of local production systems.

During FY 2021, ARS will:

1. Develop new options for alternative crops to be used in rotations with existing crops for greater production resilience, efficiency, and economic return.
2. Develop strategies to increase efficiency of water and nutrient use that enable reduced input costs and losses to the environment.
3. Develop strategies for increased resilience of production systems to extreme weather events.
4. Develop sustainability metrics appropriate for assessing trends of the long-term viability of local production systems.

GOAL AREA 3: CROP PRODUCTION AND PROTECTION

Research conducted by ARS' Crop Production and Protection Program (CPP) National Programs will deliver science-based information and technologies to meet:

- Producers' needs for increased crop productivity and quality, protection from diseases and pests, and economically and environmentally sustainable methods of crop production;
- Consumers' demands for a ready supply of high quality, safe, affordable, and nutritious food;
- Workers' needs for a safe working environment;
- The public's desire to protect the environment; and
- The global community's needs for food security.

To meet these needs, ARS will conduct research that addresses the national priorities of genetic resource conservation, genomics, and genetic improvement; prevention and treatment of plant diseases; identification and management of arthropod and weed pests, including quarantine pests; improved crop management strategies; and the development of methyl bromide alternatives. The research of the Crop Production and Protection National Programs is well integrated with other ARS research in Animal Protection and Production; Natural Resources and Sustainable Agricultural Systems; and Nutrition, Food Safety and Quality. Through the National Invasive Species Information Center and Alternative Farming Systems Center of the National Agricultural Library, key information will be disseminated to agricultural producers, the research and education community, and the general public.

Goal 3.1 – Harness the Genetic Potential of Plants to Transform U.S. Agriculture while Delivering Economically and Environmentally Sound Technologies that Improve the Production Efficiency, Quality, Health and Value of the Nation's Crops

NATIONAL PROGRAM 301 - PLANT GENETIC RESOURCES, GENOMICS, AND GENETIC IMPROVEMENT

NATIONAL PROGRAM 305 - CROP PRODUCTION

Crop plants underpin U.S. agriculture and food security. Increased crop yield, product quality, and production efficiency are required to safeguard the Nation's agricultural economy and food supply. This research goal addresses the critical needs for increased crop productivity by providing crop plants with higher inherent genetic potential. To do so requires continuous crop genetic improvement through more efficient and effective plant breeding, which exploits sources of new genes and traits from the Nation's genebanks, leading-edge breeding methods, data-mining, bioinformatic tools, and incisive knowledge of crop molecular and biological processes. ARS breeders, plant scientists, computational biologists, and many others are engaged in a global quest to transform and accelerate the pace of innovation in plant breeding and crop production.

Sustaining and enhancing the economic viability of crop production in the United States requires new technologies and methods because input costs, such as energy, water, nutrients, pest management, and labor, are increasing. New production strategies necessitate a system approach to be economically, environmentally, and socially sustainable. This requires research products that include information, decision support tools such as software, improved devices such as more efficient spray systems, and accurate and reliable sensors. Information and tools must be integrated into overall production systems for specific crops and crop sequences, and rapidly transferred to growers. As the mechanism for delivering the genetic potential of crops from "seed to table," research supporting these needs must continually refocus its efforts to support the research and development needs of changing production systems, climate and environmental shifts, economic drivers affecting U.S. farmers, and the advances in plant breeding, genetics, pest and weed control, and product quality and utilization.

This research goal also includes bee pollination research, supporting one of the most important components of crop production. The honey bee (*Apis mellifera*) is the pollinator most often managed for commercial crop pollination. While the frequency of Colony Collapse Disorder has decreased, honey bee populations continue to suffer. Bee health is threatened by pests, pathogens, pesticides, and poor nutrition. New techniques for management of honey bee diseases and pests are needed to maximize pollination. There is also an important need for conservation and in some cases commercial development of non-*Apis* bees (all bees other than honey bees) that effectively pollinate crops such as alfalfa, tree fruits, or greenhouse crops. As part of that goal, scientists seek to maintain the health and encourage proper management of bee pollinators and honey production. These scientists also do research to develop knowledge,

strategies, systems, and technologies for a diversity of crops in a range of production systems, while increasing environmental quality and worker safety.

PERFORMANCE MEASURE FOR GOAL 3.1

Develop knowledge, strategies, systems, and technologies that maximize the production efficiency of our annual, perennial, greenhouse, and nursery cropping systems. Develop new technologies and tools contributing to improving these systems to meet current and future food crop production needs of diversified consumers, while ensuring economic and environmental sustainability and production efficiency, health, and value of our nation's crops.

FY 2018 PERFORMANCE REPORT FOR GOAL 3.1

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will breed superior new crops, varieties, and enhanced germplasm.

- ARS scientists from Fargo, North Dakota, collaborated with ARS bee breeders at Baton Rouge, Louisiana, to create the world's first cryopreserved honey bee embryo. This is a major advancement in the ability to improve the biosecurity of honey bee germplasm and the accessibility of the nascent National Honey Bee Germplasm Repository.

- ARS scientists in East Lansing, Michigan, used DNA markers to develop beans that can cook 16 minutes faster than traditional dry beans. Cooking time is an important consumer trait in dry beans, especially in developing nations where cooking fuel can be scarce and expensive. Consequently, shorter cooking times could drive greater utilization of these beans.

- In 2018, ARS scientists developed and released the peanut cultivar 'Contender' for the U.S. export market. This cultivar, bred specifically for production in Oklahoma and Texas, meets export market preferences for extra-large kernels, pods, and seeds. Its production and export are expected to contribute $20 million annually to the U.S. economy.

- ARS researchers at Stuttgart, Arkansas, and collaborators at Cornell University developed 'Scarlett' rice, a variety that has high yield potential when grown in the southern United States and nutritionally superior red bran that will appeal to consumers in high-value markets.

- VR O39-16 is a grapevine rootstock that provides protection against the dagger nematode and fanleaf degeneration disease. However, the VR O39-16 rootstock is not favored by growers because scions that are grafted onto it grow vigorously, produce large vines that need substantial pruning, form dense canopies, and produce low-quality fruit. ARS researchers in Geneva, New York, developed a low vigor rootstock variety from V4 O39-16, which now provides grapevine growers with a valuable means for controlling scion vigor while protecting the vines against insects and disease.

- Sapodilla is a delicious tropical fruit, but trees grow slowly, so growers need long-term research to ensure profitable production. A 7-year field study by ARS scientists in Puerto Rico provides the first information from a replicated experiment on fruit quality traits, leaf nutrient composition, and scion/rootstock compatibility of the sapodilla cultivar 'Prolific.'

Indicator 2: During 2018, ARS will devise innovative approaches to crop genetic improvement and trait analysis.

- In collaboration with the University of North Texas and the University of Guelph, ARS researchers in Maricopa, Arizona, discovered a new protein that plays a key role in the formation of lipid droplets in plant cells. The researchers found that shutting off production of this protein resulted in much larger lipid droplets and up to 10

percent more oil in the leaves and seeds of plants. Breeding programs to develop new oilseed cultivars with increased oil content will benefit from this breakthrough.

- ARS scientists in Fargo, North Dakota, developed a new approach to facilitate interbreeding between cultivated sunflower and its wild relatives. This new method overcomes incompatibility barriers for transferring useful traits from wild relatives into cultivated sunflowers.

- To breed cotton with more uniform fiber quality, improved methods are needed for measuring that quality from breeding plots. ARS scientists in College Station, Texas, and Texas A&M AgriLife Research collaborators identified the method for selecting hand-harvested bolls that most accurately represents the fiber quality in bolls picked by mechanical harvesters. These improvements in boll sampling will help producers and breeders streamline the estimation of cotton fiber quality.

Indicator 3: During 2018, ARS will expand crop genomic information resources and advanced bioinformatic capabilities.

- ARS scientists in Corvallis, Oregon, collaborated with Oregon State University, Hopsteiner Inc., and Pacific Biosciences Inc., to complete the first hop draft genome sequence and gene annotation. These DNA sequence data will enable hop breeders to more quickly develop improved cultivars that address the needs of the brewing industry.

- Pigweed has become a troublesome weed in southeastern U.S. agricultural systems, and agriculturalists need information on areas affected by pigweed to implement effective management control strategies. ARS scientists at Stoneville, Mississippi, used free and open-source GIS software (QGIS), free government data, and online plant databases to develop and publish a county-scale geographic information database showing the distribution of three pigweeds: Palmer amaranth, redroot pigweed, and waterhemp.

- The cotton breeding and research community has lacked a secure and comprehensive online accessible breeding data management and analysis system. ARS scientists in College Station, Texas, in collaboration with Cotton Incorporated and Washington State University, developed a Breeding Information Management System (BIMS) in the CottonGen database. The release of BIMS expedites the development of new and improved cotton types to benefit U.S. farmers.
- ARS researchers in Ithaca, New York, improved statistical methods for measuring crop performance in the field which can accelerate crop improvement. Unlike prior models, their new methods are able to account for spatial variation in field experiments and account for competition between breeding lines in adjacent plots.

Indicator 4: During 2018, ARS will conserve and encourage the use of plant and microbial genetic resources and associated information.

- ARS scientists in Beltsville, Maryland, collaborated with Asian scientists to conduct DNA fingerprinting on 706 different kinds of tea originating from southeast Asia. Their discovery that these teas belonged to one of four groups of genetically similar teas will aid in the future identification of unknown tea cultivars and help the U.S. tea industry conduct quality assurance on imported and domestic teas that are otherwise difficult to classify.

- ARS scientist in Fort Collins, Colorado, developed new methods to store grape vine tissue samples in ultra-cold conditions. This new method will ensure that vital grape genetic resources are safeguarded in secure storage conditions and available indefinitely. These resources will enable breeders to continue improving the quality, productivity, and resilience of this fruit crop that has a U.S. market value of approximately $6 billion per year.

Indicator 5: During 2018, ARS will expand fundamental knowledge of plant biological and molecular processes.

- ARS researchers at Davis, California, and Las Cruces, New Mexico, collaborated with researchers at Lawrence Berkeley National Laboratories and the University of Idaho to assess the sensitivity, exposure, and vulnerability

of eight field crops to increased temperatures at midcentury (2040-2069). These data will help predict the effects of future heat stress on crops and will inform future land-use.

- ARS scientists in Lubbock, Texas, studied how a particular protein has the same maintains photosynthetic efficiency at elevated temperatures and demonstrated that this protein has the same function in conserved across both sorghum and the model plant *Arabidopsis*. This new knowledge will facilitate the development of plants that can maintain thermostability and photosynthetic function, even in the face of rising temperatures.

- In partnership with bioinformaticists at Iowa State University, ARS researchers in Ames, Iowa, discovered that just two genetic regulators control the output of more than 4,000 genes involved in crop resistance to powdery mildew. This discovery of a conserved core of genes that can be activated by known molecular signals offers new genetic mechanisms to deploy in crop protection.

- ARS researchers in Ithaca, New York, identified a protein that limits the synthesis of carotenoids in tomatoes. Additional study of the gene encoding this protein suggest that it can be manipulated via traditional breeding or targeted genetic engineering to improve nutrient and visual quality in tomato and additional fruit crops.
- Starch is the primary energy storage molecule used by plants to fuel respiration and growth during periods of limited photosynthesis. ARS researchers at Davis, California collaborated with University of California, Davis, and Yale researchers to develop a new, nondestructive approach that enables starch measurement in living plants. This new tool has applications to many horticultural crops and will support producers who are under increasing pressure to minimize water use without limiting crop longevity or yields.

Indicator 6: During 2018, ARS will develop more effective methods to enhance biotechnology for crop improvement.

- ARS scientists in Madison, Wisconsin, investigated how field size and isolation affect bee behavior and consequent pollen-mediated gene flow. Their findings showed that bees would travel as far as needed to visit flowers, despite the distances involved. This information highlights the need for carefully planning the configuration of genetically-modified and conventional crop plots to restrict potential gene flow from insect pollinator transport.

- An ARS scientist in Albany, California, developed a novel means for the efficient assembly and introduction of multiple genes into plants. This technological breakthrough overcomes previous challenges in rapidly and effectively developing crops with improved disease resistance, increased yields, and other key production traits.

Indicator 7: During 2018, ARS will develop crop production strategies to optimize crop genetic potential, mitigate losses due to biotic and abiotic stresses, and increase production efficiency.

- Brown marmorated stink bug is a highly invasive pest of agricultural and nursery crops and is a nuisance when it invades homes to overwinter. ARS researchers at Kearneysville, West Virginia, partnered with university researchers to develop brown marmorated stink bug lures that are now commercially available from three commercial companies.

- ARS researchers in Kearneysville, West Virginia, developed and patented durable catch plates that enable the mechanical harvesting of blueberries with significantly less bruise damage. In 2018, two commercial blueberry harvesting machines with the new catch plate design were built.

- ARS researchers in Tucson, Arizona, found that spring pollen provides bees with higher concentrations of necessary proteins and fatty acid nutrients than fall pollen. Nutrients in spring and fall pollen also support different types of activities and metabolic processes that the bees depend upon during these respective times of year. This new knowledge emphasizes the importance of the availability of flowering plants from spring through fall and that seasonal nutritional needs must be considered when formulating pollen supplements for bee colonies.

- ARS scientists in Wooster, Ohio, determined the specific water and steam temperatures and exposure times needed to kill the weed seeds that hitchhike onto plastic nursery containers and trays. This new knowledge will help greenhouse and nursery producers reduce weed growth in their production systems.
- ARS scientists at College Station, Texas, developed a new system that integrates airborne imaging with variable rate aerial application technology. They used the system to effectively map henbit, a winter weed, and accurately deliver prescribed rates of herbicide specifically to the weed. Integrating remote sensing and variable rate technology expands the capabilities of the aerial application business.

Indicator 8: During 2018, ARS will improve pollinator health, bee systematics and germplasm lines, and pollination.

- ARS scientists in Beltsville, Maryland, discovered that disruption of honey bee gut bacteria by antibiotic treatment could interfere with bee immunity and make bees more susceptible to Nosema, a fungal disease.
- A study by ARS scientists in Fargo, North Dakota, showed that bees accounted for 26 percent of sunflower yield and demonstrated a clear preference for certain hybrids. Almost all bee visits to non-oil sunflowers were by solitary wild bees. Growers are now using bee conservation as part of crop management, and breeders are now using pollinator attraction as a component of sunflower breeding.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 3.1

During FY 2019, ARS will:

1. Breed superior new crops, varieties, and enhanced germplasm.
2. Devise innovative approaches to crop genetic improvement and trait analysis.
3. Expand crop genomic information resources and advanced bioinformatic capabilities.
4. Conserve and encourage the use of plant and microbial genetic resources and associated information.
5. Expand fundamental knowledge of plant biological and molecular processes.
6. Develop more effective methods to enhance biotechnology for crop improvement.
7. Develop crop production strategies to optimize crop genetic potential, mitigate losses due to biotic and abiotic stresses, and increase production efficiency.
8. Improve pollinator health, bee systematics and germplasm lines, and pollination.

During FY 2020, ARS will:

1. Breed superior new crops, varieties, and enhanced germplasm.
2. Devise innovative approaches to crop genetic improvement and trait analysis.
3. Expand crop genomic information resources and advanced bioinformatic capabilities.
4. Conserve and encourage the use of plant and microbial genetic resources and associated information.
5. Expand fundamental knowledge of plant biological and molecular processes.
6. Develop more effective methods to enhance biotechnology for crop improvement.
7. Develop crop production strategies to optimize crop genetic potential, mitigate losses due to biotic and abiotic stresses, and increase production efficiency.
8. Improve pollinator health, bee systematics and germplasm lines, and pollination.

During FY 2021, ARS will:

1. Identify and/or develop new traits, tools, techniques and analytical approaches; breed new crop plants that contain new genetic diversity or protection against crop production barriers, such as diseases, pests, and other stresses.
2. Enhance and conserve genetic resources, and develop improved crop breeding methods, information, and other tools to support crop genomics and genetic improvement; develop more effective methods to enhance biotechnology for crop improvement; and expand previous discoveries and fundamental knowledge of plant biological and molecular processes.
3. Develop or improve existing production systems for current and emerging crops.
4. Determine nutritional needs of bees, and develop methods for improving bee nutrition and performance; develop methods to mitigate the impact of pathogens, pests, and pesticides; conserve bee diversity; and improve bee taxonomy.

Goal 3.2 – Protect Our Nation's Crops

NATIONAL PROGRAM 303 - PLANT DISEASES

NATIONAL PROGRAM 304 - CROP PROTECTION AND QUARANTINE

Agricultural commodities represent about 6 percent of the total value of all products exported from the United States, but insects, mites, and weeds cause considerable losses to these commodities — losses estimated to be worth tens of billions of dollars, a significant portion of the final commodity value. Post-harvest losses for corn and wheat alone can amount to as much as $2.5 billion annually.

Plant diseases are caused by many types of microbial pathogens, including fungi, oomycetes, bacteria, viruses, viroids, phytoplasmas, and nematodes. These diseases cause billions of dollars in economic losses each year to crops, landscapes, and forests in the United States. Plant diseases reduce yields, diminish product quality and shelf life, decrease aesthetic and nutritional value, and may also contaminate food and feed with toxic compounds. Control of plant diseases is essential for providing an adequate supply of food, feed, fiber, and landscape crops, but effective control requires an understanding of the biology of these disease-causing agents.

Pest and disease control methods face continuous challenges from nature and from human-associated effects. Shifts in agricultural practices can create new situations in which a previously benign insect or plant becomes a pest or a weed. Effective chemical controls are often no longer available for agricultural use. Perhaps most significantly, increases in global shipping (imports and exports) and climate change have accelerated the pace of the introduction and establishment of invasive pests and weeds. Invasive species threaten our food, fiber, and natural ecosystems and are a mounting concern. The brown marmorated stink bug and spotted wing drosophila consume our crops, while other invasive insects transmit devastating bacterial and viral diseases. Some of the se invasive insects, such as the Asian long horned beetle and emerald ash borer, decimate our forests and urban landscapes. Invasive weeds have reduced biodiversity, displaced native species, and cost billions of dollars to control each year.

Integrated pest management (IPM) is the desired strategy for controlling pests, including weeds, and diseases. IPM combines the use of pest surveillance to identify when and where pest control strategies are best applied with multiple control methods that are integrated to work optimally, while also being economical and environmentally safe. Pest control includes cultural, biological, physical, and chemical methods. By integrating the use of several methods and monitoring the activity and population growth of a pest, growers can best target pest populations while maintaining the effectiveness of each control method. Maintaining an array of effective methods is important since control strategies, especially chemical methods, can be lost for a variety of reasons, including pest and weed resistance, new regulatory requirements (arising from environmental or human safety issues), loss of public acceptance, and commercial considerations. IPM attempts to systematically apply scientific knowledge on the biology of insects and w eeds to achieve safe, harmonious, and economical systems that reduce the pest problems below economic thresholds in a sustainable manner.

New solutions to protecting crops from pest insects and weeds are needed to increase the quantity and quality of consumer-palatable food and to increase usable fiber. Sustainably controlling pests and weeds with environmentally

safe strategies is therefore essential for meeting the ARS goal to "transform agriculture to deliver a 20 percent increase in quality food availability at 20 percent lower environmental impact by 2025."

PERFORMANCE MEASURE FOR GOAL 3.2

Provide scientific information to increase our knowledge of plant genes, genomes, and biological and molecular processes to protect crops and cropping systems from the negative effects of pests and infectious diseases. Develop sustainable control strategies for crop pests and pathogens based on fundamental and applied research that are effective and affordable, while maintaining food safety and environmental quality.

FY 2018 PERFORMANCE REPORT FOR GOAL 3.2

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will continue to identify and characterize resistance genes in crop plants for insect, nematode, and plant pathogens to enhance opportunities for developing host plant resistance, and to incorporate such genes into commercially acceptable varieties.

- Methyl benzoate exists naturally as a floral fragrance in many plants. ARS scientists in Beltsville, Maryland, found that methyl benzoate also has insecticidal properties and is more toxic to gypsy moth larvae and brown marmorated stink bug nymphs than commercial insecticides. It was also found to be 5 to 20 times more toxic to spotted wing drosophila larvae, and ARS has since patented it as a safe, new insecticide for use on this fruit fly.

- ARS scientists in Fargo, North Dakota, bred the first ever sunflowers that have resistance to both Sclerotinia basal stalk rot and downy mildew. These sunflowers are now being used across the United States and internationally to breed sunflower for resistance to multiple diseases that reduce seed quality and severely affect yield.

- In 2018, the Florida Sugar Cane Variety Committee released six sugarcane cultivars that are high yielding and resistant to the devastating and costly orange and brown rust diseases. These cultivars were developed through the work of ARS researchers in Canal Point, Florida, collaborating with the University of Florida and the Florida Sugar Cane League. Florida produces twenty percent of the sugar consumed in the United States, and these cultivars are expected to increase the sustainable and profitable production of sugarcane.

- ARS scientists in St. Paul, Minnesota, identified a highly effective resistance gene to oat crown rust from wild oat and bred it into cultivated oat. The gene confers broad resistance to this devastating disease, making it highly valuable to scientists around the globe.

- ARS scientists in Oxford, Mississippi, previously discovered a compound called sorgoleone which gives sorghum its natural weed-fighting properties. These ARS scientists have now identified the complete biosynthetic process for how the plant makes sorgoleone—new knowledge that can be applied to the development of other crop varieties that can fight off weeds. Such crops could significantly reduce the need for chemical herbicide applications and increase options for crop rotations.

Indicator 2: During 2018, ARS will continue to develop fundamental knowledge about biology and ecology that provides the foundation for strategies to exclude, accurately detect and identify, and mitigate arthropod and nematode pests, weeds, and plant pathogens.

- ARS researchers in Kearneysville, West Virginia, developed PhylloLux technology, a novel plant disease-management system that combines Ultraviolet C (UV-C) irradiation followed by a specific dark period with the

application of biocontrol agents. This technology offers an alternative to fungicides that may become limited in their ability to control plant pathogens.

- Results from a study by ARS scientists in Pullman, Washington, show that fields with a long history of glyphosate usage have only minor differences in soil microbial communities compared to fields without glyphosate. Microbial communities were instead much more significantly affected by location and cropping system. These results address previous concerns about the effect of glyphosate on beneficial soil microbes.

- An experiment conducted by ARS scientists in Illinois, Maryland, and Mississippi demonstrated that GMO crops were no more likely to develop Goss's wilt than non-GMO corn and found that glyphosate applications were not associated with mineral deficiencies in these crops. These results address previous concerns about disease susceptibility and mineral deficiencies in corn exposed to glyphosate.

Indicator 3: During 2018, ARS will perform applied research and development to provide new, useful, and safe methods and products to accurately detect, identify, and diagnose arthropod and nematode pests, weeds, and plant pathogens.

- ARS scientists in Beltsville, Maryland, completed the documentation of nearly 500 additional nematode species for the USDA Nematode Collection. The specimens are used by scientists, extension agents, growers, and quarantine officials to anticipate and accurately identify nematode species for research and pest control.

- Citrus stubborn disease is a fairly widespread but manageable disease in California that is easily mistaken for the devastating citrus greening disease that is subject for quarantine and immediate removal. ARS researchers in Parlier, California, developed a sensitive procedure that distinguishes the two diseases. Their procedure is more sensitive and reliable than the standard molecular technique and can be used by regulatory agencies to differentiate between the two diseases.

- In collaboration with the University of California, ARS researchers in Salinas, California, developed two different types of molecular diagnostic tests that are specific for the *Macrophomina* pathogen that infects strawberries. The tests measure the amounts of the fungus in the soil and provide a way for its rapid detection in production fields. These assays provide researchers with the tools they need to identify the pathogen and provide growers with the ability to determine risk prior to planting.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 3.2

During FY 2019, ARS will:

1. Continue to identify and characterize resistance genes in crop plants for insect, nematode, and plant pathogens to enhance opportunities for developing host plant resistance and to incorporate such genes into commercially acceptable varieties.
2. Continue to develop fundamental knowledge about biology and ecology that provides the foundation for strategies to exclude, accurately detect and identify, and mitigate arthropod and nematode pests, weeds, and plant pathogens.
3. Perform applied research and development to provide new, useful and safe methods and products to accurately detect, identify and diagnose, arthropod

During FY 2020, ARS will:

1. Continue to identify and characterize resistance genes in crop plants for insect, nematode, and plant pathogens to enhance opportunities for developing host plant resistance and to incorporate such genes into commercially acceptable varieties.
2. Continue to develop fundamental knowledge about biology and ecology that provides the foundation for strategies to exclude, accurately detect and identify, and mitigate arthropod and nematode pests, weeds, and plant pathogens.
3. Perform applied research and development to provide new, useful and safe methods and products to accurately detect, identify and diagnose, arthropod

During FY 2021, ARS will:

1. Continue to identify and characterize resistance genes in crop plants for insect, nematode, and plant pathogens to enhance opportunities for developing host plant resistance and to incorporate such genes into commercially acceptable varieties.
2. Continue to develop fundamental knowledge about biology and ecology that provides the foundation for strategies to exclude, accurately detect and identify, and mitigate arthropod and nematode pests, weeds, and plant pathogens.
3. Perform applied research and development to provide new, useful and safe methods and products to accurately detect, identify and diagnose, arthropod

and nematode pests, weeds, and plant pathogens.

and nematode pests, weeds, and plant pathogens.

and nematode pests, weeds, and plant pathogens.

GOAL AREA 4: ANIMAL PRODUCTION AND PROTECTION

The ARS Animal Production and Protection (APP) national programs provide the scientific information and tools to help support the U.S. food animal industries to continue to compete successfully in worldwide trade, provide the supply of nutritional animal products required by the Nation, and contribute toward global food security. APP will accomplish this mission by maximizing production efficiency and animal health through scientific innovation and the discovery and development of new technologies focused on national priorities. Strategic public-private partnerships will be established to achieve our mission, including support of government action and regulatory agencies responsible for trade, biodefense, and global food security. Emphasis will be given to genetic improvements of traits related to production and production efficiencies and germplasm conservation; understanding the mechanisms of disease resistance and the development of tools to prevent, control, or eradicate diseases that threaten the U.S. food supply and public health; and identifying and developing sustainable systems for production of high quality meat, fish, milk, and eggs that also ensure animal health and well-being. The portion of the program that produces new solutions to the many veterinary problems created by arthropod pests and vectors will be leveraged to solve related problems affecting human health and the well-being of American citizens.

Goal 4.1 – Provide Scientific Information and Biotechnologies for aquaculture and animal agriculture that will improve production efficiency, industry sustainability, product quality, and nutritional value while safeguarding genetic resources.

NATIONAL PROGRAM 101 - ANIMAL PRODUCTION

NATIONAL PROGRAM 106 – AQUACULTURE

The demand for food animal products will continue to increase globally as consumers seek higher quality and more nutrient-dense sources of protein, iron, and other vital nutrients. This trend will continue as the world's population continues to grow and as animal production systems increase efficiencies across varied environments and production

systems. Animal production systems fit a unique and valuable niche in the global food production equation by utilizing feeds and forages not appropriate for human consumption. Animal production will continue to serve in this vital role in response to increasing demands for nutritious protein sources that are produced in environmentally sustainable food production systems across the globe.

The United States has historically been a leading source of quality animal products and has led the world in technological development and adoption. These advances have enabled the United States to develop one of the most efficient animal production systems on earth and ARS has been a vital part of that achievement. Furthermore, agriculture is being relied on to provide for a growing world population more now than at any other time in modern history. Pressure to feed a projected nine billion plus people by 2050 makes the role of ARS critically important. To remain competitive in the face of extraordinary growth in animal production systems around the world, while at the same time decreasing the environmental footprint of animal production, U.S. animal industries must continue to focus on the development and adoption of scientific technologies. These improvements in efficiency must be sustainable with regard to animal welfare and impacts on the environment. The application of new tools in genomics, biotechnology, metagenomics, reproductive physiology, nutrition, and molecular biology in concert with animal health and in support of traditional husbandry, animal welfare, and conservation of ecosystem services will continue to improve the long tradition of global economic competitiveness and sustainability of U.S. food animal production.

Interest in aquaculture production -- the production of aquatic animals under controlled conditions for all or part of their lifecycles – is on the rise because of the harvest of wild-caught seafood has leveled off and demand for seafood and other products of aquaculture continues to grow. The ability for U.S. aquaculture producers to meet that demand requires development of technologies to reduce the cost of production while maintaining and improving product quality. Producers, processors, and breeders are in need of systems that maximize aquatic animal production, reduce environmental impacts, increase market competitiveness, sustain producers, and earn consumer confidence. Research in the disciplines of genetics, nutrition, health, and physiology will support the biological improvement of animals, while ecology, water quality, engineering, and food science will support the improvement of systems and products to ensure sustainability.

Systems of agricultural animal management and production face formidable challenges. One of the most exacting challenges is successful adaptation to the accelerating demands of society that impact animal productivity and product quality. The demands placed on the national system of food animal production by a rapidly changing world include increasing population, increasing demand for animal products by developing nations, rising obesity, and increasing demands for better nutrition, with greater food safety and lower costs. Research on food animals and their production systems (management strategies, environmental impacts) is needed to meet these demands. These challenges will be met by using technologies that harness and enhance the genetic potential of animal germplasm. These technologies will be sustainable in that they cause no harm to the animals or the environment, and will be implementable by the animal production and food marketing industries. Production systems that harness animal biology in a sustainable way will maximize profits, secure supply, increase market competitiveness, sustain small and mid and large scale producers, conserve natural resources and maintain genetic diversity and consumer confidence .

PERFORMANCE MEASURE FOR GOAL 4.1

Provide scientific information to maximize the production efficiency of our food animal production systems. Develop new technologies and tools contributing to improved systems to meet current and future food animal production needs of diversified consumers, while ensuring economic and environmental sustainability and animal well-being.

FY 2018 PERFORMANCE REPORT FOR GOAL 4.1

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text.

Indicator 1: During 2018, ARS will identify underlying genetic and/or physiologic mechanisms relating to food animal production and production efficiencies for traits associated with growth physiology, nutrient utilization, reproductive physiology, health, and well-being in food animals.

- A study conducted by ARS researchers in Lubbock, Texas, in collaboration with industry partners demonstrated that topically administering NSAIDS to cows exposed to Bovine Respiratory Disease was effective in reducing fever when applied at the time of exposure to the disease. This topical treatment is easier to administer than injectable or oral products, ultimately improving the health and well-being of affected cattle.

- In collaboration with researchers at Auburn University, ARS scientists in Auburn, Alabama, showed that the bacteria causing columnaris disease has the ability to breakdown the protective mucus layer that coats catfish skin and thereby increases the vulnerability of catfish to bacterial infection. This new knowledge will help the field develop more effective strategies for mitigating the disease.

- In a collaboration with Auburn University and Rutgers University scientists, ARS researchers at Clay Center, Nebraska, demonstrated that the milk a pig consumes from its mother on its first day of life (colostrum) plays an important role in uterine function and development, fertility, and litter size. This knowledge reinforces the importance of colostrum consumption to enhance long-term pork production and profitability.

- ARS researchers in West Lafayette, Indiana, developed a new method for estimating core body temperature in poultry that is more accurate and induces less poultry stress than previous methods. This new method will help poultry producers to more effectively monitor heat stress, which will protect poultry welfare and increase the efficiency of feed intake.

- Results from a study conducted by ARS researchers in Leetown, West Virginia, indicate that fish farmers should change the methods they use to incubate fertilized eggs. The traditional practice of incubating eggs at 5 degrees Celsius within the first day of fertilization results in a 5 percent reduction in embryo survival compared to those eggs incubated at 10 degrees Celsius.

- To increase the efficiency of artificial insemination in the breeding of beef cattle, producers use protocols that synchronize the cows' reproductive cycles. However, these protocols often result in lower fertility rates. A study conducted by ARS scientists in Clay Center, Nebraska, in collaboration with South Dakota State University researchers suggests that increasing the number of cows expressing estrus after estrous synchronization protocols will lead to better fertility.

Indicator 2: During 2018, ARS will develop genomics infrastructure and tools to efficiently identify genes, their function, and interactions with environmental factors for exploitation in genome-enabled improvement programs for food animals.

- ARS researchers at East Lansing, Michigan, collaborated with Purdue University and University of California-Davis scientists to study the genetic basis of Marek's disease, a virus that is estimated to cost poultry producers worldwide more than $1 billion annually. Their new knowledge of the genetic underpinnings of Marek's disease

will help develop new approaches for reducing the incidence of disease, ultimately improving the health and well-being of poultry and increasing overall production efficiency.

- In collaboration with University of Georgia researchers, ARS scientists in Stoneville, Mississippi, developed a new approach for using DNA sequence data that will help catfish breeders to more rapidly and effectively breed to increase yields. This knowledge and the resulting catfish will help to improve the overall production efficiency for U.S. catfish farmers.

- A condition called "dark cutting beef" reduces consumer acceptance of beef products and results in an annual loss of more than $70 million in potential revenue. ARS researchers in Clay Center, Nebraska, discovered a genetic variant that reduces cattle susceptibility to the dark-cutting condition, which will help breeders to reduce losses associated with the occurrence of dark-colored beef.

- ARS researchers in Beltsville, Maryland, collaborated with the Council on Dairy Cattle Breeding to develop a new set of indices to breed cows with increased disease resistance. As a result these cows will be healthier than cows with health conditions that require extra farm labor, veterinary treatment, and medicine, increasing the industry's profitability by an additional $1.4 million annually.

- ARS researchers in Leetown, West Virginia, have been the first to successfully use genome editing in rainbow trout, demonstrating that their protocols achieve the intended genetic changes that can successfully be inherited by trout offspring via standard reproduction. Genome editing therefore serves as a complementary approach for furthering the scientific understanding of trout genetics and can ultimately enhance the rate at which trout breeders produce healthy, desirable trout.

Indicator 3: During 2018, ARS will develop and improve sustainable production systems for food animals, incorporating strategies to optimize production system efficiency while ensuring economic and environmental sustainability.

- An analysis conducted by ARS scientists in Madison, Wisconsin, and Virginia Tech researchers demonstrated that eliminating animal agriculture is not likely to yield the net positive environmental impacts to the degree that many have proposed. While there may be some cost-effective results and environmental benefits, other changes in the agricultural system to compensate for the elimination of animal agriculture would generate unexpected impacts and reduce these benefits.

- ARS researchers improved estimates of the water needed for cooling poultry houses throughout the United States and demonstrated that previous estimates were 25 percent greater than they needed to be. These findings will be able to reduce the costs of installing and operating evaporative cooling systems in new poultry houses.

- ARS researchers in Shepherdstown, West Virginia, demonstrated the utility of woodchip bioreactors in capturing nitrogen runoff from fish farms. This affordable, low maintenance technology can reduce environmental impacts of fish farming and reduce wastewater treatment costs.

- In collaboration with Auburn University, ARS researchers in Lubbock, Texas, demonstrated that *Salmonella* may often be present in internal beef tissues—tissues which may not be treated by traditional methods of beef decontamination. This finding reinforces the need to cook beef properly to avoid foodborne illness.

Indicator 4: During 2018, ARS will characterize nutrient requirements of food animals, measure nutrient availability of traditional and nontraditional feedstuffs, and develop strategies for improving nutrient use efficiency.

- ARS researchers in Lexington, Kentucky, have found an added-value to hop production: Surplus hops that are too old for brewing beer can instead become a cattle feed additive that promotes protein retention from the feed. Increased protein retention reduces cattle feed requirements and therefore reduces cow excrement and subsequent ammonia runoff. The hop additive ultimately saves cattle producers money and helps to protect the environment.

- The animal feed industry has been in need of a new method for accurately measuring the amount of dietary starch in animal feed to ensure the formulation of healthy pet and livestock diets. An ARS scientist in Madison, Wisconsin, collaborated with several other feed analysis laboratories to develop and approve a new, accurate starch estimation method that was used to process 1.4 million samples in 2017 alone.
- ARS researchers at Clay Center, Nebraska, collaborated with University of Nebraska researchers to elucidate the relationship between cattle gut microbial communities and the rate at which cows can convert food into mass or flesh (feed efficiency). Their new knowledge can inform future strategies for increasing cattle feed efficiency, ultimately reducing the costs required for feeding cattle and lessening the environmental impacts of cattle production.

Indicator 5: During 2018, ARS will characterize food animal germplasm for traits of importance and continue to increase the inventory of germplasm stored within the National Animal Germplasm Repository to preserve biodiversity.

- In collaboration with researchers at Virginia Tech, ARS scientists in Clay Center, Nebraska, and Dubois, Idaho, developed a new breeding strategy that improves the efficiency of sheep production by optimizing the number of lambs produced per ewe.
- Contrary to the field's prior understanding, ARS researchers in Clay Center, Nebraska, demonstrated that muscle fiber differs across different pigs. Given that fiber type influences the color of pork meat, researchers can use this new knowledge to more effectively breed pork with desirable color.
- The beef industry needs to be able to maximize the number of healthy calves reared per cow while minimizing the weight (and ultimately feed requirements) of the parental cows. ARS researchers in Clay Center, Nebraska, demonstrated that it is possible to increase cow reproductive productivity without increasing parental cow weight, providing new knowledge for cattle breeders that will translate to cost savings for the cattle industry.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 4.1

During FY 2019, ARS will:

1. Identify and understand underlying genetic and/or physiologic mechanisms relating to food animal production and production efficiencies for traits associated with growth physiology, reproductive physiology, health, and well-being in food animals and use that information to improve food animal production efficiency.
2. Develop genomics infrastructure and tools to identify genes, their function, and their interactions with environmental factors for exploitation in genome enabled improvement programs for food animals.
3. Develop and improve sustainable production systems for food animals, optimizing strategies to improve production system efficiency while ensuring economic and environmental sustainability.
4. Characterize nutrient requirements of food animals, including mechanisms of nutrient use; measure nutrient availability

During FY 2020, ARS will:

1. Identify and understand underlying genetic and/or physiologic mechanisms relating to food animal production and production efficiencies for traits associated with growth physiology, reproductive physiology, health, and well-being in food animals and use that information to improve food animal production efficiency.
2. Develop genomics infrastructure and tools to identify genes, their function, and their interactions with environmental factors for exploitation in genome enabled improvement programs for food animals.
3. Develop and improve sustainable production systems for food animals, optimizing strategies to improve production system efficiency while ensuring economic and environmental sustainability.
4. Characterize nutrient requirements of food animals, including mechanisms of nutrient use; measure nutrient availability

During FY 2021, ARS will:

1. Identify, characterize and preserve genetic variation and define physiological mechanisms affecting food animal production and use that information to improve production efficiency, product quality and/or animal well-being.
2. Develop genomics infrastructure and tools to identify genes, their functions, and their interactions with environmental factors for exploitation in genome-enabled improvement programs for food animals.
3. Develop and improve sustainable production systems for food animals; optimizing strategies to improve production system efficiency while ensuring economic and environmental sustainability.
4. Characterize nutrient requirements of food animals, including mechanisms of nutrient use; measure

of traditional and nontraditional feedstuffs; and develop strategies for improving nutrient use efficiency.

5. Characterize food animal germplasm for traits of importance and continue to increase the inventory of germplasm stored within the National Animal Germplasm Repository to preserve biodiversity.

of traditional and nontraditional feedstuffs; and develop strategies for improving nutrient use efficiency.

5. Characterize food animal germplasm for traits of importance and continue to increase the inventory of germplasm stored within the National Animal Germplasm Repository to preserve biodiversity.

nutrient availability of traditional and nontraditional feedstuffs; and develop strategies for improving nutrient use efficiency.

Goal 4.2 - Prevent and Control Pests and Animal Diseases that Pose a Threat to Agriculture, Public Health, and the Well-Being of American Citizens.

NATIONAL PROGRAM 103 - ANIMAL HEALTH

NATIONAL PROGRAM 104 - VETERINARY, MEDICAL AND URBAN ENTOMOLOGY

NATIONAL PROGRAM 106 – AQUACULTURE

Investments in animal protection research are critical to the growth and resilience of the supply of food for tomorrow and Feed the Future initiatives. Enhancing the health of animals in agricultural production systems will directly impact food quality and ensure a sufficient supply of macro and micro-nutrients to meet people's basic needs worldwide. When combined with other investments in agricultural development, research-based innovations will address some of the fundamental constraints that give rise to food insecurity by reducing production risks associated with pests and diseases.

Achieving results in animal protection research in the 21st century will demand a systems biology approach in which knowledge obtained from animal genomes, functional genomics, clinical trials, and epidemiology are integrated in the discovery and development of countermeasures for preventing and controlling disease outbreaks.

Entomological research will concentrate on priority problems affecting animal production, human health, and the well-being of American animals and citizens. The research aims to dedicate 30 percent of resources to basic research that provides relevant information about target pests and 70 percent to applied research and product development. The program seeks to attain a balance of skills among its scientists so that it can take full advantage of the latest developments in biology, while at the same time applying its efforts to solution of practical problems.

Accordingly, the goal of the ARS animal protection research programs is to protect and ensure the safety of the Nation's agriculture and food supply through improved disease detection, prevention, control, and treatment. Basic and applied research approaches will be applied to solve animal health problems of high national priority. Emphasis will be given to methods and procedures to control animal diseases through the discovery and development of:

- Diagnostics and tools for identification of pests/vectors;
- Vaccines;
- Biotherapeutics;
- Pesticides, repellents, attractants, traps, and other innovative products for pest/vector control;
- Animal, pest, and vector genomics applications;
- Disease management systems and integrated pest/vector management systems;
- Animal disease models;
- Farm biosecurity measures;

- Applications of global information systems; and
- Chemical ecology of pests and vectors.

Animal protection national programs have eight strategic objectives:

1. Develop an integrated animal, arthropod, and microbial genomics research program.
2. Launch research programs to provide alternatives to antibiotics in food animal production.
3. Build a technology-driven vaccine and diagnostic discovery research program.
4. Develop core competencies in field epidemiology and predictive biology.
5. Develop expert collaborative research laboratories recognized by the World Organization for Animal Health (OIE) and the United Nation's Food and Agriculture Organization (FAO).
6. Develop a model technology transfer program to achieve the full impact of our research discoveries.
7. Perform the full spectrum of research for improvement of veterinary, public, and military entomology.
8. Develop safe and effective methods for prevention of damage caused by arthropods to homes and households.

PERFORMANCE MEASURE FOR GOAL 4.2

Provide scientific information to protect animals, humans, and property from the negative effects of pests and infectious diseases. Develop and transfer tools to the agricultural community, commercial partners, and government agencies to control or eradicate domestic and exotic diseases and pests that affect animal and human health.

FY 2018 PERFORMANCE REPORT FOR GOAL 4.2

Listed below is a set of featured accomplishments for each of the indicators of success established for FY 2018. To access additional information on a given accomplishment, click on the accomplishment text

Indicator 1: During 2018, ARS will describe five new discoveries or developments significant for their scientific or applied value.

- Newcastle disease viruses are the most prevalent cause of respiratory disease on poultry farms worldwide, and Newcastle disease vaccines are often ineffective in production environments. ARS researchers in Athens, Georgia, discovered a correlation between Newcastle disease and infection by antibiotic resistant *Ochrobactrum* bacteria, highlighting the need for new Newcastle disease vaccination programs that will also prevent such bacterial infections.

- ARS researchers in Stuttgart, Arkansas, developed a new vaccine that protects channel catfish from columnaris disease in laboratory challenges, a disease which has severely affected channel catfish production throughout the United States.

- ARS researchers in Auburn, Alabama, demonstrated that channel catfish vaccinated with live forms of *Ichthyophthirius multifiliis* (Ich) had a 95 percent survival rate against this parasite. Ich has caused severe losses to the worldwide aquaculture industry, and this vaccine offers a promising alternative to the previous costly and ineffective treatment methods.

- ARS researchers in Pullman, Washington, documented the presence of the *Mycoplasma ovipneumoniae* bacterium—a known primary cause of pneumonia in bighorn sheep –in several goat, sheep, caribou, moose, deer, and bison species in which the bacterium had not been previously documented. Given that this disease is typically transmitted from domesticated to wild animals, this new knowledge will inform policies.

- Leptospirosis is an important zoonotic bacterial pathogen and globally more than 10 million people are infected with Leptospirosis every year, with at least 10 percent of those infections leading to serious illness. ARS

researchers in Ames, Iowa, have developed improved methods for growing the bacteria under laboratory conditions, which will improve the field's ability to detect and understand this problematic disease to develop better vaccines and control measures.

- ARS scientists in Ames, Iowa, developed protocols for killing Brucella, a bacteria that poses a severe threat to public health. This new knowledge will inform biosafety laboratories on the proper handling and disposal of Brucella, reducing the risk of inadvertently releasing the deadly bacteria and protecting the safety of laboratory personnel.

Indicator 2: During 2018, ARS will form new partnerships and continue old partnerships with industry, universities, and other government agencies in order to promote production and marketing of new methods for detection and identification of animal pathogens, arthropods that transmit pathogens, and arthropods that destroy property, including genetic markers, new methods of detecting gene sequences or antibodies or proteins, and comprehensive guides to morphological identification.

- In 2009, ARS scientists in Pullman, Washington, discovered a horse parasite that went undetected by the existing suite of diagnostic tests. These scientists just recently identified genes and proteins that can be used to develop diagnostic assays that consistently detect the new parasite. These assays will be critical for controlling the new pathogen.

- In collaboration with scientists in Mexico, ARS researchers in Athens, Georgia, identified 82 species of wild birds that frequent poultry farms in Athens and a region of Mexico in which several strains of avian influenza have recently emerged. Having a clearer understanding of the relationships between wildlife and poultry helps the industry better understand the risks posed by migratory birds as well as trade and illegal transport.

Indicator 3: During 2018, ARS will form new partnerships and continue old partnerships with industry, universities, and other government agencies in order to promote production and marketing of inventions that protect animals from pathogens or manage arthropods that transmit pathogens or damage property.

- ARS researchers in Gainesville, Florida, collaborated with APHIS researchers to develop a portable field kit that untrained personnel can use to rapidly detect fire ants. This kit will help to minimize the introduction of fire ants and related shipping delays at United States quarantine boundaries and other ports of entry.

- ARS scientists in Kerrville, Texas, collaborated with scientists at APHIS and Texas A&M University to sequence the genome of the Asian longhorned tick, a new threat within the United States that has the potential to spread diseases to humans and livestock. The new genome sequence data will accelerate the development of new vaccines and other tick control methods.

- In a study with Kansas State University researchers on Japanese Encephalitis, ARS scientists in Manhattan, Kansas, showed that planes and other cargo transport vessels present minimal risk of introducing the disease and that mosquito behavior is a more significant factor in disease transmission than originally thought. The researchers developed models to better understand the host-vector relationship which will lead to improved future measures to prevent disease outbreaks and protect our food supply from exotic pathogens.

- ARS scientists in Pullman, Washington, have shown that some breeds of sheep and goats spread more *M. ovipneumoniae* bacteria than others. This new knowledge suggests that selective breeding can help mitigate the spread of this disease.

- ARS researchers in Beltsville, Maryland, are developing a new oral vaccine for treating coccidiosis, a gut disease of poultry that costs U.S. producers $350 million annually. This new oral vaccine reduces the incidence of secondary bacterial infections associated with coccidiosis, ultimately reducing antibiotic use in poultry and improving the health and welfare of poultry flocks.

FY 2019-2021 PERFORMANCE PLAN FOR GOAL 4.2

During FY 2019, ARS will:

1. Identify five new scientific discoveries that provide scientific information contributing to solving problems of high national priority.
2. Establish strategic public and/or private partnerships that will enable the technology transfer of four ARS inventions.
3. Identify two discoveries that will contribute to the development of new diagnostics for the detection of priority pest and infectious disease agents.
4. Identify two discoveries that will contribute to the development of veterinary medical countermeasures.
5. Form new partnerships and continue old partnerships with industry, universities, and other government agencies in order to promote production and marketing of inventions that protect animals from pathogens or manage arthropods that transmit pathogens or damage property.

During FY 2020, ARS will:

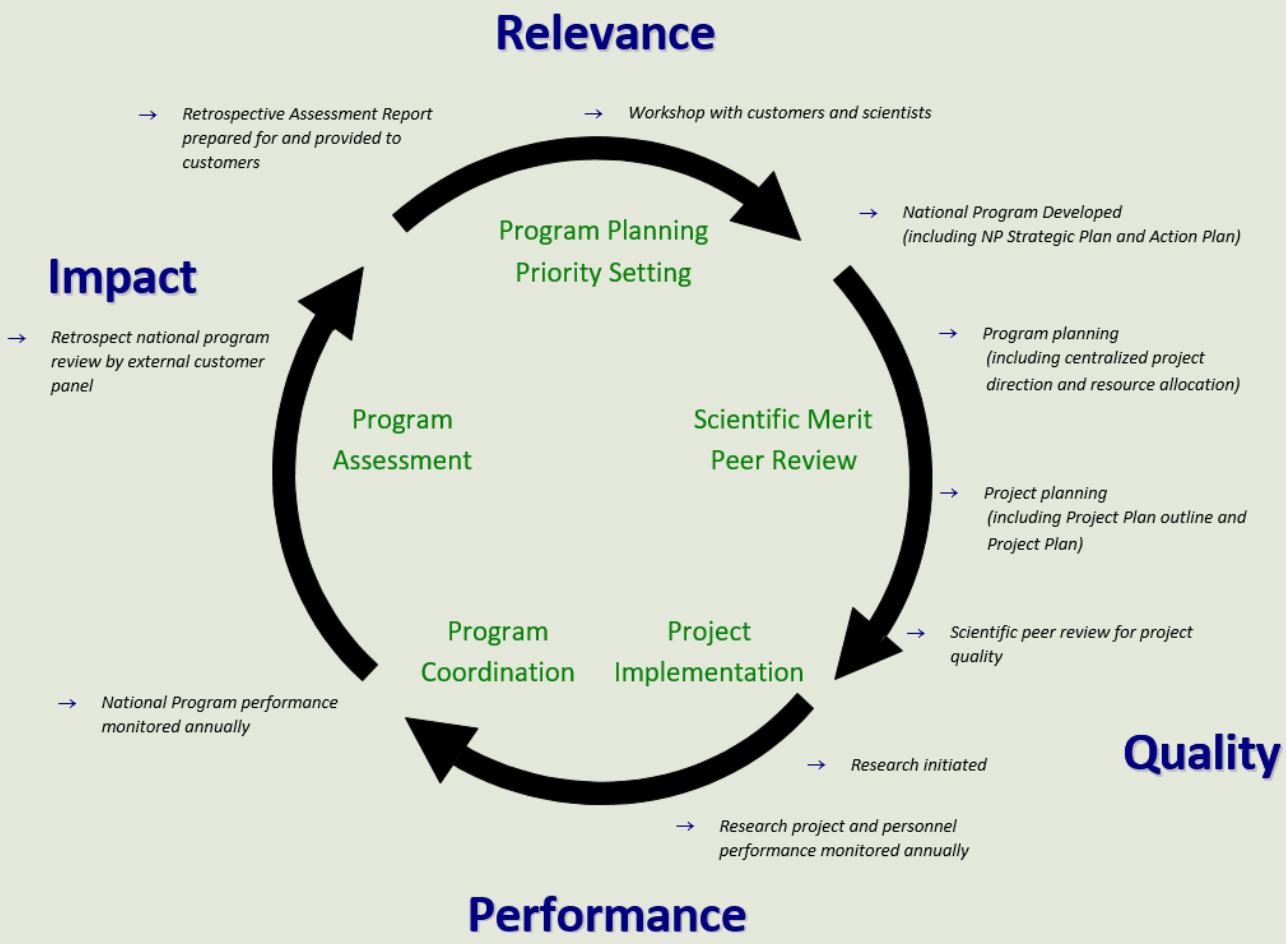
1. Identify five new scientific discoveries that provide scientific information contributing to solving problems of high national priority.
2. Establish strategic public and/or private partnerships that will enable the technology transfer of four ARS inventions.
3. Identify and cultivate intra-agency partnerships that will lead to predictive and mitigation strategies for two arthropod-borne and/or animal diseases.

During FY 2021, ARS will:

1. Identify five new scientific discoveries that provide scientific information contributing to solving problems of high national priority.
2. Establish strategic public and/or private partnerships that will enable the technology transfer of four ARS inventions.
3. Discover or develop four new tools or strategies that lead to improved integrated pest management of arthropods of medical and veterinary importance.

APPENDIX 1 - NATIONAL RESEARCH PROGRAM MANAGEMENT IN ARS

Approximately 690 research projects from around the country are aligned into 15 National Programs that encompass all the research of the Agency. The National Programs are grouped into four program areas: Animal Production and Protection; Crop Production and Protection; Natural Resources and Sustainable Agricultural Systems; and Nutrition, Food Safety, and Quality. Each of the four program areas is managed by a Deputy Administrator and each program is led by a team of National Program Leaders (NPLs). Some 25 NPLs are responsible for planning and developing research strategies to address critical issues affecting American agriculture. About 200 Research Leaders work with five geographically-based Area Directors to implement the coordinated research objectives issued by the NPLs.



Implementation of the 5-Year National Program Cycle

The overarching objectives of the National Programs are ***relevance, quality,*** and ***impact*** of ARS research, all important elements of improved accountability. Research must be ***relevant*** to the highest priority problems, the goals and outcomes of the research should significantly ***impact*** the problems, and the science must meet the highest standards of ***quality.*** To ensure that these objectives could be achieved, ARS implemented the National Program Cycle, a cycle of phases embodying a series of recurring activities.

The 5-year program management cycle illustrates the activities by which ARS conducts its research: program planning and priority setting, peer review, project implementation, program coordination, and assessment. The cycle ties these activities together in a recurring 5-year sequence to ensure effective and efficient program and project management within ARS.

Ongoing monitoring of project quality and performance takes place throughout the program cycle, and adjustments are made when necessary to improve performance or meet emerging challenges. At the end of the program's 5-year cycle, a rigorous National Program Retrospective Review is convened. The purpose is twofold: to ensure, based on feedback from an outside group of experts made up of academics, stakeholders, and government that the research is being conducted as indicated in the Action Plan, and to gain advice and insight from these same experts about the future direction of the research.

Relevance, Quality (Prospective and Retrospective), and Performance—these objectives are what a research organization must promote to be successful. Program Planning and Priority Setting, Scientific Merit Peer Review, Project Implementation and Coordination, and Program Assessment prescribe the actions the Agency undertakes carefully, thoroughly, and with outside review to demonstrate that our research is of the highest quality.

Increasing Communication Within and Outside ARS

By definition, the planning and implementation of National Program research is designed to be a participatory process requiring significant input from the broad sources of expertise and experience within and outside the Agency. Through coordinated efforts that emphasize communication with valued partners and scientists, ARS can ensure that public resources are expended in a targeted and synchronized fashion on scientifically and programmatically relevant problems.

Further, by gathering input from outside users of ARS research, the Agency meets the ever-increasing demand for public accountability. ARS solicits input from the Administration, regulatory and action agencies, producers and producer groups, university communities, and non-governmental organizations, often through face-to-face exchanges. By accounting for the needs and priority issues of these customers, stakeholders, and partners, ARS develops responsive research that emphasizes meeting short-term emergencies or requirements, as well as long-term sustained research to address problems of regional, national, and international scope and importance.

Emphasis on communication and coordination ultimately ensures that the physical, financial, and human resources of ARS are deployed appropriately to address high-priority agricultural, food, and environmental research needs of the Nation.

Farmers, producers, ranchers, and industry stakeholders have a wide variety of very specific needs, and because agricultural research is not the exclusive domain of any public or private entity, these needs must be met in a broad collaborative and cooperative effort. ARS has developed and continues to utilize an extensive network of research relationships among researchers with universities, industry, and other Federal government agencies to meet the research needs of U.S. agriculture. First among those Federal relationships is the USDA National Institute for Food and Agriculture (NIFA), USDA's extramural research agency. ARS and NIFA national program leaders work closely together to ensure that research funded by each agency is complimentary and not duplicative. For example, ARS and NIFA national program leaders have collaborated on utilizing intramural and extramural research to develop joint action strategies for research on plant diseases and pests (i.e., citrus greening), animal diseases, and water and soil conservation.

APPENDIX 2 – INTERNATIONAL COLLABORATIONS

Collaborations in Africa - 153

Algeria	1	**Ghana**	13	**Nigeria**	1
Benin	1	**Guinea-Bissau**	1	**Republic of the Congo**	1
Burkina Faso	3	**Kenya**	34	**Rwanda**	2
Burundi	1	**Lesotho**	1	**Senegal**	4
Cameroon	1	**Madagascar**	1	**Tanzania**	9
Central African Republic	1	**Malawi**	6	**Togo**	1
Cote D'ivoire	2	**Mali**	2	**Tunisia**	6
Democratic Republic of the Congo	1	**Morocco**	8	**Uganda**	8
Egypt	19	**Mozambique**	8	**Zambia**	1
Ethiopia	13	**Niger**	1	**Zimbabwe**	1
Gambia	1				

Return to Collaborations map.

Collaborations in Asia - 630

Afghanistan	1	**Kazakhstan**	12	**Saudi Arabia**	1
Azerbaijan	1	**Kuwait**	1	**Singapore**	2
Bangladesh	5	**Lebanon**	3	**South Korea**	114
Cambodia	1	**Malaysia**	3	**Sri Lanka**	1
China	259	**Mongolia**	2	**Taiwan**	19
Georgia	1	**Nepal**	1	**Tajikistan**	3
India	23	**Oman**	**2**	**Thailand**	13
Indonesia	7	**Pakistan**	19	**Turkey**	13
Israel	52	**Palestinian Territories**	2	**Uzbekistan**	3
Japan	34	**Philippines**	12	**Vietnam**	5
Jordan	3	**Russia**	12		

Return to Collaborations map.

Collaborations in Central and South America - 327

Argentina	46	**Costa Rica**	17	**Panama**	7
Bolivia	5	**Ecuador**	3	**Peru**	18
Brazil	150	**Guatemala**	6	**Suriname**	1
Chile	23	**Honduras**	6	**Uruguay**	24
Colombia	19	**Nicaragua**	1	**Venezuela**	1

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Collaborations in Europe - 821

Albania	1	**Hungary**	9	**Romania**	7
Austria	20	**Ireland**	13	**Serbia**	9
Belgium	34	**Italy**	104	**Slovakia**	8
Bulgaria	2	**Lithuania**	2	**Slovenia**	5
Czech Republic	17	**Luxembourg**	3	**Spain**	86
Denmark	33	**Macedonia**	1	**Sweden**	20
Finland	16	**Netherlands**	51	**Switzerland**	25
France	100	**Norway**	14	**Ukraine**	2
Germany	88	**Poland**	13	**United Kingdom**	111
Greece	22	**Portugal**	5		

Return to Collaborations map.

Collaborations in North America -224

British West Indies	1	**Haiti**	2	**Mexico**	65
Canada	150	**Jamaica**	2	**Trinidad and Tobago**	4

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Collaborations in Oceania - 150

Australia	113	**New Zealand**	37

Return to Collaborations map.

APPENDIX 3 - ARS NATIONAL PROGRAM ACCOMPLISHMENTS IN-DEPTH

Goal 1.1 – Enable Americans to Make Health-Promoting, Science-Based Dietary Choices

NATIONAL PROGRAM 107 - HUMAN NUTRITION

Indicator 1: During 2018, ARS will survey, release data on, and analyze national food consumption patterns of Americans.

National dietary survey data and new database released. ARS scientists in Beltsville, Maryland, released two large batches of information from What We Eat in America, an update of the dietary intake interview component of the National Health and Nutrition Examination Survey (NHANES) and the Food Patterns Equivalents Database (FPED) for 2015–2016. The former is a collaboration with the Centers for Disease Control and Prevention (CDC) and is the only nationally representative evaluation of what Americans eat that provides information on foods and nutrients in the U.S. food supply as well as what is eaten. This forms the basis for many nutrition policies throughout the country including at the USDA Food and Nutrition Service and the Department of Defense for military meals. FPED allows academic researchers to compare individual diets to the Dietary Guidelines for Americans and shows what nutrients are under- or over-consumed.

Indicator 2: During 2018, ARS will develop new methods, conduct food composition analyses, and compile databases for known, emerging, and new classes of nutrients and for branded food items.

Chemical Codex guidelines for detection of adulteration in foods and botanical supplements. Detection of economically motivated adulteration in foods and botanical supplements is a serious problem in the world market. In collaboration with the U.S. Pharmacopeia, ARS scientists in Beltsville, Maryland, assisted in developing a Food Chemicals Codex for nontargeted methods to detect adulteration. Nontargeted methods, as the name implies, employ spectral and chromatographic profiling techniques to survey the chemical composition of a sample for components that should not be present and result in a fingerprint of the product ingredients. The guidelines established general approaches for selecting methods and processing tools to detect adulteration and provide direction for researchers and laboratories needing to establish quality assurance procedures to ensure the quality of their products.

Indicator 3: During 2018, ARS will identify dietary and lifestyle intervention strategies to prevent obesity and promote healthy food choices and eating behaviors.

Moderate exercise improves mobility of older adults. As people age and become less active they lose mobility, leading to falls, hip fractures, and often loss of independence. ARS-funded researchers in Boston, Massachusetts, took part in the Lifestyle Interventions and Independence for Elders (LIFE) study, a large multicenter randomized controlled trial designed to compare the effects of moderate-intensity physical activity with an established health education program. The study showed that previously inactive people in their 70s and 80s can improve their ability to move and function by walking at a moderate speed for at least 48 minutes a week. The researchers found participants in the exercise group increased their walking speed and distance and experienced less decline in mobility than study participants enrolled in a health education program that did not include walking. Influencing older adults to walk at least 1 hour a week may reduce healthcare costs and improve the quality of life for millions.

Exercise may aid in weight loss, provided you do enough. Some people lose weight with exercise, whereas others do not, and when people do not lose the amount of weight they expect, they lose motivation. ARS researchers in Grand Forks, North Dakota, demonstrated that losing weight from exercise depends on the amount of exercise a person performs. The researchers demonstrated that people who expended 600 kcal/day, 5 days per week for 12 weeks through exercise ate the same number of additional calories as people who expended 300 kcal/day through exercise. In short, people who expended 600 kcal/day lost weight and fat, whereas those who expended only 300 kcal/day did not lose weight or fat. This study shows that people can lose weight and fat with exercise, but that they must expend more than 1,500 calories/week, and likely closer to 3,000 calories/week exercising, to have meaningful changes in weight.

Indicator 4: During 2018, ARS will determine the functions, bioavailability, interactions, and requirements for known, emerging, and new classes of nutrients across the lifecycle.

New test for children's intestinal health. Some children in rural Africa exhibit stunted growth because of intestinal inflammation. ARS investigators from Houston, Texas, studied 300 children in Malawi to compare their gut health using two different tests. Traditionally, gut health is measured by a sugar absorption test and this was compared to a panel of seven messenger RNA probes in fecal samples that serve as an indicator of intestinal cellular function. The comparison found that either test can be used to identify poor intestinal health. The new test is faster and less expensive than the sugar absorption test and will give healthcare workers the ability to diagnose intestinal inflammation with a simpler method.

Indicator 5: During 2018, ARS will publish new findings on metabolic processes that are affected by nutrient intake.

A new hormone discovered that controls desire to eat. Several hormones are involved in control of appetite including insulin, glucagon, leptin, and ghrelin, but altering levels of these hormones has not resulted in reduced eating or weight loss. Asprosin is a recently discovered hormone produced by fat cells and induced by fasting. Asprosin circulates in the blood and targets the liver to produce glucose. Scientists in Houston, Texas, found that asprosin enters the brain and activates nerves there through a series of steps that stimulate appetite and add weight and body fat. Obese humans and mice have elevated levels of asprosin in the bloodstream; blocking it in mice reduced appetite and weight. This is a new potential target for the prevention and treatment of obesity and type 2 diabetes.

Nut consumption changes intestinal bacteria numbers. ARS scientists in Beltsville, Maryland, previously reported that eating whole nuts offered fewer calories to the body than what is listed on the nutrition facts label. Ongoing analyses now show that eating almonds or walnuts results in changes of several bacterial species in the intestine. In addition, secondary bile acids, which are bacterial metabolites of the primary bile acids made in the liver and associated with increased risk of colon cancer, are significantly reduced in people who eat 1.5 ounces of walnut halves daily. Consumption of finely ground almonds to make almond butter caused no changes in intestinal bacteria. Whole nuts are one way to modify intestinal bacteria and related risks for both colon cancer and heart disease.

Following the Dietary Guidelines for Americans has limited health benefit. The Dietary Guidelines for Americans (DGA) are the basis for Federal nutrition policy and are jointly published by USDA and HHS but they had never been tested in a controlled study. DGA recommend more fruits, vegetables, whole grains, and dairy than are usually eaten. A controlled feeding study by ARS scientists in Davis, California, in which all foods were provided over 8 weeks to 52 overweight or obese women who followed the DGA showed significant improvement in systolic blood pressure but no improvements in levels of insulin, glucose, or lipids in the blood compared with women who ate a typical American diet. This was the first controlled feeding trial of the DGA. The diets were designed to maintain body weight, so a follow-up study will be conducted to determine whether weight loss from following the DGA is needed to achieve further improvements in health.

Indicator 6: During 2018, ARS will discover genetic or epigenetic factors that influence physiologic responses to diet or changes in gene expression in response to dietary intake.

A gene may be the reason for propensity to gain weight. The APOA2 gene, which encodes one of the most common proteins that moves fats through the body and plays an important role in the cardiovascular system, may also be associated with increased body mass index. ARS and ARS-funded researchers in Boston, Massachusetts, used a variety of techniques to examine genes at the molecular level and the genetic background of people involved in both the Boston Puerto Rican Health Study and the Framingham Heart Study. By closely examining the characteristics of people who reported eating high levels of red meat, poultry, cheese, and butter, the researchers found that only people with the APOA2 variant gene were likely to gain weight, whereas people without the variant maintained lower body mass index. These results may be important in understanding the variation of response to specific dietary patterns implicated in obesity.

The concentration of iron in milk is genetically controlled. Iron deficiency in infants is a major problem worldwide. ARS researchers in Houston, Texas, conducted a genome-wide association study using mice to understand how genetics regulate milk mineral concentrations and found that normal variants in a region on chromosome 1 resulted in a 35 percent increase in the concentration of iron in milk. The team also demonstrated that iron transporter genes are expressed at high levels in the mammary tissue of mice that carry genetic modifications of this region. The identification of these transporter genes could lead to strategies aimed at increasing the concentrations of iron in breast milk.

Goal 1.2 – Protect Food from Pathogens, Toxins, and Chemical Contamination during Production, Processing, and Preparation

NATIONAL PROGRAM 108 – FOOD SAFETY

Indicator 1: During 2018, ARS will determine how population systems in animals, plants, or the environment, or any combination of these influence the safety of food. ARS will determine the conditions under which microorganisms exist. ARS will determine how microorganisms may in turn influence the conditions prevailing in the environment. ARS will ensure that these technologies can be utilized by regulatory agencies, producers, and/or processors to help assure safe food products.

Invasion of internal organs by *Salmonella* ser. Enteritidis (*S.* Enteritidis). The transmission of *S.* Enteritidis inside contaminated eggs laid by infected hens is a leading human health concern and, in 2010, an outbreak of egg-associated salmonellosis cost the industry more than $100 million. It isn't clear how proposed changes to poultry housing systems affect the microbial safety of eggs produced by different genetic lines of chickens. ARS researchers in Athens, Georgia, assessed how the internal organs of four commercial genetic chicken lines (two brown egg and two white egg lines) housed in both conventional cages and colony units enriched with access to perches and nesting areas were affected by *S.* Enteritidis infection. The researchers recovered *S.* Enteritidis from intestinal samples of the white egg lines at a significantly higher frequency than from the brown egg lines in both conventional cage and enriched colony housing systems. The frequency of intestinal *S.* Enteritidis recovery was greater in one line of brown egg-laying hens raised in conventional cages than in enriched colonies. Selecting genetic stocks of laying hens with low susceptibility to *Salmonella* infections under new housing conditions may contribute to risk reduction in egg production.

Indicator 2: During 2018, ARS will develop an understanding of bacterial, viral, and fungal pathogenicity through a systems biology approach. ARS will utilize this data for pathogen intervention and control, modeling, and providing data for the development of risk assessments by regulatory agencies. ARS will ensure that these technologies can be utilized by regulatory agencies, producers, and/or processors to help assure safe food products.

Effect of atmospheric carbon dioxide levels on *Aspergillus flavus*. The fungus *A. flavus* produces the potent carcinogen aflatoxin and the effects of temperature and water on *A. flavus* distribution, growth, infectious potential, and aflatoxin

production has been well characterized. However, the effects of these two environmental factors under higher CO_2 conditions have only recently been characterized. ARS researchers in New Orleans, Louisiana, demonstrated that increased atmospheric CO_2 levels can lead to an increase in aflatoxin production. The expression patterns of genes present in several secondary metabolites (compounds that are often toxic and can also be involved in fungal development, survival, and infectivity) and gene clusters, including the aflatoxin cluster, were modified after exposure to higher CO_2 levels. Several gene networks that control fungal biological processes such as DNA replication, amino acid synthesis, and production of conidia (asexual reproductive structures also known as spores) were also affected. These results demonstrate the effect that elevated CO_2 levels can have on important fungal biological processes. These data are being used by modelers for predicting the levels of toxin contamination under various environmental conditions. These models are providing insight on how remediation efforts will be influenced by future global environmental conditions.

Genetic features unique to supershed *Escherichia coli* O157. Shiga toxin-producing *E. coli* serotype O157 causes intestinal disease in humans, but it does not cause disease in cattle harboring the bacterium in their GI tracts. Cattle that shed O157 in ≥10,000 colony forming units per gram of feces are referred to as supershedders, and limiting shedding from cattle is important for maintaining a safe and secure food supply. Supershedding cattle can easily disseminate O157 within large herds, which may increase transmission to meat at slaughter. The supershed O157 bacteria may possess unique genetic features that contribute to their increased adherence and persistence in the bovine intestinal tract. In a recently completed study by ARS researchers in Ames, Iowa, the genomes of two supershed O157 strains of *E. coli* were sequenced, analyzed, and compared with other previously characterized O157 strains. Supershed O157 have unique, recently acquired genetic features, especially in genes associated with motility, adherence, and metabolism, that could influence their persistent colonization of bovine intestines. The proteins encoded by these genes could be developed into blocking therapies aimed at preventing supershed O157 colonization of cattle.

Indicator 3: During 2018, ARS will develop innovative methods and advanced technology systems that rapidly and accurately detect, identify, and differentiate the most critical and economically important foodborne bacterial, viral, and protozoan pathogens. ARS will ensure that these technologies can be utilized by regulatory agencies and/or producers to help assure safe food products.

Recognition of emerging food-pathogens using artificial intelligence. Pathogen detection and data analysis are often limited to the types of samples present in a database. Problems often occur when new bacteria not present in the database are encountered. ARS in collaboration with the Center for Food Safety Engineering at Purdue University in West Lafayette, Indiana, explored the application of an artificial intelligence (AI) system to phenotype characteristics of various foodborne pathogens. The aim was to determine the ability of the AI to identify the number of present pathogenic classes, and to recognize new, unknown classes of foodborne pathogens that were not present in the databases. The research developed a functional prototype of an emerging pathogen detection system using AI methodology primarily based on the pattern-recognition neural network created by data scientists at Google initially for the goal of classifying natural images. The technology integrates the cutting-edge machine-learning tools with a unique optical phenotypic biosensing device developed in collaboration with Purdue University. The result demonstrated the tremendous potential of the AI technology in the areas of biosurveillance, biothreat detection, and agricultural biosafety. Additionally, it emphasized that leveraging the existing state-of-the-art informatics tools employed by the leading U.S. data management companies will lower the cost of adoption of the new AI technologies by food producers and regulatory agencies.

Indicator 4: During 2018, ARS will develop intervention and control strategies that will help to significantly decrease or eliminate pathogens in food animals and their derived products (eggs/milk), seafood, and plant crops (produce/grains/tree nuts) during critical periods of production and processing. ARS will develop and subsequently combine new/innovative processing technologies using the intelligent hurdle concept. ARS will ensure that these technologies can be utilized by producers and/or processors to help assure safe food products.

An effective method to dry and decontaminate wet whole almonds. California produces 80 percent of the world's almonds with a value of more than $5.33 billion. Contamination of almonds with *Salmonella* has caused several large and expensive recalls by the industry and outbreaks of human illness. The occurrence of rain during the harvest season may result in the complete loss of an almond crop due to increased risk of microbial contamination and lack of adequate drying technology. ARS scientists in Albany, California, developed an effective and energy-saving new technology based on sequential infrared heat and hot air to simultaneously dry and decontaminate wet whole almonds. The results were provided to industry and contributed to ARS receiving the 2018 Research and Development Award by the Institute of Food Technologists.

Reduction of inorganic arsenic content in cooked rice. Rice is a staple food for half the world population, but it may contain higher levels of toxic inorganic arsenic (iAs) than other common crops. Chronic exposure to iAs through rice is a worldwide concern for consumers. ARS researchers in Wyndmoor, Pennsylvania, developed an effective protocol to reduce iAs in cooked rice by presoaking the rice in hot water for 10 minutes, then discarding the water before cooking and using a rice cooker until the rice becomes dry. Previous efforts to reduce iAs in cooked rice took longer and were less effective. This more rapid protocol achieved similar or better iAs reduction by raising soaking temperature above the gelatinization temperature of rice starch, which causes higher diffusion kinetics to reduce iAs levels. Implementation of this protocol in daily practice would cut the cancer risk for rice consumers and improve their long-term health prospects.

A box liner with a slow-release sulfur dioxide pad enhances the killing of foodborne pathogens. California produces 99 percent of the commercial table grapes in the United States. Ensuring that they arrive safely and not contaminated at food stores for consumer purchase is a critical issue for the California Table Grape Commission and California agriculture. ARS researchers in Albany, California, at the request of the Commission, examined the survival of three common but important foodborne pathogens, *Listeria monocytogenes*, *Escherichia coli* O157:H7, and *Salmonella enterica* Thompson, inoculated on commercially packed table grapes under simulated refrigerated transit conditions. Results showed that a box liner in the shipping container enhances the bactericidal effect of a sulfur dioxide (SO_2) pad in a pathogen-dependent manner. The use of a slow-release SO_2-generating pad combined with box liner was found to be effective in killing *L. monocytogenes* and *S. enterica* Thompson, whereas the use of a SO_2-generating pad alone was more effective in killing *E. coli* O157:H7.

Improvements in radio frequency pasteurization of shell eggs. Raw shell eggs can be contaminated with *Salmonella*, causing illnesses and recalls. ARS developed and patented a radio frequency pasteurization (RFP) process that produced safer eggs with exceptional quality in a small-scale prototype. Now ARS researchers in Wyndmoor, Pennsylvania, in collaboration with a CRADA industry partner, assembled and successfully tested a larger-scale RFP unit, thus paving the way for a commercial-scale RFP unit. In addition, two breakthroughs were achieved that will facilitate commercialization. The first was the modification of RFP to operate at 40.68 MHz, which is an international frequency reserved for industrial, scientific, and medical purposes. The second modification of the RFP reduces the cost to use this technology on eggs. This will save between $10,000 to $100,000 per RFP unit. This technology can address a significant, widespread source of foodborne illness and make shell eggs safer.

Indicator 5: During 2018, ARS will develop bioinformatic databases and tools and predictive user-friendly models to understand pathogen behavior and acquisition of virulence characteristics under various stress conditions. ARS will determine the key risk factors of human pathogens in foods, and evaluate systems interventions for their impact, which will enable regulatory/action agencies to make critical food safety decisions that impact public health.

ComBase, an international microbial modeling database. ComBase is an online tool for industry and regulatory agencies to use in describing and predicting how microorganisms survive and grow under a variety of food-related conditions. ComBase further assists users in predicting and improving the microbiological safety of foods and assessing microbiological risk in foods. One of ComBase's principal features is the database, which gives users access to more than 70,000 data entries. New enhancements to ComBase include the following: each data record now indicates the number of times it has been viewed and downloaded; a YouTube channel and tutorials are available; a private data section with ComBase is available to embargo data until a publication has been released; ComBase has social media accounts on Facebook, LinkedIn, and Twitter; a new search feature has been added to the browser; each record now indicates the date that the record was added to ComBase; and an improved and simpler data donation template, plus instructional videos, have been added to the Data Submission page. The ComBase was exhibited at European and U.S. conferences to increase interactions with users and data donors.

Indicator 6: During 2018, ARS will develop innovative methods and advanced technology systems that rapidly and accurately detect and identify veterinary drugs, chemical residues, heavy metals, persistent organic pollutants, and biological toxins derived from bacteria, fungi, and plants. ARS will evaluate contaminant toxicity and mechanism of action. ARS will provide data which will enable regulatory/action agencies to make critical food safety decisions that impact public health.

Detection of drug residues. Zilpaterol is an additive that enhances the efficiency of feed conversion and causes cattle to increase in size. The compound has been approved for cattle production in North America, Central America, and South Africa; however, its use is strictly banned by the European Union, China, and many other countries since residues may affect humans. Because zilpaterol use is legal in only a few countries, the rapid and sensitive detection of it in live animals or in animal tissues is of critical concern to regulatory and trade officials worldwide. ARS scientists in Fargo, North Dakota, optimized two mass-spectrometry based techniques to allow the rapid, sensitive, and semi-quantitative screening of zilpaterol residues in animal urine and tissues in about 30 seconds per sample with little to no sample preparation needed. The new instrument-based techniques have the potential to be adapted for field use, and to be used for the rapid detection of numerous other chemical residues of importance to animal agriculture.

Development of sensitive detection assays for abrin toxin. Abrin is a natural toxin found in the seeds of the jequirity pea. The toxin is similar to ricin, a poison found in the seeds of the castor oil plant. Abrin, like ricin, is considered a select agent toxin and a potential bioterror weapon. Researchers in Albany, California, developed new monoclonal antibodies against abrin and assembled sandwich enzyme-linked immunosorbent assays (ELISA) (similar to a pregnancy test) capable of detecting a mixture of abrin isoforms. The ELISA can detect as little as 1 nanogram/milliliter of abrin in phosphate-buffered saline, nonfat milk, and whole milk, an amount that is significantly below concentrations that would pose a health concern for consumers. Fortuitously, some of these antibodies can also neutralize abrin toxicity in cell-based assays, so they may have vaccine potential. Easy, cost-effective, and more rapid methods of detection for abrin toxins are critically necessary during incidences of deliberate or suspected food contamination.

Raman sensing technology for chemical hazard detection. Detection of chemical contaminants during commercial food processing is a critical issue for rapid authentication of food ingredients and to determine potential adulteration. ARS scientists in Beltsville, Maryland, developed a line-scan high-throughput Raman imaging method and apparatus for rapid, nondestructive detection of chemical contaminants in food materials. The system can directly and rapidly analyze a sample powder in only 10 minutes, compared with conventional instruments that might take hours to perform the same analysis. The system has imaged a variety of food powders mixed with chemical additives, and results indicate that the system can provide quantitative measurement of chemical adulterants. This technology (patent No. 9,927,364) provides a practical industrial screening tool to address chemical contamination and adulteration of food products.

Detecting the "masked" derivative of T-2 toxin in wheat. Mycotoxins are secondary metabolites produced by fungi such as *Aspergillus* and *Pennicilium*. Many mycotoxins are highly toxic to humans and animals, causing a variety of secondary conditions, including cancer. T-2 toxin is produced by *Fusarium* fungi that infest oats, wheat, barley, rye, maize, and rice. Plants protect themselves from T-2 toxin by metabolizing it and adding a sugar component; this results in the formation of the metabolite T2-glucoside, which is not detected by routine tests for T-2 toxin. Digestion of the T2-glucoside in the human or animal gut may lead to the regeneration of T-2 and its associated toxicity. A novel method for detecting both toxin forms was developed by ARS scientists in Peoria, Illinois, using a new technology, called imaging surface plasmon resonance (iSPR). The method was able to detect very low levels (4 ppb) of both forms and was validated for meeting the criteria for testing grain exports at a level established by the European Union (100 ppb). Development and validation of the method ensures both the toxin and its metabolite are detected at levels that ensure food safety and support the export of U.S. commodities.

Analysis of pesticides and environmental contaminants in meats and poultry. The USDA Food Safety and Inspection Service (FSIS) is responsible for routine monitoring of pesticide residues in meat and poultry products to assure that regulatory tolerances are not exceeded, and foods are safe for human consumption. ARS scientists in Wyndmoor, Pennsylvania, developed and validated a fast, efficient, high-throughput analytical method for FSIS-priority pesticides and environmental contaminants in meat (swine, cattle) and poultry (chicken) muscle. The high throughput method for simultaneous determination of pesticides and environmental contaminants is conducted using QuEChERS-based sample preparation, extraction, and cleanup. The method was validated at three spiking levels at and below U.S. regulatory levels of concern, and satisfactory recoveries (70–120 percent) and relative standard deviations ≤20 percent were demonstrated for 219 analytes. The method was transferred to FSIS laboratories and is currently being implemented for routine monitoring of contaminants. Implementation of the new method is expected to improve regulatory monitoring, reduce the cost of sample analysis, increase sample throughput, and provide reliable data for more contaminants of concern.

Indicator 7: During 2018, ARS will develop approaches to understand the development, persistence, and transmission of antimicrobial resistant (AMR) genetic elements that result in antimicrobial resistant foodborne pathogens. ARS will develop and validate assays to rapidly detect and assess AMR pathogens. ARS will develop and evaluate alternatives to antibiotics to reduce the development of AMR in foodborne pathogens.

Effect of raising beef cattle without antibiotics on the occurrences of antimicrobial resistance. There is a significant societal concern that traditional antimicrobial use patterns for food-animal production have contributed to the occurrence of antimicrobial resistance (AMR) in human infections. In response to this concern, ARS researchers in Clay Center, Nebraska, compared fecal AMR levels between U.S. beef cattle produced conventionally, with no restrictions on antibiotic use other than regulatory compliance, and U.S. beef cattle raised without antibiotics. Fifty of 67 individual microbial AMR levels were not different between production systems, whereas 17 of 67 levels exhibited significant increases in conventional animals. However, although these increases in AMR were statistically significant, they were so small they are not likely biologically significant. More importantly, cattle raised without antibiotics typically grow more slowly, so they must be fed 50 days longer and thus produce about 2,500 pounds more manure. Therefore, the 31-percent increase in amount of manure from cattle raised without antibiotics more than offsets the small reduction in a few resistances and may actually increase the total AMR in the environment. Thus, beef cattle production without any antibiotics would not be expected to reduce the amount of AMR contributed to the environment compared with conventional production.

Goal 1.3 - Improve Postharvest Quality and Develop New Uses of Agricultural Products

NATIONAL PROGRAM 306 – QUALITY AND UTILIZATION OF AGRICULTURAL PRODUCTS

Indicator 1: During 2018, ARS will enable commercially-viable post-harvest technologies for non-food biobased products and for value-added non-food processing.

Fast and cheap detection of Zika virus in mosquitos. The accelerating global spread of arboviruses such as Zika virus highlights the need for more proactive mosquito surveillance. However, a major barrier to anticipating Zika virus outbreaks has been the lack of rapid and affordable tests for detection in mosquitoes. ARS researchers in Manhattan, Kansas, collaborated on research that showed for the first time use of near-infrared spectroscopy (NIRS)—a reagent-free, instantaneous, low-cost, and effective method—can be used to non-invasively detect Zika virus in whole, intact *Aedes aegypti* mosquitoes with a prediction accuracy of 99.3 percent. This relatively simple NIRS technology compares favorably to the current highly technological quantitative reverse transcription polymerase chain reaction (RT-qPCR) procedure. NIRS involves simply shining a beam of light on a whole mosquito for less than 3 seconds to collect a diagnostic spectrum. Given that NIRS is 18 times faster and 110 times cheaper than RT-qPCR, we anticipate that use of NIRS will be expanded for identifying potential arbovirus hotspots and guiding the spatial prioritization of vector control of the Zika virus. A proposal based on these findings has been submitted to the Department of Defense by cooperators in Australia, Brazil, Kenya, Thailand, and the United States to develop a portable, handheld, cell phone-based technique for rapid surveillance of Zika, dengue, and malaria control programs.

A treatment for peanut allergy. ARS researchers in New Orleans, Louisiana, collaborated in the characterization and development of the first peanut-based therapeutic oral immunotherapy (OIT) drug for the treatment of peanut allergy. The peanut OIT drug has been demonstrated to desensitize allergic individuals. The drug has passed Phase 3 clinical trials. Once it becomes available for public use it will be the first treatment available in the world for individuals with peanut allergy.

Almond shells improve recycled plastic properties. Compared to newly generated virgin plastic, recycled plastic often exhibits a significant loss in stiffness, strength, and heat resistance. Minerals, glass fibers, clays, and virgin plastic polymer may be added to improve the stiffness, impact strength, and heat stability of recycled plastic. ARS scientists in Albany, California, using a thermal (200° to 300°C under limited oxygen) process called torrefaction produced a residue from almond shells, an inexpensive, abundant waste byproduct from the U.S. almond nut industry. This residue improves adhesion properties when added to recycled plastic, thereby eliminating the use of expensive petroleum-based virgin plastic or other filler additives to improve recycled plastic heat stability and stiffness. This research was conducted with the California Almond industry.

A better process for making degradable food containers. There is a major trend toward making single-use food containers from renewable materials that compost easily. Traditionally, the cost of agricultural materials has been competitive with petroleum-based plastics, but processing costs are significantly higher. ARS scientists in Albany, California, developed a novel, inexpensive process for making single-use food containers from renewable plant fiber composites that degrade quickly when composted. The containers are compression molded in only a few seconds and compost more readily than paper products. A patent application has been submitted for this invention and a commercial partner is developing commercial products. This research improves the sustainability of the single-use food container industry, and provides a new degradable, sustainable byproduct from food waste or nonfood feedstocks.

Overcoming antibiotic resistance using a novel antibiotic. Beta-lactam antibiotics are a class of broad-spectrum (i.e., effective against a large variety of organisms) antimicrobials that include penicillin derivatives and cephalosporins. The use of these important drugs has been limited over the years with the development of antibiotic-resistant bacterial strains. Tunicamycin is a powerful antibiotic that can be combined with beta-lactam antibiotics to overcome this resistance. Scientists have known about this antibiotic for decades, but toxicity in human and animal cells prevented it from being used for therapeutic application. Recently, ARS researchers in Peoria, Illinois, chemically modified

tunicamycin into less harmful derivatives. The modified tunicamycins did not show any toxicity to human and hamster cells but were still capable of increasing the efficacy of clinical penicillin-based drugs by 32 to 64 times. This significant discovery now allows older-type antibiotics to once again be effective and is an important step toward combating drug resistance and is currently being evaluated by a U.S. drug company.

Repelling biting flies. Biting or blood-sucking insects (flies, mosquitos, ticks, and bed bugs) can transmit various diseases that cause major health concerns and economic losses for both animals and humans worldwide. Currently, there are no effective pesticides available for use against either biting stable flies or biting face flies. ARS scientists in Peoria, Illinois, and Lincoln, Nebraska, identified and developed a new biobased insect repellent formulation designed to meet the challenges posed by these insects. The researchers discovered that naturally derived fatty acids from coconut oil function as a very effective repellent with long-lasting effectiveness against multiple blood-sucking insects. The all-natural aqueous formulation was effective in field trials conducted on cattle in North Platte, Nebraska. The current biting fly issue in the United States costs the cattle industry more than $2.4 billion annually. This new product is being tested by U.S. cattle farmers and ranchers as a sustainable, natural technology to address their biting insect issues.

Crystal structure of Brazil nut allergen Ber e 2 solved. Food allergies prevent some people from eating nutritious nut-based products recommended by experts. In the United States, tree nuts cause as many fatal and near-fatal food allergy incidents as peanuts, but little is known about tree nut allergens in general and Brazil nut allergens in particular. The Brazil nut allergen Ber e 2 was the target of investigation when the field of protein research was in its very early stage more than a century and a half ago, but its structure remained elusive. ARS researchers in Albany, California, and their collaborators determined the Ber e 2-crystal structure, which is now a benefit to the medical industry in Ber e 2 allergenicity treatments and serves as a model system applicable in the cross-reactivity of other allergens.

Indicator 2: During 2018, ARS will develop new or improved methods to measure, predict, enhance, or reduce impacts to food marketability, nutritional quality, new bioactives and functional foods, and/or food processing technologies

Potato cultivars with ultra-low acrylamide levels. Acrylamide is an unwanted and potentially toxic byproduct that occurs when carbohydrate-rich foods, like potatoes, are processed at high temperatures into French fries. ARS scientists at the Potato Research Worksite in East Grand Forks, Minnesota, conducted the National Fry Processing Trial in collaboration with potato industry representatives and publicly funded plant breeders from Idaho, Maine, North Dakota, Oregon, Washington, and Wisconsin. Fifty-eight advanced potato clones were evaluated for acrylamide concentrations and other postharvest storage and processing qualities. Several potato clones exhibiting excellent processing characteristics also had ultra-low acrylamide levels. These varieties will be evaluated in more detailed industry trials and eventually replace current varieties used by the potato industry. As industry adopts these new potato products, producers and consumers alike will realize their benefits.

Making broccoli microgreens more nutritious and store longer. Glucosinolates (GLS) found in broccoli flower crowns are a class of vegetable-based compounds that are beneficial to human health, but many people refuse to eat broccoli. Therefore, ARS scientists investigated broccoli microgreens—a seedling stage of broccoli that children and adults will readily eat—and found they contain four times the total GLS found mature broccoli crowns. They found fortifying broccoli microgreens with calcium chloride before harvest significantly increased total GLS levels, and postharvest exposure to UV-B light further enhanced GLS levels. Preharvest calcium sprays also resulted in better overall visual quality and longer storage life. This research provides valuable information to consumers on the high nutritive value of broccoli microgreens and gives the microgreen industry a protocol for improving the nutritional quality of broccoli microgreens. MicroGreen King in North Carolina and Cityhydro in Baltimore are companies now using these findings in their microgreen production systems.

Sweet sorghum syrup: a nutrient-rich sweetener. Many sugar syrups such as corn syrup and maple syrup are used as food sweeteners, but they are low in nutritional value. ARS researchers in New Orleans, Louisiana, determined the nutritional content of many commercial syrups and sweet sorghum syrups. Sweet sorghum syrup contained twice as much protein as other syrups and had beneficial levels of potassium, magnesium, and iron. Antioxidant activity was also

higher in sweet sorghum syrups than other syrups. These results were transferred to key stakeholders, who now use them to promote sweet sorghum syrup as a sweetener.

Natural vitamin D protective film made from mushroom-stalk waste. New process technologies that produce healthful ingredients using wasted foods are greatly needed to enhance the nutritional value and shelf life of fresh fruits and vegetables. ARS researchers in Albany, California, developed and optimized a novel ultraviolet-B light treatment applied to mushroom-stalk waste that can then be dried and powdered to provide a new vegetarian ingredient with a high level of vitamin D. This colorless, tasteless, edible powder applied as a film coating to fruit bars and fresh-cut melons has been shown to help preserve quality and safety and to increase shelf life. Human clinical trials proved the bioavailability of vitamin D in these mushrooms films and numerous commercial companies use this process and sell mushroom powders as a healthy source of vitamin D.

Natural, safe food colors developed for the fresh fruit citrus industry. The citrus fresh-fruit industry consists of fresh oranges and mandarins (U.S. 2016 and 2017 production, 4.9 million and 899,000 metric tons, respectively). The industry has traditionally used "Citrus Red No.2" as a postharvest colorant during waxing to enhance the peel color of early season harvested fruit before natural orange coloring fully develops. Recently, Citrus Red No2 was listed as a group 2B carcinogen by the European Union. In response, ARS researchers in Fort Pierce, Florida, tested five oil-soluble natural colorants that could be added to citrus wax to improve citrus color. Annatto and paprika were found to have attractive color (brightness and intensity) and were compatible with fruit waxes. Annatto was more stable than paprika in storage and under simulated marketing conditions, but both annatto and paprika are being used by a commercial manufacturer of citrus waxes as natural colorants.

A new USDA standard protocol for determination of wheat quality. "Falling number" (FN) is a procedure used by the USDA Agricultural Marketing Service (AMS) and industry to gauge the level of naturally occurring alpha-amylase in wheat, an enzyme responsible for grain-starch breakdown. High levels of alpha-amylase activity lowers wheat starch concentration, giving low FN readings and resulting in lower quality, marketability, and price. This procedure is directly affected by barometric pressure and by the elevation of the testing laboratory. Lower barometric pressure at elevations above 1,000 feet can lead to misleading FN values that when retested at sea level for marketable price determination can find previously high-FN-graded wheat to have a critically low FN reading that results in a dramatic reduction in price. ARS scientists in Beltsville, Maryland, working at simulated elevations between 0 and 5,000 feet developed a correction-equation model that allows all FN values, regardless of the barometric pressure, to be reported on a sea-level basis. Initially requested by USDA's Federal Grain Inspection Service, this correction-equation was turned over to AMS for incorporation into a directive that guides Federal, state, and private laboratories on the FN procedure. This issue is important because overseas customers of U.S. wheat often have strict wheat FN requirements, thus making the procedure's accuracy a monetary concern to U.S. exporters, especially in the Pacific Northwest.

Detecting apple superficial-scald months before symptoms occur. Apple superficial-scald occurs as brown discolorations within the peel when fruits are displayed at retail stores. ARS scientists in Wenatchee, Washington, and industry partners developed a procedure to measure the components that cause superficial scald and detected the scald months before browning was observed. Tests performed by industry personnel showed the efficacy of this technology in a commercial environment. Use of this technology provides industry with a means to identify specific fruit lots at high or low risk of developing scald and can contribute to improved warehouse marketing plans.

GOAL AREA 2: NATURAL RESOURCES AND SUSTAINABLE AGRICULTURAL SYSTEMS

Goal 2.1 – Integrated, Effective, and Safe Water Resource Management

NATIONAL PROGRAM 211 – WATER AVAILABILITY AND WATERSHED MANAGEMENT

Indicator 1: During 2018, ARS will develop new or improved guidelines, technologies, and/or knowledge to increase the effectiveness of agricultural water management.

Real-time crop water stress index for precise irrigation of wine grapes. Wine grapes are intentionally water stressed to control canopy growth and induce desirable fruit quality, but few techniques are available to continuously monitor plant stress in real time. ARS scientists in Kimberly, Idaho, developed and used a cell phone-based system to continuously monitor canopy temperature, climatic conditions, soil water content, and irrigation application and to then calculate the crop water stress index. The resulting information is sent to a website where users can access the data they need to manage irrigation water application. The information system was installed in three commercial vineyards in southwestern Idaho, and two of the vineyard managers used the real-time information to make irrigation decisions. This technology allows vineyard managers to use real-time plant data to precisely manage irrigation, thereby reducing water use and improving grape quality.

Handheld device can estimate virus infection in irrigated wheat. Winter wheat is grown on approximately 3 million acres in the Texas High Plains region, one-third of which is irrigated. But the region is susceptible to wheat streak mosaic virus (WSMV), which is transmitted by the wheat curl mite. If a wheat plant is infected early in the season, it will yield little to nothing, and associated research has shown that wheat crops with high levels of infection should not continue to be irrigated. To help identify WSMV infection early in the spring, ARS scientists and engineers in Bushland, Texas, and Texas A&M AgriLife researchers demonstrated a hand-held meter can be used to detect different light wavelengths that indicate color within the plant; this information is then used to identify fields with high levels of infection that should not be irrigated. Early detection of WSMV through use of this new sensor will help wheat farmers reduce water waste and associated pumping costs.

Automated data preparation for water supply forecasting. Having an accurate estimate of streamflow is intrinsic to water resource management for agriculture, flood control, drought management, power generation, and domestic water supply purposes. But producing accurate estimates of streamflow requires manually checking dams and other measuring devices, preparing data, and running water supply forecasting models. The staff time required to do this severely limits the use of current models, which are based on the physical processes of snowmelt and hydrology over a large area. To make part of this task easier, ARS scientists in Boise, Idaho, developed and implemented software called the Spatial Modeling for Resources Framework (SMRF) that makes it possible to apply physics-based hydrologic modeling in real-time to generate better streamflow estimates. SMRF now makes it feasible to transfer complex and sophisticated hydrologic models into a functional application that can be adapted for use across the entire western United States. SMRF is being tested by water supply forecasters at the California Department of Water Resources, the Natural Resources Conservation Service National Water and Climate Center, and the U.S. Bureau of Reclamation.

Economic effects of strategic deficit irrigation on maize grain yield. In arid areas where agriculture depends on irrigation, various forms of deficit irrigation management have been used to achieve high yields with less water. ARS scientists in Fort Collins, Colorado, showed water savings of 15 to 17 percent with little effect on yield by applying moderate-deficit irrigation to maize plants during the late-vegetative stage (before flowering). Importantly, these late-vegetative deficit applications of water prevented dramatic yield losses if the water shortage occurred at the end of the season. Economic modeling revealed little benefit to producers of intentionally using deficit irrigation under current conditions of average prices for grain and water, but it also revealed that deficit irrigation during the late-vegetative stage would be economical in some regions where water is in high demand and lease prices are rising. Thus, although strategic deficit irrigation showed some (albeit limited) benefit for producing a maize crop with less water, the most important benefit to

producers is the knowledge gained that crops must be protected against late-season water shortage and the conditions under which deficit irrigation may be desirable. This information will also benefit water conservation policymakers by providing economic data to help balance agricultural and municipal water interests.

Low-cost sensing device for collecting field data. The capabilities, flexibility, and low cost of the open-source Arduino and similar electronics platforms, coupled with new and inexpensive sensing devices, has enabled agricultural and water scientists to develop prototype monitoring systems to measure plant height, canopy temperature, and canopy multispectral reflectance. ARS scientists in Stoneville, Mississippi, developed a low-cost sensing device and mounted it onto an agricultural vehicle to collect georeferenced sensor measurements as the vehicle traveled through the field. The scientists are working to improve coordination between their new sensing device and global positioning system information with the goal of demonstrating how affordable open-source components can be used to develop more refined monitoring systems to collect agricultural field data.

Indicator 2: During 2018, ARS will develop new or improved guidelines, technologies, and/or knowledge to reduce erosion and sedimentation from agricultural lands and/or improve water quality.

Chemical application setbacks safeguard water quality. Management of turfgrass on golf courses and athletic fields often involves application of fertilizers and pesticides to maintain grass health and performance. Those products are often carried away from the area via rainfall runoff into neighboring surface waters, where they enhance algal blooms, promote eutrophication, and harm sensitive aquatic organisms and ecosystems. ARS researchers in Saint Paul, Minnesota, evaluated the effectiveness of applying these chemicals away from field edges to reduce the amount that runs off after a storm. Experiments with water-soluble tracer compounds confirmed that an increase in application setback distance by 6 meters resulted in a 43 percent reduction in the total amount of applied chemical transported by storm runoff to neighboring areas. Expanding the buffer area between turfgrass and adjacent properties will help groundskeepers design chemical application strategies that maximize environmental stewardship, and scientists and regulators who develop chemical transport and risk models.

Vegetated drainage ditches and retention ponds improve water quality. In intensive agricultural areas, agricultural best management practices are used to reduce suspended solids and nutrient loads and thus improve water quality, but more information is needed to effectively combine these practices. As part of the Conservation Effects Assessment Project watershed in the Mississippi Delta, ARS researchers in Oxford, Mississippi, collected measurements of sediment, nitrogen, and phosphorus draining through vegetated drainage ditches into a vegetated sediment pond from crop-cultivated areas. Vegetated drainage ditches combined with a vegetated sediment pond were effective in reducing sediment loads and moderately effective at reducing nutrient loads in runoff, resulting in an improvement in the water quality of agricultural runoff. These study results provide regulatory and other agencies and farming stakeholders with a practical way to combine conservation practices to improve and sustain water quality and overall environmental quality.

Streambanks contribute the majority of sediment and phosphorus in streams. Eroding streambanks can be major sources of sediment and nutrients to streams, resulting in property loss and damaged aquatic habitats. ARS scientists in Columbia, Missouri, in a 4-year study, quantified streambank erosion and its contribution to sediment and phosphorus transport in two watersheds within the Central Claypan region in northeastern Missouri. Streambanks contributed an average of 83 percent of the stream sediment and accounted for 57 percent of total phosphorus exported from the two watersheds. These results, along with earlier studies showing that streambanks contributed 23 percent of the total nitrogen exported, clearly demonstrated the effect that bank erosion has on stream water quality. Streambank erosion likely will increase with larger runoff events from more severe storms resulting from climate change. Numerous methods have been developed for controlling streambank erosion, and this study indicates that improved management such as installing streambank stabilization in flood plains would improve water quality in this region.

Application of mine drainage residuals for treating horticultural greenhouse waste water. Excessive dissolved phosphorus transport occurs in agronomic cropping systems and horticultural operations. The presence of phosphorus contributes to the eutrophication of water bodies such as the Gulf of Mexico and Lake Erie. ARS researchers in West Lafayette, Indiana, constructed a phosphorus-removal structure in a greenhouse to filter dissolved phosphorus from the drainage water of pots. Ornamental, fruit, and vegetable plants were grown in traditional greenhouse media, and all

drainage water from the pots was collected and filtered through a phosphorus sorption material (PSM) on a bed of mine drainage residuals (MDRs), which are a byproduct of treating acid mine drainage pollution from coal mines. The horticultural operation produced extremely high concentrations of dissolved phosphorus and elevated concentrations of copper and zinc. The PSM/MDR structure is still removing nearly 100 percent of phosphorus and copper after 1 year of operation, whereas much less zinc has been removed (cumulative removal approximately 25 percent). This study gives greenhouse managers a way to reduce the negative environmental effects of adding phosphorus to horticultural operations through use of these filters.

Surface based vibration sensors map soil compaction with depth. Soil compaction induced by agricultural machinery can reduce crop yields in field areas where compaction becomes pronounced. The assessment and delineation of compacted soils and plow pans are needed to define tillage protocols and fertilizer application and irrigation schedules within a soil management plan. Researchers at the University of Mississippi, in collaboration with ARS researchers in Oxford, Mississippi, have developed a method using only surface-based vibration sensors to map the degree of soil compaction as a function of depth. The method sends vibrations into the soil and records them at various distances from the vibration source using ground surface sensors, where they produce images of the soil profile in much the same way that a sonogram can produce images of organs and tissues in the human body. This technique provides agricultural engineers and soil scientists with a nondestructive field mapping tool to assess soil compaction. Having prior knowledge of the spatial distribution of compacted soils may allow a more judicious use of fertilizers and water resources to increase crop yields.

Atrazine transport in karst terrain. The Pennyroyal Plateau is a karst sinkhole plain in south-central Kentucky with intensive row-crop agriculture. Water quality concerns include the seepage of agricultural herbicides into the groundwater and underground streams via sinkholes. ARS scientists in Columbia, Missouri, investigated the movement of a single application of the pesticide atrazine from a treated field to the water flowing within a cave adjacent to the field. Results showed that atrazine and two of its metabolites were present in every water sample over an 18-month period and levels remained elevated 15 months after application. Transport of atrazine and its metabolites to the cave accounted for approximately 1 percent of the applied atrazine, losses that were comparable to surface runoff losses in the Corn Belt. A year after application, atrazine and its metabolites showed very slow declines in concentration, demonstrating that transport would continue to occur over several years and result in consistent, long-term contamination of the deeper groundwater aquifer. This study benefits conservation agencies and growers by demonstrating the effect of atrazine leaching into karst aquifers and raising awareness for the need to implement management practices tailored to karst terrain.

Biochar aging changes pesticide sorption, influencing pest control and environmental fate. Water pollution from applied agrochemicals typically involves transport through the soil, where colloidal particles may play an important role in trapping them. Biochar, a carbon-rich soil amendment, can be useful for trapping agrochemicals, but its composition can change with environmental changes (freeze-thaw and wet-dry cycles), which may alter its trapping potential and have effects on water quality and the ecosystem. ARS researchers in Saint Paul, Minnesota, examined the effect of soil aging on an oak hardwood biochar that was buried in silt loam soil for 6 months. The soil-aged biochar sample absorbed significantly larger amounts (>85 percent) of all pesticides in the laboratory experiments compared with fresh biochar samples, which absorbed less than 15 percent. Both biochar samples had similar chemistries with no oxidation or chemical alterations observed after 6 months. These results show the variability of biochar absorption capacities and changes with time after its addition to soil, which will affect the environmental fate of applied pesticides and thus the possibilities for long-term control of pests. This information is significant to farmers and policymakers and will assist scientists and engineers in understanding the potential alteration in the absorption potential for biochar once it is applied to soils.

Windows Dam Analysis Modules (WinDAM) C adopted by worldwide leaders in dam safety. WinDAM C, a CCE-certified software, is a computational tool released in 2016 by ARS in cooperation with the USDA Natural Resources Conservation Service (NRCS) and Kansas State University. This decision support software is used by dam safety engineers in predicting potential dam breaches. The software incorporates algorithms developed by ARS scientists for predicting embankment dam failures from overtopping or internal erosion and includes breach outflow and breach timing estimates. Since its release, the software has been adopted by consulting engineers, academic researchers, and Federal agencies, including the U.S. Corps of Engineers, U.S. Bureau of Reclamation, NRCS, and the Tennessee Valley Authority. In FY 2018, ten

countries across North America, South America, Europe, and Asia requested the software and the majority have incorporated WinDAMC into their educational and design analysis toolboxes. This technology is helping dam safety engineers prioritize the rehabilitation schedules for the aging U.S. embankment dams and levees. Dams built, evaluated (using WinDAMC), and maintained by USDA NRCS provide an estimated $2.5 billion in annual benefits to producers, shippers, communities, and others. ARS and their collaborators are currently exploring options to use WinDAMC in developing early flood warning systems that can be used by emergency managers, city planners, and policy makers in establishing zoning regulations, developing flood inundation maps, and improving emergency action plans.

Real-time decision support tool measures soil moisture and runoff potential. Producers need accurate predictions of soil moisture and surface runoff to gauge the best time to apply manure, fertilizer, and pesticide. The Real-time Conservation Effects Assessment Project (CEAP) model is a highly detailed, national-scale model that is aiding agricultural producers in timing their field operations. CEAP is a congressionally-mandated multiagency effort to evaluate the effects of current and past USDA conservation programs and potential future policies. CEAP uses a system of models and detailed climate, soils, landcover, and cropland management data for the contiguous United States to predict agricultural effects on water quality. This tool is leveraged by real-time CEAP data to make short-term future predictions of runoff and soil moisture. Climate data are updated each day with observed NEXRAD and National Weather Service 3-day forecasted precipitation. Simulations of 3 million units are performed each night on a high-performance server and summarized by county. Predicted soil moisture and surface runoff data are processed and interpreted into application advisories and warnings that are publicly available via the real-time CEAP website (https://realtimeceap.brc.tamus.edu/). Farmers are now using the CEAP model to better time pesticide and fertilizer applications to prevent losses in runoff.

Indicator 3: During 2018, ARS will develop new or improved knowledge, tools, technologies, guidelines, and/or conservation practices to better protect water resources, improve the overall effectiveness of USDA conservation programs, and/or improve watershed management and ecosystem services in agricultural landscapes.

Antibiotic resistance genes and antibiotics can be transported off agricultural fields in subsurface drainage water. Antibiotic resistance is an increasing medical problem, and the effect of agricultural use of antibiotics on resistance in human pathogens is not clear. Previous reports have indicated elevated levels of antibiotic resistance genes (ARGs) in surface water and groundwater around confined animal feeding operations that administer antimicrobials, but little is known about how their transport from tile-drained fields amended with swine manure affects downstream environments. ARS scientists in Ames, Iowa, and Iowa State University collaborators found higher levels of two genes that confer resistance to antibiotics in tile drainage and river water in spring and fall following swine manure application. Approximately 840,000 swine are raised within the watershed. A companion study also documented the presence of two veterinary antibiotics. The study provides new information establishing that ARGs and antibiotics are being transported off farmed fields in drainage water. These findings provide new science-based information to improve our understanding of this problem.

Geophysical techniques for assessing soil salinity across multiple scales. Knowing the salinity level within a field is valuable for individual producers to optimize their local production, whereas knowledge of salinity levels across hundreds of square miles is valuable to policymakers and decisionmakers at the state level. However, developing maps of soil salinity at any scale is a technological challenge because soils are highly variable in their properties, especially salinity. The compendium of work by an ARS scientist in Riverside, California, has resulted in an integrated salinity mapping system consisting of 1) a platform of ground and satellite sensors, 2) protocols and guidelines for mapping soil salinity, and 3) software for selecting sampling sites to calibrate sensors. The system gives stakeholders reliable, reproducible, and accurate maps of soil salinity. Thanks to this new ARS-developed mapping system, it is now possible to determine soil salinity levels on a wide scale, include soil saline content as a factor in selecting suitable crops for production, and include soil salinity information in estimating potential agricultural revenue.

Improved soil erodibility formulation. Recent enhancements to USDA soil erosion models employ more physical descriptions of erosion processes, which requires knowledge of soil properties, land use, land management, and hydrologic variables to calculate soil erodibility. ARS researchers in Oxford, Mississippi, tested three soils that ranged in clay and sand content to develop a prediction tool for agricultural erosion. The results suggest that soil erodibility is

affected by the initiation of particle movement, clay content, and the void ratio, whereas results for critical shear stress testing suggest that silt, void ratio, and water potential best indicate the initiation of motion. These findings were recently successfully implemented within the Revised Universal Soil Loss Equation 2 (RUSLE2), which is used by USDA for conservation planning purposes.

Goal 2.2 – Improve Quality of Atmosphere and Soil Resources, Understand Effects of Climate Change

NATIONAL PROGRAM 212 – SOILS AND AIR

Indicator 1: During 2018, ARS will develop management practices and decision tools to improve quality and resilience of agricultural soils, protect air quality, improve production amidst climate variability, and reduce net GHG emissions.

A newly developed tool provides accurate estimates of nitrate surface runoff. The Soil Vulnerability Index (SVI), recently developed by the Natural Resources Conservation Service (NRCS), is a practical tool for identifying fields that have a high risk of nutrient-related pollutant transport through surface runoff and leaching. ARS scientists from Beltsville, Maryland, tested the suitability of the SVI method on the Choptank River watershed. Outputs from a computer simulation model, the Soil and Water Assessment Tool (SWAT), were compared to the SVI classification scheme. Results indicated that although the SVI method was less accurate at identifying nitrate pollution caused by leaching, it was more accurate at estimating surface runoff of organic nitrogen. Based on the pollutant type of interest, NRCS state offices and other local agricultural management agencies can use the SVI method to classify crop fields that are vulnerable to surface runoff and leaching processes.

Indicator 2: During 2018, ARS will manage odor and reduce atmospheric emissions from animal production facilities, including increased efficiency of recovery and utilization of manure nutrients, biogas, and other byproducts.

Novel gas-permeable membranes greatly reduce gaseous ammonia in poultry barns. Conservation and recovery of nitrogen from livestock and urban wastes is important for both economic and environmental reasons. ARS researchers in Florence, South Carolina, developed new systems using gas-permeable membranes to collect and reuse ammonia that is harvested from waste in poultry barns and thus removing ammonia from the air. The membrane manifolds are suspended inside the barns and the gaseous ammonia closest to the litter is removed. The technology has been demonstrated at University of Maryland Eastern Shore chicken houses through a National Institute of Food and Agriculture grant. In rooms fitted with the ammonia recovery system, the ammonia level decreased 46 percent in the air and 45 percent in the litter, and bird mortality was reduced 47 percent. The new system offers poultry producers a better way to manage ammonia and bird health in their poultry barns.

Ground soybean hulls can be used in swine operations to reduce manure odors. Odors from confined animal feeding operations can be a nuisance to neighbors. Ground soybean hulls contain a naturally occurring enzyme called soybean peroxidase, which has been shown to reduce odors from swine manure in laboratory tests. Scientists from Iowa State University and ARS in Bushland, Texas, carried out a farm-scale experiment in a realistic swine production setting to further evaluate how odors could be reduced. The team found that applying ground soybean hulls to swine pens resulted in a 36 to 80 percent reduction in the chemicals most responsible for swine odor. The total treatment cost, including materials and labor, was $2.62 per marketed pig. These results give swine producers and consultants a new and cost-effective way to reduce odors.

Indicator 3: During 2018, ARS will develop management practices that promote soil biological components and improve agricultural system productivity resulting in validated and quantitative positive impacts on agro-ecosystem function.

Microbial inoculants can reduce nitrous oxide emissions from nitrogen fertilizer application. The loss of nitrous oxide (N_2O) is of concern because the loss of nitrogen from the soil means that plants cannot use it and it is a potential

contributor to global warming. Over the past few decades, N_2O emissions have increased worldwide due to several factors, including increases in cultivated crop area, excessive application of nitrogen fertilizers, and livestock production. But loss of N_2O from fertilizer is considered to be the largest contributor from agriculture as a whole. ARS researchers in Auburn, Alabama, have identified microbial inoculants that can improve plant production and plant nutrient efficiency. Development of these microbial inoculants was conducted to reduce N_2O losses that may arise from fertilizer nitrogen use. ARS research led to the discovery that specific combinations of soil microorganisms applied with fertilizer can reduce N_2O emissions, which was the basis of a new U.S. patent. The newly patented microbial inoculant will help reduce N_2O emissions from production agriculture and could lead to an income stream in the carbon trading market while reducing the effects of greenhouse gas emissions.

New soil health measurement allows analysis of multiple enzymes in one sample. Farmers are interested in how their management and cropping practices promote, sustain, or degrade soil health. They need simple soil health tools to help them select sustainable soil management practices, but simple measures of soil health have been difficult to develop. The enzyme activities of soil organisms are highly sensitive to management and represent measures of soil functions, but the current protocols are time consuming because each enzyme is measured separately. To solve this problem, ARS scientists in Lubbock, Texas, and Morris, Minnesota, developed an assay that can measure multiple enzyme activities in one soil sample, thus simplifying the measurement and providing a protocol that is adaptable to many climatic zones and cropping systems. This method provides a powerful index related to soil health. The new assay will enable producers and land owners to assess soil health and then adopt cropping practices that improve soil health.

Indicator 4: During 2018, ARS will reduce the abundance, movement, and environmental impact of pathogens in manure and Pharmaceutically Active Compounds (PACs), and assess the presence, distribution, and impact of antibiotic resistant bacteria and antibiotic resistance genes in manures, soils, and surrounding environments.

Antibiotic resistance is more common in natural prairies than in organic farming operations. Bacteria that are resistant to antibiotics are found throughout the natural world, even in areas where antibiotics have never been used. The use of antibiotics in modern agricultural production is a concern for the public and research community alike because it is thought that irresponsible antibiotic use may lead to the development of antibiotic-resistant microorganisms that could affect human health. ARS researchers in Lincoln, Nebraska, found that antibiotic resistance to two classes of antibiotics was detected at high levels in 13 Nebraska organic farming operations. Interestingly, most of the resistance genes were detected more frequently in nearby natural prairie soils than in soils on the organic farms. This information suggests that farming practices that use manure do not lead to an increase in long-term antibiotic resistance in the soil and will inform and support U.S. policy positions for international trade negotiations around antibiotic use in U.S. agricultural products.

Beef cattle raised without antibiotics have lower levels of resistant bacteria than conventionally raised beef cattle. There is an increasing concern that antibiotic use in food animals leads to antibiotic-resistant foodborne bacteria. ARS scientists from Clay Center, Nebraska, and Bowling Green, Kentucky, in collaboration with Colorado State University researchers, investigated the health of beef cattle raised without antibiotics. Fecal samples were collected monthly over 1 year from 30 cattle raised without antibiotics and from 30 conventionally raised cattle. Levels of third-generation cephalosporin-resistant *E. coli*, erythromycin-resistant *Enterococcus* species, and erythromycin and tetracycline resistance genes were significantly lower in cattle raised without antibiotics. Resistance to most of the remaining antibiotics, and the levels of bacteria such as *Salmonella,* were not different between the two groups. This study indicates that optimized antibiotic stewardship can reduce the burden of antibiotic resistance associated with food animal production systems. Results of this study can be used for quantitative risk assessment to further quantify the effect of raising beef cattle without antibiotics to reduce human exposure and subsequent possible infections from antibiotic-resistant bacteria.

Goal 2.3 - Develop and Transfer Economically Viable and Environmentally Sustainable Production and Conservation Practices, Technologies, Plant Materials and Integrated Management Strategies, Based on Fundamental Knowledge of Ecological Processes, that Conserve and Enhance the Nation's Diverse Natural Resources Found on its Range, Pasture, Hay, and Turf Lands

NATIONAL PROGRAM 215 - RANGELAND, PASTURE & FORAGES

Indicator 1: During 2018, ARS will provide improved germplasm and cultivars that can be released for pasture, harvested forages, turf, biofuels, rangeland restoration, and conservation.

Near-infrared reflectance spectrometry (NIRS) calibrations to predict switchgrass ethanol yields. Conventional wet chemistry analysis of biomass for composition and conversion to ethanol is time-consuming and expensive. A team of ARS scientists from Lincoln, Nebraska; Peoria, Illinois; St. Paul, Minnesota; and Madison, Wisconsin, developed NIRS calibrations that, along with biomass yield data, enable concentrations of switchgrass hexose and pentose sugars to be rapidly and accurately determined, allowing calculation of ethanol yields from each sugar in switchgrass samples. These calibrations will have multiple uses in breeding, genetics, and management research and could be used by biorefineries to predict ethanol yield of switchgrass biomass. The calibrations have been transferred to the NIRS Consortium, which is making them available to other switchgrass research groups and laboratories.

Gene discovery for late flowering in grasses. Perennial forage grasses are the basis of the meat and dairy industry, providing essential nutrition to ruminant animals. Because these grasses require expensive nitrogen inputs, there is a trend toward growing grass-legume mixed pastures that require less nitrogen while increasing forage mass and nutritive value. However, most grasses mature before alfalfa and other legumes, thereby greatly diminishing the anticipated improved nutritive value. Maturation is associated with switching from a vegetative to a flowering state, so later flowering is desirable for grasses used in these mixtures. Previous selection for later flowering generally resulted in decreased seed production, so the selected plants could not be easily propagated. ARS researchers in Logan, Utah, have identified late-flowering genes in orchardgrass and developed molecular markers for rapid late-flowering selection. The markers were used to identify late-flowering orchardgrass germplasm and gave grass breeders in China and the United States a valuable tool for distinguishing these genes from genes that control seed production. The markers will also enhance the development of grasses specifically for grass-legume mixtures that better match the timing of maturity among the component plants and improve their overall nutritional quality.

Indicator 2: During 2018, ARS will provide forage, pasture, and rangeland management technologies and strategies that reduce inputs while improving livestock performance and sustaining the environment.

Molasses can replace corn in grazing dairy cow diets. Farmers who operate grazing dairy farms are interested in replacing corn with molasses as a food supplement for their animals to reduce feed costs and meet the demands of specialty milk markets such as those for organic or grass-fed milk. ARS scientists in University Park, Pennsylvania, gave either corn meal or liquid molasses to grazing, lactating dairy cows and examined the effect on milk yield and milk composition, milk fatty acid profile, and nitrogen use efficiency. Results suggest that molasses can replace corn meal on an equivalent basis without negatively affecting milk yield and composition, while slightly improving nitrogen use efficiency and beneficial fatty acids found in milk. This information offers farmers who operate grass-fed dairy farms a more economical and healthful supplement for their cows.

Massive seed banks limit Russian olive control. Land managers throughout the West are having difficulty controlling Russian olive trees and reinvading seedlings. In Montana, ARS researchers from Sidney and Miles City, with staff from the Natural Resources Conservation Service in Miles City and Bridger, determined successful practices for controlling invasive Russian olive populations and for returning native species to degraded areas. They found that tree shearing followed by immediate herbicide application to the cut stump resulted in 96 percent Russian olive mortality. Because Russian olive is a nitrogen fixer, a high weed abundance was expected to limit the success of native species planted in their place. However, revegetation was successful in that almost all planted species became established. Although revegetation resulted in increased native species diversity and cover, there was no evidence in this 5-year study that the plantings served to competitively exclude weeds. Newly emerged Russian olive seedling counts were highly variable (approximately 50 to 5,000 seedlings per acre) in the removal area every year of the study. This information provides critical information for understanding the seed banks of this species and mitigation strategies that can be used for its control.

Seeding and herbicides establish native plants in downy brome-invaded landscapes. Managers are struggling to restore native plants to degraded rangelands invaded by downy brome and other invasive weeds with the end goal of increasing livestock forage production and improving wildlife habitat. ARS scientists in Miles City, Montana, collaborating with Montana Department of Environmental Quality and coal mining industry representatives, seeded native grasses, forbs, and shrubs after herbicides were applied to control downy brome in former coal mining fields that became dominated by downy brome after initial seeding efforts failed. The herbicide glyphosate, when applied in fall, just after downy brome emerged, substantially reduced downy brome cover and promoted native grass and forb establishment. Additionally, this treatment allowed establishment of big sage, among the most difficult and important species to restore to western U.S. rangelands. The strategic application of herbicides timed to the emergence of downy brome will improve efforts to remediate brome infestation of rangelands.

Cocksfoot mottle virus is infecting orchardgrass in forage production fields in California. Orchardgrass (*Dactylis glomerata* L.) is a cool-season perennial grass commonly grown in pastures for forage, hay, and silage. Cocksfoot mottle virus (CfMV), a disease known to occur in seed production fields in Oregon, reduces yield and shortens the stand life of orchardgrass. In April 2017, several forage growers in northern California were experiencing extensive die-off in their fields, and ARS researchers in Corvallis, Oregon, found CfMV to be present in all "diseased" samples tested from these fields. This research demonstrated the spread of this important plant disease within the United States and identified CfMV as the cause, which is the first step toward effectively managing it in affected regions. Because no pesticide treatments are currently available to prevent CfMV, growers are being encouraged to look for symptoms in early spring. Mechanical transmission can be prevented by harvesting clean fields first, or by thoroughly cleaning machinery between fields to limit the spread of the disease. When growers replant their fields, they should also consider using cultivars that are more resistant to CfMV.

Successful rangeland restoration following disturbance depends on the presence of helpful soil biology. Invasive alien plants are believed to be less dependent on mycorrhizal (beneficial root fungi) associations than native plants, and weak mycorrhizal responsiveness might thus be a general mechanism of plant invasion. ARS scientists in Miles City, Montana, determined from experiments on 68 Northern Plains grassland species and 95 Central Plains species that symbiotic mycorrhizal associations increased the biomass of 19 percent and 61 percent of species, respectively. However, plants from the Northern Plains tended to have varied responses to these associations. Findings indicate that many plant species may have difficulty becoming established in areas with degraded soil biology. Some plants in the Northern Plains appeared to be less dependent on mycorrhizal association, suggesting that they become more easily established in areas with degraded soil biology. Invasive grassland plants had a wide range of interactions with mycorrhizas and some invasive plants are thought to degrade the quality of a site's soil mycorrhizal biology. There was no evidence that invasive species respond differently to mycorrhizas than native species. Knowing how various plants depend on beneficial soil organisms, combined with assessments of soil microorganisms, will facilitate restoration efforts by matching soil management actions with the species mix that is desired for that location.

Goal 2.4 – Develop Integrated Solutions for Agriculture Enabling Greater Productivity, Profitability, and Natural Resource Enhancement

NATIONAL PROGRAM 216 – SUSTAINABLE AGRICULTURAL SYSTEMS RESEARCH

Indicator 1: During 2018, ARS will develop integrated solutions to increase agricultural system productivity, profitability and natural resource stewardship with metrics to describe the sustainability of the solutions.

Increasing crop diversity increases economic returns and reduces risk. Increasing crop diversity by growing a larger variety of crops in rotation has been proposed to increase sustainability; however, for producers to adopt these rotations as standard practice, they need to be profitable. In a long-term crop rotation study, ARS researchers in Mandan, North Dakota, showed that crop productivity and economic returns increased with increasing crop diversity, whereas economic risk decreased. In most cases, increasing crop diversity also resulted in higher soil organic carbon levels, which allows producers in the region to simultaneously realize economic benefits of $25 to $83 per acre while maintaining or building soil organic carbon.

Optimizing yield, profit, and environmental protection. ARS researchers in Tifton, Georgia, found that strip tillage (ST) in conjunction with winter cover crop planting and poultry litter application improved plant nitrogen availability by more than 24 lb/acre/yr in sandy landscapes of the southeastern Coastal Plain via microbial cycling of organic nitrogen and reduction of nitrate leaching. Total soil nitrogen content increased 27 percent over 5 years with ST compared with 22 percent with conventional tillage (CT). Cumulative nitrate-nitrogen leached from soils during the 5-year study was 126 lb/acre (CT) versus 109 lb/acre (ST). Both of these values were higher than the 5-year average tile flow losses of nitrogen but suggest that leaching from the top 6 inches of soil is an important pathway for dissolved nitrogen loss from the rooting zone in this landscape. Regardless of tillage, soil microbial biomass nitrogen was equal to or higher than soil inorganic nitrogen, suggesting that soil microbial biomass is a key factor for retaining nitrogen in the rooting zone and thus mitigating soil nitrate loss and delivery to ground and surface waters.

Decision support tools that help growers select biochars to improve soil health and economic return. Despite the known agronomic benefits of biochar, few farmers have adopted biochar-based strategies to improve soil health or increase plant productivity primarily because standards and agronomic recommendations regarding application rates and techniques are lacking. ARS researchers in Corvallis, Oregon, in collaboration with researchers from Oregon State University, published the *Pacific Northwest (PNW) Biochar Atlas*, a suite of decision-support tools designed to alleviate uncertainty regarding the use of biochar on farms. The atlas includes a soils property explorer that allows users to identify soil deficiencies in soils across the PNW. A biochar selection tool pairs these deficiencies with biochar types best suited to their soil needs and crop type and calculates the carbon sequestration, fertilizer, and liming value of amending at different rates. A cost-benefit calculator determines the cost savings from offsetting fertilizer, lime, and irrigation water, and potential income from increased crop yield. The website is useful for both growers and researchers and has had nearly 20,000 page visits in the first 6 months, with visitors from 75 countries.

Goal 3.1 – Harness the Genetic Potential of Plants to Transform U.S. Agriculture while Delivering Economically and Environmentally Sound Technologies that Improve the Production Efficiency, Quality, Health and Value of the Nation's Crops

NATIONAL PROGRAM 301 - PLANT GENETIC RESOURCES, GENOMICS, AND GENETIC IMPROVEMENT

NATIONAL PROGRAM 305 - CROP PRODUCTION

Indicator 1: During 2018, ARS will breed superior new crops, varieties, and enhanced germplasm.

Successful cryopreservation of a honey bee embryo. ARS scientists from Fargo, North Dakota, collaborated with ARS bee breeders at Baton Rouge, Louisiana, to create the world's first cryopreserved honey bee embryo. Honey bee sperm is currently stored by the ARS National Animal Germplasm Program in Fort Collins, Colorado, and sperm preservation provides biodiversity, but embryo preservation enables breeders to access genetically identical lines of bees. This is a major advancement in the ability to improve the biosecurity of honey bee germplasm and the accessibility of the nascent National Honey Bee Germplasm Repository.

Deciphering the genetics of fast cooking dry beans. Cooking time is an important consumer trait in dry bean, and long cooking times discourage greater utilization of beans. ARS scientists in East Lansing, Michigan, previously discovered bean germplasm that significantly reduces cooking time, but the genetic control of the trait was unknown. The scientists developed a population from a cross between a slow cooking bean and a fast cooking bean. The cooking times for individuals in that population ranged from 21 - 135 minutes. The beans were grown in Tanzania under temperate and hot humid tropical climate for two field seasons and scientists observed that beans grown in the hot humid zone took 15 minutes longer to cook than those grown in the temperate zone. They determined cooking time was strongly influenced by genetic factors that were controlled by interactions of four different regions of the genome. After tagging those four regions with DNA markers, the researchers identified several bean lines containing genes from all four regions, which made them cook 16 minutes faster. This work demonstrated the potential value of integrating cooking time into breeding programs and the value of using molecular markers to help select for fast cooking beans. Breeders are now using these lines and markers to develop fast cooking beans.

New 'Contender' high oleic peanut cultivar increases profits for southwest U.S. producers. Virginia-type peanuts are grown on approximately 35 percent of peanut acres in Oklahoma and in Texas for the export market, which, unlike domestic markets, requires larger pods, kernels, and seeds. The high oleic cultivar 'VENUS,' which was released by ARS in Stillwater, Oklahoma, in 2016, is produced and marketed domestically, but it does not consistently meet export market preferences for extra-large kernels, pods, and seeds. In 2018, ARS scientists developed and released the peanut cultivar 'Contender' for the U.S. export market. Contender is unique among cultivars developed for southwestern U.S. production because of its enhanced market characteristics, including large and bright pods (averaging 9 pods per ounce) and large seed size (averaging 104 g/100 seed). Contender was developed for optimal performance in Oklahoma and Texas, and its production and export is expected to contribute $20 million annually to the U.S. economy.

Release of high-antioxidant 'Scarlett' rice. The outer bran layer of the rice grain contains most of the nutritional value of the grain, while the interior endosperm is primarily composed of starch. Generally, rice varieties with purple or red brans have compounds that offer more nutritional benefits than brown rice. ARS researchers at Stuttgart, Arkansas, and Cornell University developed 'Scarlett' rice, a variety that contains high levels of lipophilic antioxidants and polyphenols in its red bran. Scarlett rice will benefit rice growers because of its high yield potential when grown in the southern United States; its nutritionally superior red bran will also be appealing to consumers in high-value markets.

Rootstock variety released for controlling scion vigor in grafted vines. VR O39-16 is a grapevine rootstock that provides protection against the dagger nematode and fanleaf degeneration disease. However, the VR O39-16 rootstock is not favored by growers because scions that are grafted onto it grow vigorously and produce large vines that need substantial pruning, form dense canopies, and produce low-quality fruit. ARS researchers in Geneva, New York, doubled the chromosome numbers of a VR O39-16 rootstock vine and developed 'A4,' a low vigor grapevine rootstock variety. This new rootstock provides grapevine growers with a valuable option for controlling scion vigor and protecting against damage from the dagger nematode and fanleaf degeneration disease.

Rootstocks identified for sapodilla production in Puerto Rico. An increasingly global economy has generated a greater demand for healthy and more diverse food products and has opened a window of opportunity for commercial tropical fruit production and marketing. Sapodilla is a delicious tropical fruit, but trees grow slowly, so growers need long-term research to ensure profitable production. ARS scientists in Puerto Rico conducted a 7-year field study to determine the yield, fruit quality, nutrient composition, and scion/rootstock compatibility of the cultivar 'Prolific' that was grafted onto 16 rootstocks at the USDA-ARS Research Farm in Isabela, Puerto Rico. Fruit from the most productive rootstocks averaged 4,479 fruit/ha, or 1,245 kg/ha. The average individual weight of fruit was 282 grams and ranged from 264 grams to 303 grams. This study provides the first information from a replicated experiment on fruit quality traits, leaf nutrient composition, and scion/rootstock compatibility of sapodilla cultivar 'Prolific.'

Indicator 2: During 2018, ARS will devise innovative approaches to crop genetic improvement and trait analysis.

Discovery of a new protein that controls oil content in plants. Oilseed crops synthesize and store large amounts of oil (up to 40 percent dry weight) in their seeds. This oil provides carbon and energy reserves for germinated seedlings and is an important nutritional resource for humans and animals. While the enzymes for oil synthesis in plants are generally well understood, the processes involved in the "packaging" of oil into subcellular structures called "lipid droplets" are poorly known. In research collaborations with the University of North Texas and the University of Guelph, ARS researchers in Maricopa, Arizona, discovered a new protein called Lipid-Droplet Associated Protein – Interacting Protein (LDIP) that plays a key role in the formation of lipid droplets in plant cells. Disrupting the LDIP gene resulted in much larger lipid droplets and up to 10 percent more oil in the leaves and seeds of plants. These results open new avenues for using non-transgenic mutation breeding strategies to develop agriculturally-important plants with enhanced oil concentrations. Scientists studying the basic mechanisms of oil formation in plants and plant breeders developing new oilseed cultivars with increased oil content will benefit from this breakthrough.

Novel double haploid method produces fertile plants from interspecific sunflower crosses. Sunflower, an important oilseed crop, produces oil that is high in nutritional value for human consumption. Wild sunflower species are known to possess many unique genes for sunflower improvement, but transferring genes from wild species into cultivated sunflower is restricted by cross incompatibility and hybrid sterility, and some crosses between species are sterile and cannot produce seed. ARS scientists in Fargo, North Dakota, developed a tissue culture method of directly producing plants from the tubular flowers of a cross between cultivated sunflower and wild relatives. Plants generated from this tissue culture system produced the same chromosome number and phenotype as their parents. This discovery provides a new method to produce large numbers of fertile sunflower plants derived from crosses with wild species and is helping scientists and breeders overcome incompatibility barriers for transferring useful traits from wild relatives into cultivated sunflowers.

Estimating fiber quality from hand-harvested bolls during cotton breeding. Cotton, the source of the most valuable "natural" fiber, is a key U.S. crop with a production value of $7 billion in 2017. The quality of the cotton fiber determines its value, but its fiber quality varies more than synthetic fibers precisely engineered to meet consumer textile demands. To breed cotton with more uniform fiber quality, improved methods are needed for measuring that quality from breeding plots. ARS scientists in College Station, Texas, and Texas A&M AgriLife Research collaborators identified the method for selecting hand-harvested bolls that most accurately represents the fiber quality in bolls picked by mechanical harvesters. Cotton bolls harvested from the top half of the plant generally have lower fiber quality than bolls harvested from the bottom half of the plants, so obtaining samples that combine bolls from all positions on the plant

provide the most accurate estimates of fiber quality for cotton breeding. These improvements in sampling will help producers and breeders streamline the estimation of fiber quality.

Indicator 3: During 2018, ARS will expand crop genomic information resources and advanced bioinformatic capabilities.

Completion of hop draft genome with gene annotations. Hop breeding is hindered by a lack of information on gene families, promoters, and transcription factors associated with economically important traits. Previously published hop genomes were incomplete and missing up to 33 percent of the estimated hop genome and the genes in these missing regions. ARS scientists in Corvallis, Oregon, along with collaborators at Oregon State University, Hopsteiner Inc., and Pacific Biosciences Inc., completed sequencing and assembly of the complete (2.8 Gigabase) genome. Researchers also identified the location and plausible function of genes that were added to the genome. Scientists now have the capability of determining and identifying which genes or gene families are expressed during pathogen attack, hop cone formation, and plant growth, with new gene expression studies currently underway. These new research abilities enable hop breeders to more quickly develop improved cultivars that address industry needs.

Mapping pigweed with free data and open source software. Pigweed has become a troublesome weed in southeastern U.S. agricultural systems, and agriculturalists need information on areas affected by pigweed to implement effective management control strategies. ARS scientists at Stoneville, Mississippi, used free and open-source geographic information system (GIS) software (QGIS), free government data, and online plant databases to develop and publish a county-scale geographic information database showing the distribution of three pigweeds: Palmer amaranth, redroot pigweed, and waterhemp. Database queries were used to demonstrate applications of GIS for precision agriculture applications at the county level, such as tallying the number of counties affected by the pigweeds, identifying counties reporting glyphosate-resistant pigweed, and identifying cultivated areas in counties with glyphosate-resistant pigweeds. This research demonstrated that free and open-source geographic information software such as QGIS has strong potential as a decision support tool and could be used for developing precision weed management at the county scale.

Release of cotton breeding information management system. The cotton breeding and research community has lacked a secure and comprehensive online accessible breeding data management and analysis system. ARS scientists in College Station, Texas, in collaboration with Cotton Incorporated and Washington State University, developed a Breeding Information Management System (BIMS) in the CottonGen database. The newly developed module enables cotton breeders to create and manage access to their private breeding programs; upload phenotypic data from the Field Book App or Excel templates; generate input files for Field Book; archive their entire data in the BIMS; search and filter accessions/lines by name, trial, location, cross, parent, and traits; and perform basic statistical analysis. With the release of BIMS, cotton breeders can now manage their own breeding data and analyze them with CottonGen's publicly available genomic, genetic, and breeding datasets much more effectively and efficiently, thus expediting development of new and improved cotton types for profitable use by U.S. farmers.

Improving breeding efficiency with modeling. Genomic prediction models need to be trained with individual phenotypes as closely related to the selection candidates as possible, so newly generated breeding lines with few propagules (seed or vegetative) need to be evaluated in field experiments. ARS researchers in Ithaca, New York, improved statistical methods to account for spatial variation in field experiments and developed methods to account for competition between breeding lines in adjacent plots. They showed that the accuracy of genomic prediction from models trained with the new statistical methods was higher than the accuracy from models trained using standard statistical methods. A direct correspondence exists between genomic prediction accuracy and realized gain from selection, so these modeling enhancements should enable more rapid crop improvement.

Indicator 4: During 2018, ARS will conserve and encourage the use of plant and microbial genetic resources and associated information.

Identifying teas by their DNA fingerprint. The global market for tea (*Camellia sinensis*) is valued at $40 billion/year, $12 billion of which is from the U.S. market, but it is difficult to identify or classify cultivated tea plants or their harvested

leaves. ARS scientists in Beltsville, Maryland, collaborated with Asian scientists to analyze the DNA "fingerprints" of 760 different kinds of tea that originated from China, India, Vietnam, Laos, Myanmar, Thailand, Korea, and Japan. They discovered these teas belonged to one of four groups of genetically-similar teas, either a small-leaved China type or three broad-leaved Assam types (Indian, Chinese, and Cambodian). Each of the four genetic groups appears to have been domesticated from wild plants independently in different regions, but plants in different groups all can easily interbreed, resulting in a wide array of hybrids in teas. This DNA grouping method has already been applied to help tea researchers in California and Mississippi identify unknown tea cultivars. The method can also enable U.S. tea growers and the U.S. tea industry conduct quality assurance of imported and domestic-grown teas and ensure "trueness-to-type" of materials marketed as premium tea products.

Safeguarding valuable genetic resources for grape. Grape is the most valuable fruit crop in the United States, with an annual market value of approximately $6 billion per year. New genes are continually needed by breeders to improve grape's quality, productivity, and resistance to environmental extremes, pests, and diseases. Those genes are contained in grape genetic resources collections managed by the USDA/ARS National Plant Germplasm System, primarily in the form of field plantings that are constantly vulnerable to environmental extremes and biological threats. ARS scientists in Fort Collins, Colorado, developed new methods to "cryopreserve" (store under ultra-cold conditions) samples of grape tissues from the growing points of vine stems. The procedure is applicable to genetically diverse grape plants, is highly flexible, and saves labor. These discoveries will ensure that vital grape genetic resources required by grape producers and breeders are safeguarded in secure storage conditions and available indefinitely.

Indicator 5: During 2018, ARS will expand fundamental knowledge of plant biological and molecular processes.

Vulnerability of field crops to temperature changes in the southwestern U.S. ARS researchers at Davis, California, and Las Cruces, New Mexico, collaborated with researchers at Lawrence Berkeley National Laboratories and the University of Idaho to assess the sensitivity, exposure, and vulnerability of eight field crops to increased temperatures at midcentury (2040-2069). This county-level spatial simulation revealed the complexity of temperature increases and provides guidance for prioritizing agricultural transformations and adaptations to help minimize land-use conflicts. Future temperature shifts were associated with changes in the composition and quantities of wheat, barley, oats, alfalfa, maize, cotton, rice, and safflower crops. For example, heat stress is projected to reduce maize yields by 27 percent, representing a 12 percent decline on top of known historic yield losses due to heat stress, and may reduce cotton yields by 38 percent, the latter of which will be greatest in the southern Central Valley, eastern New Mexico, and southern Arizona. The area suitable for cotton may double and expand northward, 14 percent of the current land used for alfalfa production will become be unsuitable, and 20 percent of current land used for maize production will be lost. However, in some cases, simply moving field crops to new areas puts them where high-value specialty crops are already grown. Land management goals must reflect an appropriate balance between agriculture, conservation, and other land uses as resources become affected by climate changes, particularly in the southwest U.S. region.

Discovery of genes involved in crop thermotolerance. Rising air temperatures could threaten plant chloroplast thermostability and photosynthetic function, both of which are critical for high crop productivity. ARS research scientists in Lubbock, Texas, used the experimental plant *Arabidopsis* to describe how the protein FtsH11 maintains photosynthetic efficiency at elevated temperatures. This same protein was then studied in a sorghum mutant library to identify a similar mutant protein, sbFtsH11, which was found to have similar functions conveying thermotolerance. This work establishes a new functional mechanism that directly impacts crop thermotolerance and could enable direct manipulation or improvement of thermotolerance by breeding or engineering this trait into crop plants.

Master regulators of powdery mildew resistance. Understanding how plant pathogens manipulate their hosts will enable geneticists and breeders to promote more stable and more efficient crop production. ARS researchers in Ames, Iowa, partnered with bioinformaticists at Iowa State University to discover master regulators of plant disease resistance. Two of these regulators control the output of 961 and 3,296 "worker" genes, respectively. Moreover, of the 961 genes regulated during the early stages of attack, more than 30 percent of these are repurposed as infection progresses. Thus, these genes are part of an immune complex that is activated by multiple signals and encodes proteins functioning together to achieve immunity in response to different pathogen isolates or infection stages. This discovery of a

conserved core of genes that can be activated by known molecular signals offers new mechanisms to deploy in crop protection.

Tomato nutritional improvement. Tomatoes are among the most widely consumed fruit in the United States and are central components of many home gardens. They are important sources of dietary carotenoids including the antioxidant lycopene (which give tomatoes their characteristic red color) and beta-carotene, which our bodies convert to the necessary nutrient vitamin A. ARS researchers in Ithaca, New York, demonstrated that a protein from tomato originally identified in orange colored cauliflower provides a crucial regulatory step in limiting the synthesis of carotenoids in tomatoes. Expression of this protein during early fruit development resulted in accumulation of carotenoids (lycopene and beta-carotene) prior to ripening initiation and resulted in higher ripe fruit carotenoid levels. No changes in other ripening parameters were observed. These results suggest that the gene encoding this protein can be manipulated via traditional breeding or targeted genetic engineering to improve nutrient and visual quality in tomato and additional fruit crops.

A non-invasive method to quantify starch reserves at micrometer resolution. Starch is the primary energy storage molecule used by plants to fuel respiration and growth during periods of limited photosyn thesis. Until now, starch could only be measured using destructive techniques, which limited studies on carbohydrate metabolism in living plants. Prior methods also lacked adequate spatial resolution to study starch metabolism in different cell types. ARS researchers at Davis, California, Yale University researchers, and scientists at University of California, Davis, used X-ray microcomputed tomography and a novel machine-learning algorithm to quantify plant starch content over time within the woody stems of living grapevines. After validating the machine-learning algorithm, the spatial distribution of starch was characterized in woody stems at micrometer resolution as the plants were exposed to experimental conditions that halted photosynthesis and starch production. This new tool has applications to many horticultural crops and will support producers who are under increasing pressure to minimize water use without limiting crop longevity or yields.

Indicator 6: During 2018, ARS will develop more effective methods to enhance biotechnology for crop improvement.

Pollinator behavior and managing geneflow between genetically engineered (GE) and conventional crops. Approximately 35 percent of the crops grown for human consumption benefit from insect pollinators, including honey bees, bumble bees, and leaf cutting bees. ARS scientists in Madison, Wisconsin, used miniaturized radio frequency identification (RFID) to study how field size and field isolation affect bee be havior and subsequent gene flow. All the bees in the study visited more flowers in large patches and would travel as far as needed to visit flowers, despite the distances involved. These findings suggest carefully planning the configuration of genetically-modified and conventional alfalfa plots in close proximity could help restrict gene flow resulting from pollinator activities. This information is useful to farmers, the alfalfa seed industry, and the regulatory agencies concerned about adventitious presence in alfalfa seed-production fields.

New system for engineering novel traits into crop genomes. The genetic improvement of crops is one of the most effective ways to increase agricultural productivity. Until now, it has been difficult to genetically engineer improvements in complex traits like yield or disease resistance that require the action of multiple genes. An ARS scientist in Albany, California, developed a novel technology called Gene Assembly in Agrobacterium by Nucleic Acid Transfer using Recombinase technology (GAANTRY), that allows the efficient assembly and introduction of multiple genes into plants. The system can be used to join multiple genes together in a simple, reliable, and highly effective process, and then used to generate transformed plants that frequently produce all the introduced traits as desired. This technological breakthrough enables the use of crop biotechnology to effectively improve complex traits in a wide array of crop plants and should enhance the development of crop plants with improved disease resistance, increased yields, and other key production traits.

Indicator 7: During 2018, ARS will develop crop production strategies to optimize crop genetic potential, mitigate losses due to biotic and abiotic stresses, and increase production efficiency.

Brown marmorated stink bug (BMSB) commercial pheromone lure development. BMSB is a highly invasive pest of agricultural and nursery crops and is a nuisance when it invades homes to overwinter. Based on the identification of the BMSB pheromone and pheromone synergist, ARS researchers at Kearneysville, West Virginia, and university collaborators around the country developed lures that are now commercially available from three commercial companies, AgBio, Trece and AlphaScents. The lures can be used with crop-compatible trap designs to measure BMSB presence, relative abundance, and seasonal activity.

New catch plate design for mechanical blueberry harvesters. Blueberry growers want to replace expensive hand pickers with machines to harvest blueberries, but current blueberry harvesting machines use hard fruit catching plates that cause significant damage to the harvested blueberries falling on them. To machine harvest blueberries without bruise damage, ARS researchers at Kearneysville, West Virginia, developed durable catch plates (U.S. Patent No. 9750188) and field test results showed that the machine with new catch plates harvested blueberries with significantly less bruise damage. In 2018, two commercial blueberry harvesting machines with the new catch plate design were built.

Seasonal pollen nutrients align with seasonal bee activity. ARS researchers in Tucson, Arizona, found that spring pollens provided higher concentrations of necessary proteins and fatty acid nutrients than fall pollens. The spring nutrients support brood rearing, foraging, and reducing the incidence of brood diseases, while fall pollens contained more nutrients that mobilize stored resources needed to thermoregulate the winter cluster. The source of pollen even affected changes in adult bees, which grew larger brood food glands when fed spring pollen than when fed fall pollen. Findings from this study underscore the need for flowering plants to be available to bees from spring through fall, and that seasonal nutritional needs must be considered when formulating pollen supplements for bee colonies.

Hot water and steam can be used to sanitize plastic nursery pots and trays for weed seed. Seeds of many weeds, particularly bittercress and creeping woodsorrel, stick to plastic nursery containers and trays and are reintroduced into production systems when that plastic is reused. ARS scientists in Wooster, Ohio, determined the specific temperatures and exposure times necessary when using either hot water or steam to kill weed seeds on plastic containers and propagation trays. Temperatures of 194° F provided nearly complete control of seeds for both species. The results of this work can be used by greenhouse and nursery producers to control weed seeds between crops and drastically reduce weed populations in propagation and other phases of production where herbicides are limited.

Integrating aerial imaging and variable rate technology for precision herbicide application. Remote sensing and variable rate technology are becoming more available for aerial applicators, and practical methodologies for effectively integrating these technologies are needed for site-specific aerial applications of crop production and protection materials. ARS scientists at College Station, Texas, demonstrated how to integrate an airborne imaging system and a variable rate aerial application system for site-specific management of the winter weed henbit. Results showed that the imaging system was effective for mapping henbit infestations and that the variable rate system could accurately deliver the product at the desired rate to the prescribed areas for effective weed control. The methodology and results from this study will be useful for aerial applicators to incorporate airborne imaging and variable rate application systems into their aerial application business to increase their capabilities and profits.

Indicator 8: During 2018, ARS will improve pollinator health, bee systematics and germplasm lines, and pollination.

Antibiotic treatment could increase honey bee vulnerability to fungal disease. Antibiotics indiscriminately wipe out both good and bad bacteria, leading to antibiotic resistance and causing other potential bee health problems. ARS scientists in Beltsville, Maryland, discovered that disruption of honey bee gut bacteria by antibiotic treatment could interfere with bee immunity and make bees more susceptible to Nosema, a fungal disease. This study adds new evidence that antibiotic treatment not only leads to the complex problem of antibiotic resistance, but also damages gut microbial communities that help regulate immune function in honey bees.

Native pollinators support consistent high sunflower yields. Low or inconsistent yields are challenging for individual sunflower growers and the overall sunflower market. Pollinators are needed to ensure high yields, especially when sunflower hybrids do not effectively self-pollinate because of crop genetics or environmental conditions during flowering. ARS scientists at Fargo, North Dakota, grew 15 confection sunflower hybrids over two years and documented contributions of bee pollination to crop yields. On average, bees accounted for 26 percent of yield and lines that attracted more bees obtained higher benefits from pollinators. Although honey bee colonies were located adjacent to the research plots, almost all bee visits to confection sunflowers were by solitary wild bees. These results document the contribution of wild bees to sunflower yield increases and their clear preference for certain hybrids. Growers are now using bee conservation as part of crop management, and breeders are now using pollinator attraction as a component of inbred and hybrid development.

Goal 3.2 – Protect Our Nation's Crops

NATIONAL PROGRAM 303 - PLANT DISEASES

NATIONAL PROGRAM 304 - CROP PROTECTION AND QUARANTINE

Indicator 1: During 2018, ARS will continue to identify and characterize resistance genes in crop plants for insect, nematode, and plant pathogens, to enhance opportunities for developing host plant resistance, and to incorporate such genes into commercially acceptable varieties.

Discovery of a new class of safer insecticides. Methyl benzoate exists naturally as a floral fragrance in many plants. ARS scientists in Beltsville, Maryland, found that methyl benzoate also has insecticidal properties and is more toxic to gypsy moth larvae and brown marmorated stink bug nymphs than commercial insecticides. It was found to be 5 to 20 times more toxic to larvae of a fruit fly called the spotted wing drosophila than it is to these other two insects and is also environmentally friendly. ARS has patented it as a safe, new insecticide for use on this fruit fly. Furthermore, studies of methyl benzoate analogs may help explain how a related compound, DEET, works so well as an insect repellant. Further chemical analyses will help improve the efficacy of this new class of insecticide.

Release of disease-resistant germplasm from wild sunflowers. Sclerotinia basal stalk rot (BSR) and downy mildew are two fungal diseases that are major yield-limiting factors in global sunflower production. The use of resistant hybrids, where available, is the most efficient and environmentally friendly means of managing these diseases. ARS scientists in Fargo, North Dakota, transferred resistance to BSR from three species of wild annual sunflowers into cultivated sunflower, resulting in the release of seven sunflower germplasm lines. All lines except one also contain resistance to downy mildew derived from one of the parents. These lines represent the first oilseed sunflowers with resistance to Sclerotinia BSR and downy mildew together and are being used across the United States and internationally to breed sunflower for resistance to multiple diseases that reduce seed quality and severely affect yield.

Six disease-resistant sugarcane cultivars for Florida growers to mitigate the impact of disease. The biggest challenges facing Florida sugarcane growers are orange rust and brown rust disease, which cause considerable yield losses and increase costs due to repeated fungicide applications. Orange rust was first identified in Florida in 2007, so many of the most widely-planted, high-yielding sugarcane cultivars are susceptible. ARS researchers in Canal Point, Florida, collaborated with partners at the University of Florida and the Florida Sugar Cane League to identify and develop new sugarcane cultivars with resistance to rust diseases. In 2018, six cultivars were released by the Florida Sugarcane Variety Committee, three for production in muck soils and three for sand soils. In addition to orange and brown rust resistance, these new cultivars have high yields for increased profitability. Florida produces twenty percent of the sugar consumed in the United States, and cultivars CP 11-1314, CP 11-1956, and CP 11-2248 for muck soils and CP 10-1620, CP 10-1716, and CP 10-2195 for sand soils are expected to increase sustainable and profitable production.

Characterization and selection of a new highly effective oat crown rust resistance gene from wild oat, *Avena strigosa*, into cultivated oat. Oat crown rust (*Puccinia coronata* f. sp. *avenae*) is a major disease that can result in a significant reduction in global oat production. ARS scientists in St. Paul, Minnesota, identified a new, highly effective resistance gene to oat crown rust from wild oat, *Avena strigosa*, and introduced it into cultivated oat through a technique called

marker-assisted selection. The gene confers broad resistance to this devastating disease of oat, making it highly valuable to scientists around the globe.

Completion of the synthetic pathway of a bioherbicide. No new herbicides with new modes of action have been discovered since the 1980s, and this has exacerbated the herbicide-resistance problem. ARS scientists in Oxford, Mississippi, previously discovered a compound called sorgoleone which gives sorghum its natural weed-fighting properties. This compound holds potential to be an effective new bioherbicide with a new mode of action. These ARS scientists have now identified the complete biosynthetic process for how the plant makes sorgoleone, including all the genes involved. In addition, they discovered the sorgoleone protein is produced only in the roots of the sorghum. With this information, scientists now have the tools in hand to develop the production of sorgoleone in other crop species, which could lead to new crop varieties with enhanced resistance to weeds. Weed resistant crops could significantly reduce the need for chemical herbicide applications and increase options for crop rotations.

Indicator 2: During 2018, ARS will continue to develop fundamental knowledge about biology and ecology that provides the foundation for strategies to exclude, accurately detect and identify, and mitigate arthropod and nematode pests, weeds, and plant pathogens.

PhylloLux technology for crop protection. New approaches are needed for controlling strawberry diseases. Current strategies that rely mainly on the use of fungicides have significant limitations because they have become less effective in their ability to control plant pathogens. In addition, restrictions on the use of fungicides and public demand for produce free of pesticide residues are both increasing. ARS researchers in Kearneysville, West Virginia, developed PhylloLux technology, a plant disease-management system that combines Ultraviolet C (UV-C) irradiation followed by a specific dark period with the application of biocontrol agents. The PhylloLux system can also be used to control mites, the major arthropod pest in strawberry production. Microbiome analysis revealed no major shift in the composition of the microflora of fruits and leaves that would indicate an increase in foodborne pathogens after antagonist treatment. The potential of this technology goes well beyond its application to strawberries to include other fruit and vegetable crops as well as ornamental plants and nursery stocks.

Glyphosate (Roundup) has only subtle and minor effects on soil microbes. The herbicide glyphosate is the most widely used herbicide in the United States and is a key tool in the direct-seed no-till system that reduces soil erosion and fossil fuel inputs. However, Pacific Northwest growers have been concerned about glyphosate's non-target effects on beneficial soil microbes such as bacteria and fungi. ARS scientists in Pullman, Washington, used next-generation sequencing to compare microbial communities obtained from fields with a long history of glyphosate use and fields where glyphosate had never been used. Results indicated the effects of glyphosate were very minor and that fungal and bacterial communities were much more significantly affected by locations and cropping systems; in fact, plant roots killed by glyphosate provided nutrients that supported the increased growth of soil bacterial and fungal communities. There was previously little scientific information on this topic, and these findings help address concerns farmers may have about the environmental effects of glyphosate in crop production.

Glyphosate not found to affect disease rates or mineral uptake in GMO corn and soybeans. Glyphosate (the active ingredient in the herbicide Roundup®) and genetically modified (GMO) corn with glyphosate resistance have dominated agronomic cropping systems throughout the United States for nearly twenty years. Concerns have arisen that genetically engineered corn may be more susceptible to a disease called Goss's wilt following glyphosate application. A report was also made that significant mineral deficiencies might develop in GMO corn and soybeans following glyphosate use. ARS scientists in Illinois, Maryland, and Mississippi conducted a very large experiment across several years and several regions to quantify these effects. They found that GMO crops were no more likely to develop Goss's wilt than non-GMO corn and found that glyphosate applications were not associated with mineral deficiencies in these crops. In conclusion, these unintended effects do not occur in association with GMO crops or glyphosate applications.

Indicator 3: During 2018, ARS will perform applied research and development to provide new, useful and safe methods and products to accurately detect, identify, and diagnose arthropod and nematode pests, weeds, and plant pathogens.

Documentation of 500 new nematode specimens. Plant-parasitic nematodes are microscopic roundworms that attack plant roots and cause an estimated $10 billion of crop losses each year in the United States and $100 billion globally. One problem with reducing nematode-related crop losses is that nematode species are notoriously difficult to identify in part due to a lack of reference materials. ARS scientists in Beltsville, Maryland, completed the documentation for nearly 500 additional nematode species for the USDA Nematode Collection over the last 20 years. This work is significant because it provides information about the numbers and kinds of nematodes known to exist and which specimens can be obtained from the Nematode Collection. The specimens are used by scientists, extension agents, growers, and quarantine officials to anticipate and accurately identify nematode species for research and pest control.

Improved detection method that differentiates two citrus pathogens. *Spiroplasma citri* causes citrus stubborn disease (CSD), which has symptoms that are easily mistaken for Huanglongbing (HLB), caused by *Candidatus* Liberibacter asiaticus (CLas). CSD is fairly widespread in California but is a manageable disease of citrus, while HLB is a devastating citrus disease subject to quarantine and immediate removal of infected trees. ARS researchers in Parlier, California, developed a sensitive procedure to identify and quantitate *S. citri* and CLas from citrus and vector tissue using a technique called droplet digital PCR (ddPCR). This process is more sensitive and reliable than the standard molecular technique when pathogen counts in the test tissues are low. The ddPCR test provides a robust method to test symptomatic and non-symptomatic citrus samples for CSD and HLB in a single test, saving time and money, and can be used by regulatory agencies as an improved testing procedure to differentiate between deadly HLB and the more benign CSD.

Diagnostics for Macrophomina root and crown rot. Since using methyl bromide for soil fumigation has been banned, *Macrophomina phaseolina* has emerged as a pathogen in California strawberry production. ARS researchers in Salinas, California, and University of California collaborators developed two different types of molecular diagnostic tests that are specific for the *Macrophomina* types capable of infecting strawberry. The tests measure the amounts of the fungus in the soil and provide a way for its rapid detection in production fields. Isolates of the fungus that are highly infectious on strawberry are, with a few exceptions, genetically identical. These assays provide researchers with the tools they need to identify the pathogen and provide growers with the ability to determine risk prior to planting.

Goal 4.1 – Provide Scientific Information and Biotechnologies for aquaculture and animal agriculture that will improve production efficiency, industry sustainability, product quality, and nutritional value while safeguarding genetic resources.

NATIONAL PROGRAM 101 - ANIMAL PRODUCTION

NATIONAL PROGRAM 106 – AQUACULTURE

Indicator 1: During 2018, ARS will identify underlying genetic and/or physiologic mechanisms relating to food animal production and production efficiencies for traits associated with growth physiology, nutrient utilization, reproductive physiology, health, and well-being in food animals.

NSAID transdermal applications reduce fevers associated with Bovine Respiratory Disease challenge. Treating Bovine Respiratory Disease (BRD) is estimated to cost cattle producers more than $30 per head, and more than 55 percent of feedlots use a non-steroidal anti-inflammatory drug (NSAID) to reduce the fever associated with BRD. ARS scientists in Lubbock, Texas, worked with an industry partner to determine if administering a topical NSAID (as opposed to oral or intravenous administration) would reduce fever associated with BRD if the NSAID is administered before the animal is

exposed to the disease. Results from this study indicated that fever was reduced in calves when the topical NSAID was administered at the time of exposure, but the topical application was ineffective if animals were treated 3 days before exposure. These findings give producers new options for topically treating calves that have developed fever associated with BRD infection. It is much simpler to administer than injectable or oral products, which will support its appropriate use, reduce animal stress during application, reduce potential medical waste contamination, and ultimately improve animal comfort and well-being.

Virulent *Flavobacterium columnare* degrades catfish mucus. *Flavobacterium columnare* is a bacterium that causes columnaris disease in farmed fish and is a concern for U.S. and international aquaculture producers. Skin mucus is an important defense protecting fish health, but some pathogens have developed adaptions for penetrating this protective layer. ARS researchers at Auburn, Alabama, collaborated with Auburn University scientists and identified the components of catfish mucus that are vulnerable to bacterial damage from the pathogen. They also found that a highly virulent *F. columnare* isolate growing in catfish mucus showed significantly elevated enzyme activity compared to a moderately virulent isolate. This activity may promote greater bacterial virulence by increasing the pathogen's ability to break down the protective mucus layer, which in turns enhances bacterial colonization and disease that may kill that fish host. The data provide new insights on the pathogenic mechanisms of *F. columnare* in columnaris disease that researchers can use in developing strategies for mitigating the disease.

Colostrum deficiency in piglets affects uterine function in adulthood. Similar to other animals including humans, the first milk that a pig consumes from its mother is called colostrum and contains many hormones and other substances that affect the development of multiple tissues and organ systems. Previous research from ARS showed that if female piglets do not get adequate colostrum at birth, their reproductive capacities are diminished. To determine the mechanism behind this reduced fertility, ARS scientists at Clay Center, Nebraska, collaborated with Auburn University and Rutgers University scientists to identify colostrum-deficient female piglets and their normal littermates at birth. The piglets were then allowed to mature and uterine function was measured by comprehensively measuring the genes expressed by the uterus during early pregnancy. They found more than 1,100 genes were expressed differently between adults that had consumed adequate amounts of colostrum and adults that did not consume adequate colostrum amounts just after birth. Many of the genes that differed in expression were involved in immunity and in uterine acceptance/support of the fetus. This research strongly indicates that colostrum deficiency on the first day of life alters uterine development, has lasting effects on subsequent uterine function during pregnancy, and can lead to impaired fertility and litter size. This research reinforces the need to manage colostrum consumption of newborn female piglets to enhance long-term pork production and profitability.

A prediction equation to estimate the core body temperature of chickens from facial skin temperature. Heat stress in poultry reduces feed intake and growth rates and can be lethal. Monitoring heat stress in poultry relies on accurate measurements of core body temperatures, but current methods require physically restraining the birds, which can further elevate the body temperature and result in inaccurate measurements. ARS researchers in West Lafayette, Indiana, developed a prediction equation to estimate core body temperature from a chicken's facial skin temperature, which is collected with a thermal camera, combined with other factors. This equation is expected to help researchers collect more accurate body temperature data in experiments that explore factors contributing to heat stress without having to handle animals and manually take their temperatures. In addition, it may have practical applications for poultry producers for determining when their birds are suffering from heat stress or whether their flocks have fevers or illness.

Incubation temperature impacts rainbow trout embryo survival. Incubation temperature is commonly manipulated to control and predict hatch date in salmonids so that suppliers can consistently provide their customers with eyed eggs across the spawning season. However, there is little information on how temperature changes affect embryo survival. ARS scientists in Leetown, West Virginia, found that incubation at 5 degrees Celsius within the first day of fertilization reduced embryo survival around 5 percent compared to incubation at 10 degrees Celsius, and that rapidly transferring embryos between 10 degrees Celsius and 5 degrees Celsius after 100-degree days of incubation did not affect survival. This information suggests that stakeholders should end the practice of initially incubating fertilized eggs at 5 degrees Celsius.

Cows that demonstrate estrus during an estrous synchronization protocol are more fertile. To increase the efficiency of using artificial insemination for breeding beef cattle, cow-calf producers use protocols that synchronize the cows' reproductive cycles, but these protocols often result in lower fertility rates. ARS researchers at Clay Center, Nebraska, collaborated with South Dakota State University researchers to see if early embryonic mortality (day 16 of pregnancy) was greater in cows that did not demonstrate behavioral estrus after an estrous synchronization protocol and artificial insemination. Results showed that there was no difference in embryonic survival between two different reproduction strategies; there was also no difference in uterine protein or glucose concentrations, which are measures of uterine function. However, the researchers found estrous associated hormone concentrations were three times greater in cows that demonstrated behavioral estrus, and while there was no difference in embryonic development on day 16, pregnancy rate at day 35 was reduced in cows that did not demonstrate behavioral estrus. These results suggest that increased hormones that occur at estrus may influence embryo-uterine interactions such as implantation, which is needed for embryo survival between day 16 and 35 of pregnancy. These results suggest that increasing the number of cows expressing estrus after estrus synchronization protocols will lead to better fertility and greater adoption of the technology by cow-calf producers.

Indicator 2: During 2018, ARS will develop genomics infrastructure and tools to efficiently identify genes, their function, and interactions with environmental factors for exploitation in genome enabled improvement programs for food animals.

Finding genetic activities that drive Marek's disease transformation in chicken. Marek's disease, which is caused by a poultry virus that also causes cancer, is estimated to cost poultry producers worldwide more than $1 billion annually. Understanding how Marek's disease virus (MDV) induces tumors is critical for developing vaccines or poultry that have genetic resistance to the disease. ARS researchers at East Lansing, Michigan, collaborated with Purdue University and University of California-Davis scientists to sequence tumor DNA and RNA to identify mutations associated with tumor formation. They found that most tumors had either low expressions of the Ikaros gene, which is the master regulator for immune cell development and is associated with tumor suppression, or mutations in its key regions. This information will aid future efforts to improve Marek's disease vaccines and to select birds for superior resistance to Marek's disease, which will improve the health and well-being of poultry, improve production efficiency, and reduce poultry wastes.

Genomic selection for growth and carcass yield in the Delta Select strain of channel catfish. Determining the relative value of an individual fish for breeding has depended on traditional methods that use parentage information and trait measurements. ARS scientists in Stoneville, Mississippi, collaborated with University of Georgia scientists to develop a technology that uses genome information to improve the accuracy of breeding value estimates. This approach led to 30 percent improvement in breeding value accuracy for growth and carcass yield in 2,000 Delta Select strain catfish. The improved breeding value accuracy will result in more rapid genetic gain for growth and carcass yield in the Delta Selects, which will be released to U.S. catfish farmers to improve their production efficiency.

A gene alteration reduces dark-cutting lean beef. Abnormally dark-red "dark cutting" beef, which occurs when an animal's muscle energy stores are depleted, reduces consumer acceptance of beef products and results in an annual loss of more than $70 million in potential revenue. More information is needed about why, under equal production conditions, some cattle deplete their muscle energy stores and exhibit the dark red color and others exhibit a typical bright, cherry-red color. ARS scientists at Clay Center, Nebraska, discovered a naturally-occurring genetic mutation in cattle that reduces the susceptibility of cattle to the dark-cutting condition and helps explain much of the unexplained variation in susceptibility to dark cutting. The sequence associated with darker meat is highly conserved across all mammals, and the mutation associated with bright red lean meat appears to have originated in British cattle breeds. The frequency of the bright red colored meat mutation varies among breeds and is very low in Holstein steers, which are the primary source of dairy beef. Breeders who select for this trait should be able to significantly reduce the costly occurrence of dark red colored beef and reduce losses associated with customer rejection of dark-cutting beef products.

Lifetime merit indices for dairy cattle now include health traits. Genetic economic indices for dairy cattle are used to improve the efficiency of the U.S. dairy population by ranking animals based on their combined genetic merit for economically important traits, but health traits had not been included because they were not available. ARS researchers

in Beltsville, Maryland, collaborated with the Council on Dairy Cattle Breeding to develop genetic evaluations for disease resistance to the six most common and costly health events for U.S. dairy cattle and then added these traits to the lifetime merit indexes. The economic impacts of direct expenses associated with health traits, such as clinical mastitis treatment, were given greater emphasis, and traits previously correlated with health, such as somatic cell score, were given reduced emphasis. In August 2018, the Council on Dairy Cattle Breeding adopted and officially released the revised indices to the dairy industry. Breeders can use the new indices to select for genetic traits to use in breeding new cow lines that are healthier and more profitable than cows with health conditions that require extra farm labor, veterinary treatment, and medicine. Breeders using the original index increased the profitability of dairy by $250 million annually, while breeding dairy cows using the new index will increase profitability by an additional $1.4 million annually.

Gene editing in rainbow trout. Advancements in gene editing technologies have enabled the induction of targeted mutations in genes of interest, allowing for precise manipulation of the genome. ARS researchers at Leetown, West Virginia, have provided the first proof-of-concept for rainbow trout by demonstrating that this technology can produce fish that exhibit a desired trait and that these genetic modifications are transmitted to the next generation via typical reproduction. Gene editing provides a new opportunity to understand gene function and an alternative strategy that can complement other approaches to genetic improvement.

Indicator 3: During 2018, ARS will develop and improve sustainable production systems for food animals; incorporating strategies to optimize production system efficiency while ensuring economic and environmental sustainability.

Demonstrating the impact of eliminating animal agriculture. Farmed animals provide essential nutrients in human diets, but also produce greenhouse gases and use food resources that could potentially be used by people. ARS scientists in Madison, Wisconsin, collaborated with Virginia Tech University scientists to evaluate the hypothetical impact of converting U.S. agriculture to a plant-only system by completely eliminating livestock production. They found that removing livestock production resulted in the production of substantially more food; however, people consuming a plants-only diet without supplementation would need to consume more calories than needed to meet dietary requirements for other nutrients. Even with this extra caloric intake, people consuming a plant-only diet will have more nutrient deficiencies. While greenhouse gas emissions associated with U.S. agriculture were projected to decline 28 percent, agriculture only contributes 9 percent of greenhouse gas production to national levels, so total U.S. net greenhouse gas production would only be reduced 2.6 percent. The need to produce synthetic fertilizer to replace animal manures and other systemic changes also reduced the benefits of removing livestock from U.S. agricultural production. These findings show that changing a complex system may have some cost-effective results but may also generate unexpected impacts that reduce these benefits. Recommendations for changes in the U.S. agricultural system requires integrating studies from multiple disciplines to adequately evaluate potential impacts.

Water supply rates for recirculating evaporative cooling systems. Heat stress in poultry reduces their feed intake and growth rates and can sometimes result in death. New poultry houses use increased ventilation rates to improve cooling, but this has increased water usage. Regional water supply systems incorporate planning and design to control supply costs and ensure peak demands are met, especially during drought. However, few water use estimates are available for recirculating evaporative cooling pad and fan systems, and design guidance has emphasized planning for extreme temperatures, which has resulted in excessive capacity recommendations and water overuse. To improve these estimates, ARS researchers used historical weather data from 732 weather stations across the continental United States to estimate water use rates for different levels of ventilation system efficiency. Their results showed that estimated water supply rates for proper ventilation in U.S. regions with high levels of poultry production, including the Southeast, Delmarva Peninsula, and Iowa, were approximately 25 percent lower than current recommendations, indicating that the water flow rates and the evaporative equipment to provide adequate cooling are larger than they need to be. These results will reduce the capital and operating costs of installing and running evaporative cooling ventilation systems for new poultry houses.

Use of woodchip bioreactors to improve water quality in fish farm effluents. As with all intensive agricultural systems, fish farms produce waste that has the potential to impact the surrounding environment. ARS extramural researchers in Shepherdstown, West Virginia, determined that woodchip bioreactors can capture nitrate nitrogen and suspended solids from aquaculture effluent streams to minimize nutrient discharge into surrounding waterways. A cost and engineering assessment demonstrated that the woodchip bioreactor is an affordable, low maintenance technology that can be used to treat aquaculture effluent, reduce environmental impacts, and reduce wastewater treatment costs.

Salmonella migration out of gastrointestinal tract can potentially contaminate ground meat products. Significant progress has been made over the past 20 years to reduce foodborne pathogens such as *E. coli* from entering the food chain through contaminated meat. However, there has been no reduction in *Salmonella* contamination levels associated with beef production. ARS scientists in Lubbock, Texas, collaborated with Auburn University researchers to determine if *Salmonella* is able to migrate from the cattle digestive system into lymph nodes and joint fluid and contaminate ground meat products. They identified *Salmonella* outside the digestive system in various musculoskeletal lymph nodes and in some of the ground beef samples. *Salmonella* that migrates to these internal tissues is not eradicated by traditional methods such as topical washes and sprays used to reduce *E. coli* contamination on beef carcasses, and may pose a risk of contaminating various cuts of meat and ground meat products. This reinforces the need to cook beef properly to avoid foodborne illness.

Indicator 4: During 2018, ARS will characterize nutrient requirements of food animals; measure nutrient availability of traditional and nontraditional feedstuffs; and develop strategies for improving nutrient use efficiency.

Older, low-value hops could be used as a natural, growth-promoting feed additive for cattle. Some protein in animal feed is not available to cattle and some other ruminants because they possess gastrointestinal tract bacteria that degrade the nutrient before it can be utilized. As a result, the protein degraded by the bacteria is lost to the environment, where it contributes to ammonia emissions and nitrogen loads that that contribute to nutrient pollution. It also increases production costs because producers need to purchase enough feed to ensure livestock gain weight and obtain sufficient protein to maintain growth. These bacteria can be controlled with a natural compound in the hops plant, but while hops are generally too expensive to use in cattle feed, older hops no longer suitable for beer production could be available for alternative uses. ARS researchers in Lexington, Kentucky, discovered that even after being stored for 5 years, hops can control the bacteria in the cattle gastrointestinal tract, allowing the animals to gain weight more rapidly and efficiently. In past years, brewers used only half the harvested hops for beermaking, which left a surplus available for coproduct development, but the availability of this surplus varies from year to year. This result indicates surplus hops that are too old for brewing beer can be used as a valuable feed additive for improving nitrogen usage in cattle.

New dietary starch method to improve information for consumers. Accurate information on feed composition is essential for formulating healthy livestock diets and for informing consumers about the nutritional qualities of animal feeds and pet foods. Starch is a dietary carbohydrate that can provide energy to meet an animal's requirements in properly balanced diets, but too much or too little starch can cause health disorders. An ARS animal scientist in Madison, Wisconsin, developed a new assay to determine dietary starch concentration and then tested it in a collaborative study with 14 state, commercial, and research feed analysis laboratories. The starch method has been approved by the Association of Official Analytical Chemists International and received final approval for use in animal feed and pet food labeling, replacing a previous method that was no longer valid. In 2017, commercial feed analysis laboratories ran dietary starch analyses valued at $1.3 million on over 1.4 million samples. This research provided pet food manufacturers and animal agriculture with an assay to accurately determine the amount of starch in their feeds.

Rumen microbiome community profiles are associated with feed efficiency. Feed costs are estimated to be 60 percent of the total cost of raising cattle. Improving feed efficiency and reducing subsequent levels of wastes such as manure will reduce feed inputs and their environmental impacts. In cattle, microbes in the rumen degrade forages into metabolites that can be used for growth, but more information is needed about how the rumen microbial composition affects feed efficiency. ARS researchers at Clay Center, Nebraska, and University of Nebraska collaborators characterized the rumen microbial communities (microbiomes) of each individual in two large animal cohorts (125 heifers and 122 steers) to

identify specific bacterial members associated with feed efficiency traits in beef cattle. This innovative study showed that the species and abundance of the microbes present in the rumen account for 20 percent of the variation in feed efficiency. These data demonstrate that rumen microbial communities have a significant effect on feed efficiency and will inform future strategies for altering these communities to improve feed efficiency in cattle.

Indicator 5: During 2018, ARS will characterize food animal germplasm for traits of importance and continue to increase the inventory of germplasm stored within the National Animal Germplasm Repository to preserve biodiversity.

Genetic resources for responsible lamb production. The efficiency of sheep production is significantly influenced by the number of lambs born per ewe. But sufficient feed resources, which may not always be available on western rangelands, are required to support lamb production. ARS researchers at Clay Center, Nebraska, evaluated reciprocal crosses between Romanov and Rambouillet breeds to identify genetic traits that could be used to increase lamb production and found that half-blood Romanov crossbred ewes were equivalent in lamb production (2 per year) regardless of whether they were descended from Romanov or Rambouillet males. However, ARS researchers in Dubois, Idaho, collaborated with Virginia Tech University scientists to test the limits of lamb production per ewe in the harsh conditions of the U.S. mountains. They determined that production levels of 2.2 lambs per ewe each year are optimal, because ewes rearing triplets had higher lamb loss rates. These findings indicate that Romanov/Rambouillet crossbred ewes will be useful in increasing the number of lambs produced per ewe in the harsh U.S. production environments of the western mountains.

Genetic factors are associated with myoglobin concentration of porcine longissimus muscle. The pork industry is concerned about a recent increase in light colored regions in ham because consumers, especially Asian consumers, prefer a consistent redder-colored lean throughout the product. Myoglobin is the protein that is primarily responsible for the red color, and its concentrations vary with muscle fiber type. ARS scientists at Clay Center, Nebraska, conducted a genome-wide analysis to identify genetic markers associated with myoglobin content in pork and found at least two major regions of the genome affecting myoglobin concentration, as well as several other regions with minor effects. These results further indicate that a primary factor associated with myoglobin concentration in pork is the percentage of the different fiber types present in the meat. This finding contradicts a commonly held belief that fiber type content within muscles is similar across animals. This knowledge will inform selection methods to improve overall pork color and color consistency throughout the product and increase consumer acceptance of pork products.

Genetic evaluation of beef cattle breed differences in mature weight. The cow-calf sector of the beef production system produces calves that are then raised to produce beef. With increased selection for faster growth rates in the beef cattle industry, adult cow weights have also increased substantially because some of the same genes contribute to both traits. The increase in adult cow weight has resulted in higher maintenance energy requirements for the national cow herd and associated higher demands for feed resources. However, heavier cows do not necessarily produce more calves or weaned calf weight over their lifetime so information is needed about the genetic relationships between adult cow weight and lifetime production to help breeders make appropriate genetic selections for weight and productivity. ARS researchers used data from the germplasm evaluation program in Clay Center, Nebraska, to estimate differences in adult weight for 18 beef cattle breeds and identify correlations between cow weight and cumulative number of calves and weaned calf weight. They found that adult weight differed among breeds by 125 pounds, a difference that would reduce daily feed demands by 2 pounds and substantially lower feed costs over a cow's lifetime. There was little genetic relationship between cow weight and productivity, indicating the two traits can be selected independently without significantly affecting the other and can be incorporated with traits for economic values and other characteristics to select cows based on overall economic value. These results will help producers make breeding decisions when choosing sires in commercial cattle production.

Goal 4.2 - Prevent and Control Pests and Animal Diseases that Pose a Threat to Agriculture, Public Health, and the Well-Being of American Citizens.

NATIONAL PROGRAM 103 - ANIMAL HEALTH

NATIONAL PROGRAM 104 - VETERINARY, MEDICAL AND URBAN ENTOMOLOGY

NATIONAL PROGRAM 106 – AQUACULTURE

Indicator 1: During 2018, ARS will describe five new discoveries or developments significant for their scientific or applied value.

Bacterial involvement in birds infected with Newcastle disease viruses. Newcastle disease viruses are the most prevalent cause of respiratory disease on poultry farms worldwide, and Newcastle disease vaccines are often ineffective in production environments. ARS researchers in Athens, Georgia, assessed samples from infected birds in countries where Newcastle disease is endemic and identified previously unrecognized infections with *Ochrobactrum* bacteria that contain antibiotic resistance genes. This work resulted in the publication of the complete draft genome of eight *Ochrobactrum* bacteria and demonstrated Newcastle disease infection is often accompanied by bacterial infections, including infections with multidrug-resistant *Ochrobactrum*. These findings demonstrate that additional factors can be associated with Newcastle disease in poultry production facilities. In addition, the discovery of previously unrecognized co-infections with novel multidrug-resistant bacteria highlights the need for effective Newcastle disease vaccination programs to prevent secondary bacterial infections that may require the use of antibiotics and potentially lead to the evolution of antimicrobial resistant bacteria.

Testing of a recombinant protein vaccine to protect catfish against columnaris disease. *Flavobacterium columnare* is a bacterium that causes columnaris disease, which severely affects channel catfish production in the United States. ARS researchers at Stuttgart, Arkansas, previously identified *F. columnare* proteins that activate the adaptive immune response. They followed up this work with the development of a new recombinant protein vaccine that in laboratory tests provides excellent immune protection against columnaris disease.

Immune responses of channel catfish after vaccination with *Ichthyophthirius multifiliis*. *Ichthyophthirius multifiliis* (Ich) is a parasite of fish and causes severe losses to aquaculture industries worldwide. Treating Ich with chemicals is costly and often ineffective after the parasite penetrates the fish host skin and gill tissue. More information is urgently needed about protective immune responses in fish to develop effective vaccines against the parasite. ARS researchers at Auburn, Alabama, investigated the expression of innate and adaptive immune-related genes in surface and internal tissues of channel catfish following vaccination with live forms of Ich. The research demonstrated significantly higher antibody levels and 95 percent survival in vaccinated fish than non-vaccinated fish. These results reveal new insights into the molecular responses that may govern protective immunity of catfish against Ich infection.

Mycoplasma ovipneumoniae identified in a wider array of animals. Current evidence suggests that the *Mycoplasma ovipneumoniae* bacterium is the primary agent of pneumonia in bighorn sheep. Until recently, the host range of the bacterium was thought to be restricted to *Caprinae* species (sheep, goats, musk ox), and domestic sheep and goats were believed to transmit the bacterium to bighorn sheep, an assumption used in the development of grazing practices and policies by Federal and State agencies. However, ARS researchers in Pullman, Washington, identified *M. ovipneumoniae* in caribou, moose, Dall's (thinhorn) sheep, and mountain goats. They also collaborated with several veterinarians and a state agriculture department and identified this bacterium in captive white-tailed and mule deer exhibiting respiratory illness, and in a bison. Determining the accurate host range of this bacterium is vital for livestock producers and Federal and State stakeholders, because current policies to restrict grazing and interactions between domestic small ruminants and bighorn sheep do not adequately address possible transmission routes and don't effectively mitigate disease transmission.

New methods to study leptospirosis in animal hosts. Leptospirosis infects humans and animals worldwide; more than 10 million people are infected every year, and at least 10 percent of infections lead to severe disease. Infected cattle experience abortion, stillbirth, premature birth and reproductive failure. Current cattle vaccines were developed using studies conducted 25 years ago and may not target the many different strains of leptospires that are currently circulating. In addition, leptospires grown under laboratory conditions do not express the same proteins normally found during natural infection. ARS researchers at Ames, Iowa, developed a new method for culturing leptospires that more closely mimics natural infection and results in the expression of Leptospira proteins typically found during infection. These findings are providing new insights on Leptospirosis colonization and infection in natural hosts and could lead to new detection and control strategies.

Validating Brucella inactivation methods. Select agents are pathogens that the Department of Health and Human Services (HHS) and/or USDA have identified as severe threats to public health and safety. These pathogens are regulated through the Federal Select Agent Program, which has emphasized the need to validate methods for inactivating select agents because of publicized failures involving the danger posed by their improper disposal. ARS scientists at Ames, Iowa, found that the select agent Brucella could be inactivated after being heated at 95°C for 1 hour, after immersion in a 67 -percent methanol solution for 5 days, or after formalin treatment for 30 minutes. Filtering blood samples containing Brucella through a 0.22 um filter also removed all viable Brucella pathogens. This published data is of great interest to regulatory and biosafety personnel who work with the hundreds of laboratories where select agents are studied and provides effective and validated procedures for mitigating the risk of inadvertent pathogen release and ensuring the safety of laboratory personnel.

Indicator 2: During 2018, ARS will form new partnerships and continue old partnerships with industry, universities, and other government agencies in order to promote production and marketing of new methods for detection and identification of animal pathogens, arthropods that transmit pathogens, and arthropods that destroy property, including genetic markers, new methods of detecting gene sequences or antibodies or proteins, and comprehensive guides to morphological identification.

Diagnostic tests to detect horses infected with *Theileria*-like parasite. During a 2009 equine piroplasmosis outbreak in Texas, ARS scientists in Pullman, Washington, discovered a new parasite of horses that resembles *Theileria equi*. However, it is genetically distinct and undetectable by official diagnostic tests, which could leave the United States vulnerable to the import of infected horses. ARS scientists identified potential genes and proteins that can be used to develop diagnostic assays and tested them to see if they could be used in molecular or serologic assays to detect horses infected with the *Theileria*-like parasite. They found that all horses infected with the *Theileria*-like parasite were consistently detected by these newly developed assays. This information will provide diagnostic assays that can be used by the Animal and Plant Health Inspection Service to develop strategies for controlling the newly emerging pathogen.

Wild birds in Mexico are risk factors for avian influenza introductions. In the past, wild birds have introduced avian influenza (AI) viral strains to different parts of North America and they continue to pose a significant risk for introducing and/or spreading AI. To identify epidemiological risk factors between poultry and wild birds living close to humans and farms, ARS researchers in Athens, Georgia, and scientists in Mexico conducted field studies to evaluate the risk of wild birds introducing AI to poultry farms in the Altos de Jalisco region in west central Mexico. This is where the country's largest concentration of poultry farms is located, and the region recently experienced an emergence of low pathogenic AI H5N2 and the highly pathogenic AI H7N3. The researchers identified 82 species of wild birds linked to poultry farms; the wild birds most frequently observed were Mexican great-tailed grackles and barn swallows, indicating these two species present the largest potential risk for introducing AI to poultry production facilities in the Jalisco region. Demonstrating epidemiological connections between wildlife and poultry clarifies the potential risk wild birds pose to the poultry industry. In addition, this work indicates the U.S. poultry industry is at significant risk of AI introductions from the Jalisco region through trade, wild bird migrations, and illegal transport of birds.

Indicator 3: During 2018, ARS will form new partnerships and continue old partnerships with industry, universities, and other government agencies in order to promote production and marketing of inventions that protect animals from pathogens or manage arthropods that transmit pathogens or damage property.

Red imported fire ant detection device. Fire ant introductions at U.S. ports and at quarantine boundaries are a constant problem and the ants must be rapidly identified to minimize shipping delays. ARS researchers at Gainesville, Florida, and APHIS researchers at Biloxi, Mississippi, developed a rapid field-portable kit that untrained personnel can use to identify fire ants. The kit is based on the lateral flow immunoassay technology used in home pregnancy tests and can confirm the presence of fire ants within 10 minutes without any prior training or knowledge. Agdia, Inc. (https://orders.agdia.com/invictdetect-isk-49700-0010) has acquired the Biological Material License for the monoclonal antibodies in the test from USDA and is commercially manufacturing the kits under the trade name INVICTDETECT.

Sequencing the Asian longhorned tick genome. The Asian longhorned tick (*Haemaphysalis longicornis)*, orginally from Asia, is a serious pest of livestock; it is an aggressive biter with a diverse host range, can reproduce asexually, and is a vector of several debilitating agents of livestock and human diseases. This tick has recently established populations in at least nine U.S. states. As part of an emergency response to assist USDA-APHIS, ARS scientists at Kerrville, Texas, collaborated with researchers at Texas A&M University AgriLife in College Station, Texas, to sequence the genome of the tick. The completed genome opens new avenues of research on tick control methodology, including vaccine development and detection of pesticide resistance-associated genes.

Models to improve integrated pest management of mosquitoes and determine risk of emerging disease threats to the United States. ARS scientists in Manhattan, Kansas, collaborated with Kansas State University researchers to develop models quantifying the risk from introduction of Japanese encephalitis and Rift Valley Fever viruses to the United States. The analysis suggests that airplanes and cargo ships currently present a minimal risk of introducing Japanese Encephalitis. However, the results also indicate the behaviors of mosquitoes responsible for disease transmission play a more significant role than originally realized. Another model used disease outbreak data from South Africa to better understand host and vector roles in the spread of Japanese Encephalitis and Rift Valley Fever viruses between farms in the Midwest, Texas, and the eastern seaboard. The results are useful to epidemiologists, State and Federal mosquito management districts, and health care specialists for improving the surveillance and population management of disease vectors to prevent disease outbreaks in humans and livestock, as well as to Federal emergency planners who may need to quickly develop plans for protecting food supplies from the introduction of exotic pathogens.

Significant domestic sheep breed differences in nasal shedding of *Mycoplasma ovipneumoniae*. *Mycoplasma ovipneumoniae* is carried by domestic sheep and goats and has been implicated as an important pathogen in bighorn sheep that negatively impacts their population recovery. ARS scientists in Pullman, Washington, discovered that different breeds of sheep have different rates of *M. ovipneumoniae* shedding and that significantly fewer Rambouillet are high shedders, compared to Polypay and Suffolk breeds. These findings suggest a genetic association with carriage and shedding of *M. ovipneumoniae* and indicate it may be possible to mitigate shedding through breeding, which will support the development of *M. ovipneumoniae* control strategies for livestock producers.

Nanoparticles improve vaccines against coccidiosis. Coccidiosis, a gut disease of poultry, costs U.S. producers $350 million annually due to poor weight gain and treatment costs. Current vaccines contain low doses of highly infectious organisms, and the World Organization for Animal Health has designated coccidiosis a high priority disease needing improved vaccines to reduce the need to treat infected poultry with antibiotics for secondary infections. ARS scientists in Beltsville, Maryland, developed an oral vaccine enhanced with protective antigens attached to nanoparticles and found it improved weight gain and feed efficiency in chickens given the vaccine at hatch. This technology may markedly improve the health and welfare of poultry flocks, reduce poultry production costs, and reduce antibiotic use in poultry by reducing the incidence of secondary bacterial infections associated with coccidiosis.