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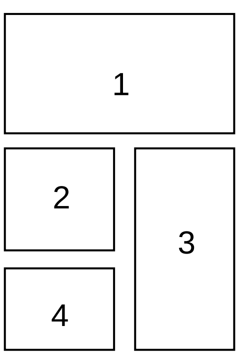
National Program 305

CROP PRODUCTION

ACCOMPLISHMENT REPORT 2007-2011

Captions of front page photos:



1. ARS research enables variable-rate aerial application of pesticides, fertilizers, and harvest aides to row-crops in field zones that require different amounts of spray material while minimizing off-target drift under different atmospheric conditions. *Photo by Steve Thomson/ARS*

2. The brown marmorated stink bug, a recently introduced invasive insect, has developed into a significant pest to tree fruit and vegetable crops in the Mid-Atlantic area. *Photo by ARS Kearneysville*.

3. Experimental honey bee colonies set in a California almond orchard. Almonds alone use 60 percent or more of all honey bee colonies in the United States each year. *Photo by Robert Danka/ARS.*

4. An alfalfa leafcutting bee (*Megachile rotundata*) on an alfalfa flower. *Photo by Peggy Greb/ARS.*

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NATIONAL PROGRAM 305
Crop Production

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BACKGROUND AND GENERAL INFORMATION

National Program 305 – Crop Production has been described by some as the crop research program within the USDA Agricultural Research Service 'where the rubber meets the road.' This national program builds on other ARS research that develops better crop varieties and devises ways to keep them safe from diseases and pests and applies information to develop ways to bring those crops to the field and produce better yields with fewer amounts of fertilizers, pesticides, and herbicides. This is the home of research dedicated to solving the field-scale challenges facing U.S. producers, including the critical area of plant pollinators.

The research conducted by the scientists involved in NP 305 seeks to enhance American agricultural productivity and sustainability; to ensure a high quality and safe supply of food, fiber, feed, ornamentals, and industrial products for the nation; and do so in a way that protects the environment. Maintaining U.S. agricultural competitiveness is a continuing challenge to provide economically viable and environmentally sound sustainable crop production systems, while meeting the increased U.S. and world demand for agricultural products. Sustainable production dictates that agricultural practices benefit the producer, the worker, the consumer, and the general public. Management practices must be economical, while safeguarding surrounding ecosystems. New mechanization technologies must promote a safe work environment, a more efficient system of production, and the production and processing of a higher quality product.

The mission of NP305 focuses on conducting the research to address these challenges, and those of emerging problems as needed, such as the recent outbreaks of colony collapse disorder (CCD) of bees and the brown marmorated stink bug.

As this report documents, during 2007-2011, NP 305 has made significant contributions to U.S. crop production, in terms of the number and quality of accomplishments as well as the breadth of issues addressed. ARS scientists have developed improved nutrient, water, and pest management strategies; decision support software and models; new sensors and mechanization technologies; safer and more efficient aerial and ground-based spray application technologies; strategies to expand market niches; and new production systems. These significant advances and research products are being used by agricultural practitioners, researchers, federal regulatory agencies, and agriculture affiliated entrepreneurs.

As detailed in Appendix 1, NP 305 consists of 24 active projects located in 14 different states. The 71 scientists working in NP 305 are a multi-disciplinary group, and most are specialists in entomology, plant physiology, plant pathology, or agricultural engineering. Significant contributions to NP 305 also come through multidisciplinary teams of scientists with specialties in genetics, agronomy, horticulture, food technology, and meteorology.

PLANNING AND COORDINATION FOR THE NP 305 5-YEAR CYCLE

Customer and stakeholder interactions and research coordination play key roles in helping ARS' National Program Leaders (NPLs) guide NP 305 research. NP 305 researchers and administrators held a workshop in February 2007 to engage customers, stakeholders, and research partners in identifying major crop production issues and priorities that would be a match for the resources and expertise of ARS scientists. Incorporating input from customer/stakeholder interactions, the NPLs' knowledge of the science subject matter, and input from other ARS scientists, the writing team identified the priority needs that could be realistically addressed with ARS resources and base funding. These individual research needs were aggregated into problem statements under each of the two research components. The final Action Plan guided development of new individual NP 305 research projects that began the current 5-year research cycle in 2007.

The individual Project Plans include statements about the agricultural problem being addressed; the anticipated products to be generated; the planned research contributions for mitigating or solving the larger NP 305 Problem Statements; and timelines and milestones for measuring progress toward achieving project objectives. In compliance with the Agricultural Research, Extension, and Education Reform Act of 1998, each of the 24 individual Project Plans were evaluated for scientific quality and feasibility by external peer review panels. Project Plans were subsequently revised in accordance with recommendations of the review panel before implementation. The next 5-year research cycle for NP 305 will begin with a new Action Plan to be written in June-July 2012, and new project plans developed in the early part of 2013.

ARS NPLs function as the NP 305 leadership team that coordinates and plans research by the 14 research units (laboratories) located throughout the United States; there are also projects at five research units with other national programs that contribute to the goals of NP 305. These NP 305 NPL team also coordinate NP 305 activities with other national programs and with other outside agencies and departments. Some of the interagency research coordination associated with NP 305 was conducted through the Federal Colony Collapse Disorder Steering Committee (which includes representatives of USDA National Institute of Food and Agriculture (NIFA); USDA Animal and Plant Health Inspection Service (APHIS); USDA Natural Resources Conservation Service (NRCS); USDA National Agricultural Statistics Service (NASS); and the U.S. Environmental Protection Agency (EPA)); the Federal Interagency Committee for Invasive Terrestrial Animals and Pathogens; the USDA Research, Education, and Economics Specialty Crop Research Initiative Implementation Planning Team (with representatives from USDA Economic Research Service (ERS), NASS, NIFA, EPA; and the Office of Science and Technology Policy (OSTP) Interagency Working Group on Scientific Collections.

STRUCTURE OF NATIONAL PROGRAM 305

Given the discrete nature of the production systems research in this National Program, the NP 305 Action Plan (2007-2012) is divided into two distinct Components – Integrated Sustainable Crop Production Systems and Bees and Pollination. There is little crossover collaboration between projects in the two Components because of the nature of their research goals and methods. However, the two components taken together, and in concert with other national programs, strive to achieve breakthroughs in the understanding and response to challenges and opportunities presented in the production of the Nation's food, fiber, fuel, ornamental, and feed crops.

Component 1: Integrated Sustainable Crop Production Systems.

This component encompasses ARS' efforts to improve existing, or develop new production systems for many traditional and potential new crops. These enterprises are complex and depend on highly integrated management components that address crop production and protection, resource management, and mechanization. New technologies must address the need for lower-cost, higher-efficiency inputs that foster conservation of energy and natural resources, while maintaining profitability and promoting environmental sustainability. Furthermore, production systems must address the needs of small, intermediate, and large farming enterprises, including those using field, greenhouse, orchard, and vineyard production platforms, through conventional, organic, or controlled environments.

Given that the production systems of many crops vary by plant type, geography, and use, the research in this Component is further focused into three main production areas: Annual crop production systems; Perennial crop production systems; and Greenhouse, high tunnel, and nursery production systems.

Component 2: Bees and Pollination.

The research in this component strives to ensure pollination of the nation's bee-dependent crops – particularly fruits, nuts, berries, melons, vegetables, and alfalfa forage – and to safeguard the beekeeping industry and its production of honey and other hive products. Only a few species of bees have been adapted for commercial pollination, and their health and management are essential to agricultural production. Native pollinators are in decline and the nation's chief pollinator, the honey bee (*Apis*), has recently been decimated by colony collapse disorder, a recent and very serious threat to the survival of the industry. Currently non-honey bee pollinators are not cost-effective for agricultural use and new management tools are needed for this to change. To provide for pollination by honey bees, ARS research has focused on improving honey bee health and methods of crop pollination, and developing new and improved tools based on genomics, genetics, physiology, germplasm preservation, and cell culture. To safeguard and develop non-*Apis* pollinators, ARS scientists seek to improve the management systems to protect both the supply and biodiversity of agricultural pollinators and pollinators of native plants used in land conservation and restoration.

RELATIONSHIP OF NP 305 TO OTHER NATIONAL PROGRAMS

ARS research is organized into four national program areas that include Nutrition, Food Safety, and Quality; Animal Production and Protection; Natural Resources and Sustainable Agricultural Systems; and Crop Production and Protection (CPP). NP 305 is one of five national programs within CPP, and research conducted under this national program often contributes to attaining the goals of other national programs by solving production issues that address:

- NP 301 – Plant Genetic Resources, Genomics and Genetic Improvement (Crop breeding, genetics, genomics, genome databases, and bioinformatics, germplasm conservation and characterization).
- NP 303 – Plant Diseases.
- NP 304 – Crop Protection and Quarantine (Insect and weed pest issues, trade).
- NP 308 – Methyl Bromide Alternatives (Disease and pest control method alternatives to using methyl bromide)

The research encompassed by NP 305 is crucial to developing safe, secure, and efficient crop production systems. NP 305 scientists attempt to find optimal production methods for new varieties and to integrate the control of weeds, pests, and disease that ultimately lead to healthier crops with higher yield and quality. On the flip side, successful integrated production methods developed within NP 305 add to the knowledge of scientists in other CPP national programs in developing management approaches for pests, weeds, and diseases, and in the development of new crop varieties tailored for specific production techniques and climates.

NP 305 also contributes to other national programs outside CPP, specifically to National Program 215, Pasture, Forage and Rangeland Systems, and NP 216, Agricultural System Competitiveness and Sustainability, in the Natural Resources and Sustainable Agricultural Systems program area. Research from NP 305 on non-*Apis* bees help to provide sustainable supplies of pollinators for alfalfa and native/wildland seed grown by farmers that contribute to the NP 215 goals of enhancing the conservation and restoration of ecosystems and agroecosystems. For NP 216, the field-scale research in NP 305 contributes to that national program's landscape/watershed-scale goal of enhancing productivity, profitability, energy efficiency, and natural resource stewardship for different kinds and sizes of American farms.

In addition, NP 305 accomplishments are often achieved in close cooperation with public and private sector collaborators. Many NP 305 researchers are located on land-grant university campuses, with the association strengthening research capacities of both institutions. These partnerships enable ARS researchers to participate in and contribute to the training of America's future agricultural researchers and entrepreneurs.

HOW THIS REPORT WAS CONSTRUCTED AND WHAT IT REFLECTS

In this report, NP 305 accomplishments and their impact are organized and presented according to the Action Plan research Components, their constituent Subcomponents, and Problem Statements as described in the 2007-2011 Action Plan. Accomplishments are reported beneath the relevant problem statements with specific reference to outcomes and impacts including products, groups of products, or other themes. Since fiscal resources and research capacity are not uniformly distributed among the components, more accomplishments may be reported under some problem statements than others.

The NP305 Accomplishment Report is a distillation of some of the most significant research accomplishments of the past 5 years achieved by scientists working in this national program. By necessity, it is a 5-year snapshot that encompasses on-going research and the early benefits of that research. In a report on the value of agricultural research, ERS pointed out that the benefits of that research (www.ers.usda.gov/publications/eb10/eb10.pdf) usually trail the completion of the research by 5 to 10 years before the technology is completely developed, transferred, and adopted by end users. Figure 1, taken from that ERS report shows the flow of research costs and benefits over a 30-year timeline. It is important to recognize that benefits often increase over a number of years after the completion of the research, remain constant for a significant time before declining as newer technologies become available.

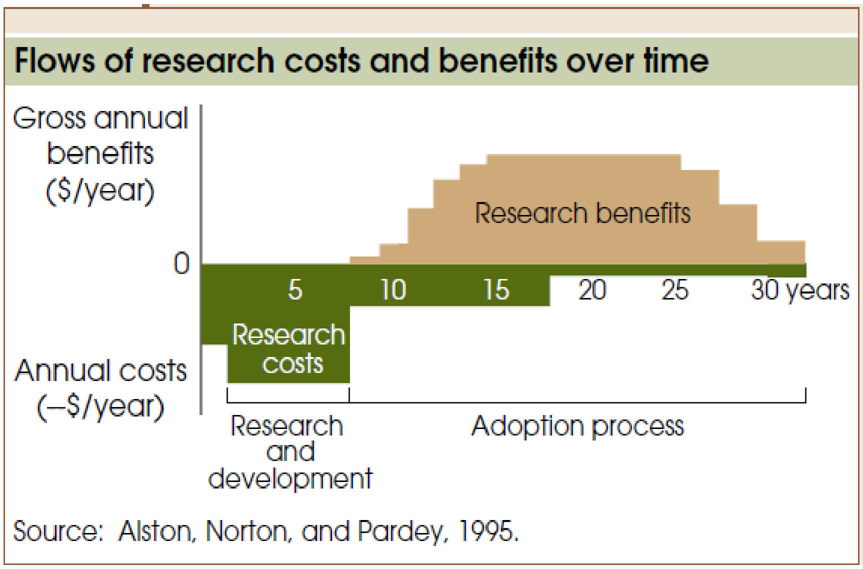

Figure 1: Flows of research costs and benefits over time.
SOURCE: USDA ERS, *Economic Returns to Public Agricultural Research*; Economic Brief Number 10 • September 2007

Thus in the case of NP 305, many of the accomplishments and breakthroughs in this report do not necessarily show immediate impact, though that should not detract from the significance of those findings. The content of this report is mostly derived from the annual reports of the NP 305 projects from the past 5 years. This report stresses the impacts of those accomplishments and, where relevant, cites key publications or Web links documenting those accomplishments.

A list of the 24 research projects in this National Program is in Appendix 1, organized by ARS project number under the associated Action Plan Component. Publications authored by researchers contributing to NP 305 are listed by ARS project number in Appendix 2. Appendix 3 contains selected supporting information and documentation supporting the accomplishments and impact of NP 305 research.

This report was prepared for an external (to USDA) retrospective review of NP 305 to assess how well this National Program attained its projected goals, as outlined in its current Action Plan. Accordingly, the purpose of the retrospective review is not to judge the performance of individual NP 305 research projects, but to gauge the overall impact of the National Program. Consequently, the report does not attempt to catalogue all the individual accomplishments reported by the scientists assigned to NP 305's research projects.

In the same way that only selected accomplishments are reported, details of those accomplishments are selected and/or summarized to illustrate the overall variety of products and knowledge generated by this national program. In some cases, the results from an individual study that focused on one crop are described, while in other instances, similar research or achievements are aggregated across the National Program. Individual researchers or projects are not identified by name in the narrative text; instead, their achievements are described in the context of contributions towards accomplishing the National Program's stated commitments to U.S. agriculture.

COMPONENT 1: Integrated Sustainable Crop Production Systems

In this Component, ARS scientists focused on key factors limiting crop production in economically important annual, perennial, nursery, protected environment, and containerized crop production systems. Component 1 research is about integration of biological factors (plants, pests, and beneficial organisms), physical factors (soil texture, water, sunlight, and nutrients), and/or machines at various scales from within a plant to across a field. This research included traditional high-input production agriculture, low-input systems, organic systems, and new crops for both small and large operations. Products of Component 1 include new knowledge; improved management strategies; models and decision support aids; and new or improved sensors and equipment.

A summary of significant accomplishments by ARS researchers, often made in collaboration with university and industry scientists, are highlighted in the following pages. The outputs of this research are used by growers, extension specialists, and Federal, State, university, and industry researchers. Outcomes from customer use of ARS-developed products can be short-term outcomes (changes in knowledge), mid-term (changes in behavior or decision-making), or long-term (changes in a condition). Some floriculture facilities are evaluating new knowledge from ARS research on the interactions between supplemental CO_2, plant nutrient demand, and plant response to abiotic stresses for use in their seedling or plug production – a short-term outcome. Particle film technology developed in NP 305 is now being used in the United States on 35 percent of apples, 25 percent of pear, and 10 percent of walnut – a mid-term outcome. Nearly all new blueberry fields in the Pacific Northwest now use drip irrigation following best irrigation practices developed in NP 305 research that demonstrated reduced inputs, increased growth, and early production, along with reduced root rot – a long-term outcome. Previous to that research, 90 percent of the blueberry fields had been sprinkler irrigated, which was more costly for growers. The 5-year timeframe of this report dictates that most of the outcomes reported here will be in the short-term or mid-term categories.

ARS projects in the following 14 locations contributed directly to NP305 research in this Component: Davis, California; Byron, Georgia; Houma, Louisiana; Beltsville, Maryland; Morris, Minnesota; Stoneville and Poplarville, Mississippi; Wooster and Toledo, Ohio; Lane, Oklahoma; Corvallis, Oregon; College Station, Texas; Kearneysville, West Virginia; and Mayagüez, Puerto Rico. ARS projects in four other locations also contributed to NP305 research including: Maricopa, Arizona; Dawson, Georgia; Florence, South Carolina; and Prosser, Washington.

The NP 305 Action Plan identified 54 Anticipated Products in Component 1 that were expected to result from this research. These Anticipated Products now serve to help measure the national program's progress during the past 5 years in meeting the needs of crop researchers and producers. Under each of the Problem Statements, the report will list the accomplishments that highlight our progress in meeting the Anticipated Products for that Problem Statement. Because of the nature of the research, many accomplishments may contribute to more than one Anticipated Product.

SUBCOMPONENT 1A: ANNUAL CROPPING SYSTEMS

This subcomponent focuses on agronomic row crops, as well as specialty crop production systems grown for a single season. ARS research addressed management of water, nutrients, and pests; early season cold damage; extension of the production season; and production systems for new crops. A significant portion of the annual crop research effort focused on the development or improvement of ground- and aerial-based spray application technologies. Crops ranged from peanut and cotton to strawberry and peppers to cuphea and lesquerella.

PROBLEM STATEMENT 1A.1: *Develop integrated strategies for soil, water, and nutrient management for optimal yield and economic returns in annual cropping systems.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Improved understanding of crop nutrition requirements for specific annual crops grown in conventional and organic systems.
2. Improved water management strategies with better decision support systems for irrigated and rain-fed cropping systems.
3. Improved residue management and tillage systems that promote infiltration and water use efficiency while reducing soil erosion.

PROBLEM STATEMENT 1A.1 SELECTED ACCOMPLISHMENTS:

Nitrogen in groundwater sufficient for some crops. The nitrogen in fertilizers applied to crops has moved into the groundwater in some agricultural regions. Growers irrigating with groundwater must consider groundwater nitrogen content to avoid over application of nitrogen. ARS researchers in Corvallis, Oregon, determined that nitrogen in groundwater irrigation water is often adequate for maximizing growth from transplanting to fruit-set in processing tomato. This finding has been incorporated into best management practices for tomato production and provides a profitable approach to reduce nitrogen fertilizer application while protecting groundwater resources from further nitrate contamination.

Machado, R.M.A., D.R. Bryla, M.L. Veríssimo, A.M. Sena, and M.R.G. Oliveira. 2008. Nitrogen requirements for growth and early fruit development of drip-irrigated processing tomato (*Lycopersicum esculentum* Mill.) in Portugal. J. Food Agr. Environ. 6:215–218.

Nitrogen affects severity of anthracnose crown rot in strawberry. Anthracnose crown rot is a serious disease of strawberries throughout the southern United States. ARS researchers in Poplarville, Mississippi, found that strawberry plants receiving substantial nitrogen fertilizer have higher anthracnose crown rot disease ratings than plants receiving little or no nitrogen. Disease was less severe in plants treated with nitrate nitrogen than in plants receiving ammonium nitrogen. This research is enabling growers to better manage strawberries to reduce anthracnose crown rot.

Smith, B. J. 2009. Nitrogen fertilizer affects the severity of anthracnose crown rot disease of greenhouse grown strawberries. Online. Plant Health Progress DOI:10.1094/PHP 2009 0609 01 RS.

Improved irrigation strategies in vegetables and row crops. Water is an increasingly precious resource requiring wiser agricultural use, and improvements are needed for irrigation scheduling of annual vegetable and row-crops. ARS scientists in Parlier, California, and Corvallis, Oregon, developed daily coefficients of water uptake for crops, such as broccoli, iceberg lettuce, bell pepper, and garlic to facilitate irrigation scheduling. These coefficients, after being added to the California Irrigation Management Information System, are helping growers better manage water resources and costs and have reduced irrigation water use by at least 10 percent, saving California farmers at least 221 million cubic meters of water per year. In Dawson, Georgia, ARS researchers refined subsurface drip irrigation strategies for cotton, peanut, and corn in the southeastern United States and identified the relative economics of different irrigation strategies. The subsurface drip strategy for row-crops represents a new irrigation strategy for economically producing row crops in farmlands previously not suited for irrigation. This method was adopted by the NRCS Environmental Quality Incentives Program that provides financial incentives to help farmers meet environmental regulations. Farmers in the western and southeastern United States are successfully applying these irrigation strategies to increase production efficiency or to reduce water use and cost.

Bryla, D.R., T.J. Trout, and J.E. Ayars. 2010. Weighing lysimeters for developing crop coefficients and efficient irrigation practices for vegetable crops. HortScience 45:1597–1604.

Nuti, R.C., Lamb, M.C., Sorensen, R.B., Truman, C.C. 2009. Agronomic and economic response to furrow diking tillage in irrigated and non-irrigated cotton (*Gossypium hirsutum* L.). Agricultural Water Management. 96:1078-1084.

PROBLEM STATEMENT 1A.2: *Develop automation and mechanization systems and strategies to optimize pest management, improve crop yield and quality, reduce worker exposure, and protect the environment while maintaining a profitable production system.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. New or improved automated and robotic systems for production, harvesting, and processing of agricultural crops.
2. Protocols using remote sensing technologies to better manage crop systems for water stress, nutrient management, and pest control.
3. Efficacious, reliable, and sustainable pest management systems.
4. A greater understanding of relationships between application parameters and biological and environmental impacts.
5. Application systems that combine optimal nozzle, adjuvants, formulation, and application protocols with real-time weather monitoring to reduce the likelihood of damage to non-target plants, animals, and water resources.
6. Weather monitoring systems that facilitate deciding if, when, and how chemical agents are to be applied over a wide geographical area.
7. A pilot warning system to alert pilots to aerial spraying above a preset altitude.
8. Development of application technologies to deliver organic products.

PROBLEM STATEMENT 1A.2 SELECTED ACCOMPLISHMENTS:

Fusion of remotely sensed data enhances detection of cotton plants. Aerial and ground-based remotely sensed data have been available for detecting the type and vigor/health of vegetation over large areas, but techniques for accurate discrimination between plant species were lacking. ARS scientists in College Station, Texas, developed a remote sensing strategy that uses a multi-sensor data fusion technique to analyze aerial and ground-based spectral reflectance data, independently and then combined, to accurately discriminate between cotton plants and other crop types. This strategy benefits the Boll Weevil Eradication Program by detecting cotton plants harboring weevils that would otherwise go unnoticed and untreated; thus improving control of the boll weevil and increasing cotton yield. Based on these findings, Cotton Inc. is currently funding several projects related to identification and subsequent elimination of volunteer cotton in eradication zones.

Zhang H, Lan Y, Lacey R, Hoffmann W C, Huang Y. 2009. Analysis of vegetation indices derived from aerial multispectral and ground hyperspectral data. Int J Agric & Biol Eng, 2(3):1-7.

New imaging technologies for managing weed and disease pests of agronomic row-crops. ARS researchers in Stoneville, Mississippi, and College Station, Texas, adapted multispectral and hyperspectral imaging for mounting on aircraft that enable rapid and ready detection of herbicide and disease damage (e.g., cotton root rot). The airborne multispectral platform – a promising new tool for remote sensing – can serve as a management tool to limit crop loss via efficient detection and assessment of disease and pest infestations. This research was the first to demonstrate that useful data for pest control can be obtained from standard agricultural aircraft equipped with a turnkey imaging system. Manufacturers are now designing multispectral systems for protecting crops in an environmentally sensitive manner.

Huang, Y., Thomson, S.J. Ortiz B.V., Reddy K.N., Ding W., Zablotowicz R.M., and Bright Jr J.R.. 2010. Airborne remote sensing assessment of the damage to cotton caused by spray drift from aerially applied glyphosate through spray deposition measurements. Journal of Biosystems Engineering. 107:212-220.

Lan Y., Zhang, H., Lacey, R., Hoffmann, W.C. and Wu, W. 2009. Development of an Integrated Sensor and Instrumentation System for Measuring Crop Conditions. Agricultural Engineering International: the CIGR E-journal. Manuscript IT 08 1115. Vol. XI. April.

Canopy opener maximizes spray application efficiency. Conventional boom sprayers inadequately deliver pesticides to the inner foliage of dense canopy plants, such as soybean. ARS researchers in Wooster, Ohio, designed a mechanical ‘canopy opener’ device mounted ahead of the nozzles on a conventional boom sprayer. When the sprayer moves, the device pushes the top part of the canopy forward and permits effective pesticide delivery into lower parts of the plants. The researchers also developed mathematical models to help optimize the device design and placement on the sprayers. The device is inexpensive in design and can be easily built and integrated into conventional boom sprayers. The technique is being used by other researchers to deliver the best possible spray penetration and coverage for controlling insects, diseases, and weeds for soybeans, vegetables, and ornamental nurseries.

Zhu, H., Brazee, R.D., Fox, R.D., Derksen, R.C., Ozkan, H.E. 2008. Development of a canopy opener to improve spray deposition and coverage inside soybean canopies: Mathematical models to assist opener development. Transactions of the ASABE. 51(6): 1905-1912.

New air-assistance ground rig spray application technology. Certain vertical or horizontal surfaces of narrow-row crop canopies are often difficult to treat due to lack of spray penetration into the canopy. ARS researchers in Wooster, Ohio, found that small-droplet applications, designed to improve canopy coverage, effectively protect soybean target areas when air-assistance provides extra energy to penetrate the lower canopy. Air-assisted delivery is less effective at treating the upper wheat canopy, whereas twin-fan nozzles enabled high deposits on vertical plant surfaces (heads and stems). In the bell pepper canopy, air-assisted delivery deposits more spray on fruit than conventional approaches and enabled improved spray coverage deep within canopies and on lower leaf surfaces, which are hard to protect. This work demonstrates the advantage of air-assisted, low-drift nozzle technology for improved control of pests in bell peppers and row-type vegetable crops, and documents how simple modifications to conventional sprayers, such as using twin-pattern nozzles, can deliver spray to target areas with a vertical orientation.

Ozkan, H.E., Paul, P.A., Derksen, R.C.**,** Zhu, H. 2012. Influence of application equipment on deposition of spray droplets in wheat canopy. International Advances in Pesticide Application -- Aspects of Applied Biology. 114:317-324.

Derksen, R.C., Zhu, H., Ozkan, H.E., Hammond, R., Dorrance, A. 2008. Determining the influence of spray quality, nozzle type, spray volume, and air-assisted application strategies on deposition of pesticides in soybean canopy. Trans. of the ASABE. 51(5):1529-1537.

Guidelines for controlling Fusarium by aerial applicators. Fusarium head blight is a major wheat and barley disease throughout the United States. Although aerial fungicide application provides a rapid method of containing Fusarium head blight outbreaks, optimized methods are needed to maximize spray deposition on wheat heads. ARS researchers in College Station, Texas, developed optimization protocols for aircraft spray deposition with conventional hydraulic nozzles, electrostatic nozzles, and rotary atomizers. Hydraulic nozzles set at the lowest spray rate and largest droplet size, along with electrostatic spray nozzles, maximize spray deposits on wheat heads. This research establishes guidelines for aerial fungicide applications that increase deposition on wheat heads to maximize disease control, while minimizing off-target deposition and potential adverse environmental impacts.

Fritz, B. K., Hoffmann, W. C., Martin, D. E. Thomson, S. J. 2007. Aerial application methods for increasing spray deposition in wheat heads. Appl. Eng. Agric. 23(6):709-715.

Assessment of drift reduction technologies. New technologies are needed to efficiently monitor the dispersal of very small droplets over large sampling areas and to evaluate insecticide treatment efficacy. ARS researchers in College Station, Texas, and Stoneville, Mississippi, definitively assessed protocols for testing drift reduction technologies. This involved both low- and high-speed wind tunnel testing for ground and aerial applications, including assessments of various spray nozzles and associated droplet sizes. The first ‘spread factor equations’ were developed to accurately describe how ambient conditions and formulations affect the actual size of spray droplets and the potential for drift or penetration. Optimal spray droplet sizes and spray rates were identified to enable the most effective delivery of spray products against cotton and corn pests. This research provides applicators with sound information, protocols, and new technologies for assuring compliance with evolving regulatory requirements. In addition, the research provides for total accounting for applied materials and increases understanding of transport and deposition of agricultural sprays. Approximately 1,300 aerial applicators (based on Web site downloads) consult this information to select appropriate spray nozzle setups and aircraft settings to ensure maximum product delivery to the targeted pest. Data collected in some of these tests were used in the registration package for a new insecticide, Zenivex, submitted to the EPA. ARS scientists' findings and expertise are contributing to development of the Drift Reduction Technology program and regulations in coordination with the EPA.

Thomson, S.J., Lyn, M.E. 2011. Environmental and spray mixture effects on droplet size represented by water sensitive paper used in spray studies. Trans. ASABE. 54(3):803-807.

Hoffmann, W.C., Fritz, B.K., Lan, Y. 2009. Evaluation of a proposed drift reduction technology (DRT) high-speed wind tunnel testing protocol. J. ASTM Int. 6(4):1-12.

New aerial variable-rate application technology for pesticides and fertilizers. Variable-rate technologies enable tailoring application of pesticides and fertilizers, but depend on accumulation of vast amounts of remotely sensed multispectral imaging from aircraft or satellites. Although variable rate aerial application systems are on the market, data are insufficient to determine if the technologies function adequately. ARS researchers in Stoneville, Mississippi, and College Station, Texas, developed a cockpit-compatible, variable-rate aerial application system controller:

- That changes flow-rates relative to ground speed;
- Uses new methodologies, technologies, and protocols to create accurate user-friendly, variable-rate field-based prescription maps; and
- That has sensing systems well-suited for use on unmanned aerial vehicle to an accuracy of 20 feet.

This research provides critical information on how close an applicator aircraft can fly to neighboring fields and enables automatic spray shut-off to prevent off-target application. These tools will enable farmers to manage row-crops with accurate variable-rate aerial application of pesticides and fertilizers and enable aerial applicators to reduce chemical input costs, application time, aircraft fuel expenditures, and potentially negative environmental impacts.

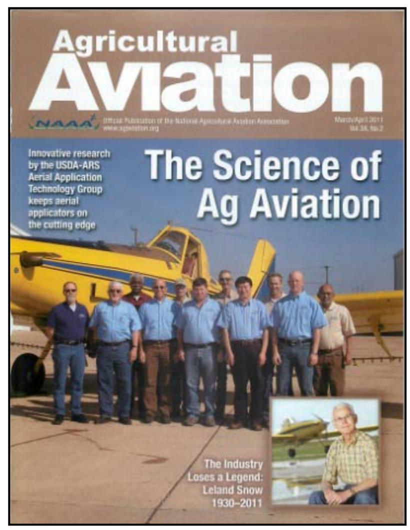

Figure 2: ARS' innovative research on aerial spray applications and technologies was featured in the March/April 2011 issue of *Agricultural Aviation.*

Thomson, S.J., Huang, Y., Hanks, J.E., Martin, D.E., Smith, L.A. 2010. Improving flow response of a variable-rate aerial application system by interactive refinement. Computers and Electronics in Agriculture 73(1):99-104.

Huang, Y., Hoffmann, W.C., Lan, Y., Wu, W., Fritz, B.K. 2009. Development of a spray system for an unmanned aerial vehicle platform. Applied Engineering in Agriculture. 25(6):803-809.

New spray nozzle technology improves herbicide application efficiency. New spray nozzles have potential for increasing deposition within a crop canopy with a commensurate reduction in off-target drift damage to neighboring crops. ARS researchers in College Station, Texas, and Stoneville, Mississippi, developed deposition/efficacy information for glyphosate, a widely used herbicide, applied through conventional hydraulic nozzles and compared to new flat fan nozzles, new rotary atomizers, and electrostatic nozzles. The findings demonstrated the superiority of the new nozzles, which increased the efficacy of herbicide application. Biological responses measured downwind differed among crops, with corn being the most sensitive to drift, followed by soybean and cotton. Inferred glyphosate concentration and associated action thresholds were determined from the degree of plant injury by off-target drift, providing important information for aerial applicators to improve efficacy, reduce glyphosate use per acre, and limit non-target crop damage by drift. This is the first quantification of adjacent field crop damage due to low concentration exposure of glyphosate. Because glyphosate is the most frequently applied herbicide worldwide, this work has potential broad impact when applied to aerial spray applications. Additionally, proper nozzle selection is enabling applicators to reduce the amount of liquid spray and save aircraft energy consumption, application time and costs, and promote environmental stewardship.

Ding, W., K. N. Reddy, L. J. Krutz, S. J. Thomson, Y. Huang, and R. M. Zablotowicz. 2010. Biological response of soybean and cotton to aerial glyphosate drift. Journal of Crop Improvement. 25:291-302.

Huang, Y. and S.J. Thomson. 2011. Characterization of in-swath spray deposition for CP-11TT flat-fan nozzle used in low-volume aerial application of crop production and protection materials. Transactions of the ASABE. 54(6):1973-1979.

Adverse weather conditions identified for preventing off-target movement of spray. Aerial applicators should not spray during unfavorable atmospheric conditions, which include both atmospheric temperature inversions and, surprisingly, stable atmosphere. Spray application within a temperature inversion layer can drift for miles causing serious damage to non-target plants. ARS researchers in College Station, Texas, and Stoneville, Mississippi, found that spraying in the mid-southern United States should not occur at wind speeds lower than 3 mph, or during any time when there is less than 3 to 4° F temperature rise from the morning low. The time window when spraying is permissible is shortened by about 2 hours under cooler weather conditions. This research is helping farmers maximize the benefit of pesticide applications while minimizing environmental impact, as these are the first guidelines for those environmental conditions. These findings/guidelines contributed to a body of information that led to State regulations in Arkansas. Other states are considering adopting these guidelines as well.

Fritz, B. K., Hoffmann, W. C., Lan, Y., Thomson, S., Huang, Y. 2008. Low-level atmospheric temperature inversions: characteristics and impacts on aerial applications. Agric. Eng. Int.: the CIGR eJournal. Manuscript PM 08 001. Vol. X.

A new cockpit laser-based pilot warning system for determining height of spray release. Determination of spray release height is critical as it is one of the greatest influences on the propensity for off-target drift from aerial application. ARS researchers in Stoneville, Mississippi, developed a new laser-based data logging and monitoring system to determine height of spray release from agricultural aircraft so that aerial applicators can stay within a narrow range of heights, thus improving precision and reducing off-target drift. This pioneering system is now marketed for application aircraft to enable pilots to stay within a range of application heights for minimal off-target drift.

Huang, Y. and Thomson, S.J. 2011. Characterization of spray deposition and drift from a low drift nozzle for aerial application at different application altitudes. International Journal of Agricultural and Biological Engineering. 4(4):28-33.

Air-propelled abrasive grit for organic post-emergence weed control. There is an inadequate arsenal of economically viable products/tools for effectively controlling weeds in organic annual crop farming operations. ARS researchers in Morris, Minnesota, in collaboration with AgResearch-New Zealand and South Dakota State University, developed the new technique of applying abrasive grit propelled by compressed air for post-emergence weed control in row crops. Organic growers and stakeholder groups are interested in developing this technology for field-scale use. A four-row implement prototype is under development that propels corn cob grit (or other grit, such as lime gravel for simultaneous liming) using compressed air through pairs of nozzles aimed at either side of a corn or soybean row.

Forcella, F., James, T. and Rahman, A. 2011. Post-emergence weed control through abrasion with an approved organic fertilizer. Renewable Agric. Food Systems. 26:31-37.

Improved techniques/protocols for spray applications to control pests of humans. Effective control of insects that vector human diseases requires precise spray application techniques. ARS researchers in College Station, Texas, determined the effects of wind speed and screening material on spray droplet penetration into bioassay cages. This research provided critical data and guidance on the impact of wind speed and cage design/construction on spray droplet movement into bioassay cages. A system for monitoring the flight movement of mosquitoes in the wind tunnel was also developed. These sampling techniques and protocols provide major advancements in the predictive value of laboratory and field test data guiding spray application to control disease-transmitting arthropods. These results are being incorporated into Mosquito Abatement District testing protocols and will also impact data interpretation by chemical companies and the EPA.

Fritz, B.K., Hoffmann, W.C., Bonds, J.A.S., Farooq, M. 2011. Volumetric collection efficiency and droplet size accuracy of rotating impactors. Trans. ASABE 54(1):57-63.

Hoffmann, W.C., Jank, P.C., Klun, J.A., Fritz, B.K. 2010. Quantifying the movement of multiple insects using an optical insect counter. J. Amer. Mosq. Control Assoc. 26(2):167-171.

PROBLEM STATEMENT 1A.3: *Decision support systems to optimize pest management.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. An enhanced information database for improving crop management decision support systems and complex models.
2. Computer-based decision support systems and models that optimize pest management strategies.

3. User-friendly software products for weed phenology and optimization of herbicide application timing.
4. Decision tools that can be used to avoid spraying during conditions favorable for off-target movement of sprays.
5. Models for quantification of drift and associated deleterious effects during temperature inversions vs. non-inversion conditions.

PROBLEM STATEMENT 1A.3 SELECTED ACCOMPLISHMENTS:

Improved spray drift simulation model, technology, and techniques. Off-target movement of aerially applied sprays has the potential to damage neighboring crops. However, there are several different operating standards applicators can select to minimize the potential for off-target spray movement. ARS researchers in College Station, Texas, and Stoneville, Mississippi, used simulation software, computer drift models, wind tunnel, and laboratory studies to identify and document the level of drift and associated drift/off-target damage from aerial sprays over agricultural crop canopies, as well as the conditions that minimize drift. Pilots rely on these data to modify normal operational methods near field edges and under elevated wind speeds to reduce spray drift. These findings are being incorporated into an International Standards Organization (ISO) Standard for aerial application Best Management Practices.

Fritz, B.K., Hoffmann, W.C, Bagley, W.E. 2010. Effects of spray mixtures on droplet size under aerial application conditions and implications on drift. Appl. Engr. Agric. 26(1):21-29.

Huang, Y, W. Zhan, B. Fritz, S.J. Thomson, and A. Fang. 2010. Analysis of impact of various factors on downwind deposition using a simulation method. Journal of ASTM International. 7(6):1-10 Paper ID JAI102771.

Smart phone mobile applications for determining spray system performance. Application equipment for control of pests vectoring plant and animal diseases requires precise understanding of system performance. ARS researchers in College Station, Texas, developed a set of smart phone mobile applications (distributed as "vector sprays" on the Apple and Android app stores or at http://apmru.usda.gov/aerial/HomePage.htm) that provide a user friendly interface for determining spray system performance and set-up required to deliver specific droplet size sprays. Within 3 months of becoming publically available, the apps have been downloaded 518 times from users in 34 countries. The apps (http://itunes.apple.com/us/app/vector-sprays/id476010486?mt=8) help applicators worldwide to precisely setup and operate efficaciously.

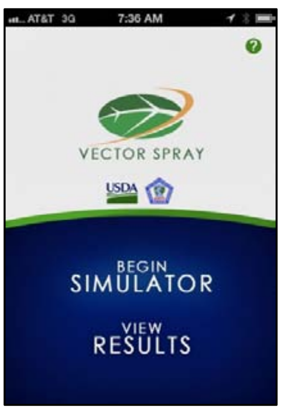

Figure 3: The Vector Spray smart phone application developed by ARS scientists is free through the ARS Web site and Apple and Android app stores.

Hoffmann, W.C., T.W. Walker, T. Gwinn, V.L. Smith, D. Szumlas, Y. Lan, and B.K. Fritz. 2009. Spray chararacterization of ultra-low volume sprayers typically used in vector control. J. Amer. Mosq. Control. 25(3):332-337.

Hoffmann, W. C., Walker, T. W., Martin, D. E., Barber, J. A. B., Gwinn, T. L., Smith, V., Szumlas, D., Lan, Y. and Fritz, B. K. 2007. Characterization of truck-mounted atomization equipment used in vector control. J. Am. Mosq. Control Assoc. 23(3):315-320.

Better control of weed pests via models. Several major weeds, such as common groundsel, giant ragweed, and giant foxtail, are serious problems in many crops, and their optimum control would benefit from improved approaches for determining when best to apply herbicides. ARS researchers in Morris, Minnesota, developed user-friendly, Web-based models that enable growers and consultants to predict the timing and extent of emergence of groundsel, early and late-emerging phenotypes of giant ragweed, and giant foxtail to improve pre- and post-emergence control of these weeds. These models assist farmers and crop advisors in making timely weed management decisions; thus, improving efficiency and reducing the cost of weed control. Several hundred copies of the software have been downloaded from the Web (www.ars.usda.gov/Services/docs.htm?docid=11787) and additional copies have been distributed in CD format. The models are primarily being used by crop consultants, but also by organic farmers, agri-chemical industry representatives, university classroom instructors, and extension educators.

McGiffen, M., Spokas, K., Forcella, F., Archer, D., Poppe, S. and Figueroa, R. 2008. Emergence prediction of common groundsel (*Senecio vulgaris*). Weed Sci. 56:58-65.

Schutte, B.J., Regnier, E.E., Harrison, S.K., Spokas, K.A. and Forcella, F. 2008. A hydrothermal seedling emergence model for giant ragweed (*Ambrosia trifida*). Weed Sci. 56:555-560.

Cardina, J., Herms, C.P., Herms, D.A. and Forcella, F. 2007. Evaluating phenological indicators for predicting giant foxtail (*Setaria faberi*) emergence. Weed Sci. 55:455-464.

PROBLEM STATEMENT 1A.4: *Develop crop production systems that are productive, profitable, and environmentally acceptable.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Improved region-specific cropping system practices for existing, new, and alternative crops.
2. Cropping systems that use remote sensing, global positioning systems (GPS), and geographic information system (GIS) data for prescription application of production and crop protection materials.
3. Methods for using remote sensing and spatial application inputs for optimizing crop quality.
4. Improved knowledge of how environment and production practices determine crop processing characteristics, flavor component quantities, and/or nutritional composition.
5. Knowledge of genetic and production practice interactions on food and fiber quality components.

PROBLEM STATEMENT 1A.4 SELECTED ACCOMPLISHMENTS:

New strategies for improving production and market expansion of mid-Atlantic Coast region strawberry industry. Strawberry producers within the mid-Atlantic coast region experience many challenges. ARS researchers in Kearneysville, West Virginia, and Beltsville, Maryland, found that when strawberry transplants are prepared in July and held uncovered in small containers until field planting in early September, more than 86 percent flower by mid-October. Transplants treated similarly, except held under red and blue nets during August, do not reflower until early January, demonstrating that a simple change in greenhouse management can delay bloom by several months, and enabling growers to better regulate production of spring and autumn strawberry crops. ARS researchers also developed novel production systems based on modification of runner tip size, plugging dates, and strawberry genotypes for either summer-fruiting or autumn-fruiting strawberries. These new strategies enable farmers to better develop new strawberry production systems tailored to their specific needs and circumstances while helping regional producers tap into new marketing niches and windows and expand markets.

Takeda, F., Glenn, D.M., Callahan, A., Slovin, J. and Stutte, G.W. 2010 Delaying flowering in short-day strawberry transplants with photoselective nets. Int. J. Fruit Science 10:134-142.

Takeda, F., Glenn, D.M., and Stutte, G.W. 2008. Red light affects flowering under long days in a short-day strawberry cultivar. HortScience 43:2245-2247.

Production systems for new crops in the upper Midwest. Farmers in the upper Midwest need economically and environmentally sustainable crops to improve the profitability of their farms. ARS researchers in Morris, Minnesota, discovered that camelina, an alternative oilseed that can serve as feedstock for biofuels, can be successfully grown as a low-input cash cover crop in the northern Corn Belt. Greatest seed and oil yields were achieved by planting in late September to early October into no-tilled soil without herbicide and only a low amount of nitrogen fertilizer. Winter camelina was harvested early enough to enable production of a second seasonal crop. This new crop and cropping strategy provides farmers with an additional economic opportunity and information for wiser management decisions for producing camelina. ARS researchers found that another new crop, cuphea, requires little nitrogen compared to corn. Residual soil nitrogen after corn or soybean harvests is sufficient for a subsequent cuphea crop. Cuphea harvest by swathing is cheaper than direct combining because it reduces seed drying costs. Corn and soybean were more profitable when grown the year following cuphea than when they were each grown year after year. These findings are included in the growers' guide supplied by Technology Crops International (TCI), a specialty seed company that contracts with farmers in the northern United States, Canada, and northern Europe for cuphea seed production. SarTec Corporation/Ever Cat Fuels, a biodiesel manufacturer, is contracting with farmers to grow around 2,500 acres of camelina in Minnesota for biodiesel feedstock in 2012, and TCI has contracted with farmers to grow cuphea in the upper Midwest, Canada, and Europe. This research is stimulating additional funding from Procter and Gamble, Aveda Corp. (Estée Lauder), TCI, PepsiCo, ADM, Solazyme, FloraTech and DARPA (DoD), while Aveda Corp. is developing new products from cuphea oil in place of imported oil.

Figure 4: This May/June 2008 cover of Agronomy Journal highlights ARS research for cuphea as a viable (and less intensive/expensive) alternative oilseed crop for manufacturing cosmetics and quality soaps. The crop is commercially grown in the upper Midwest.

Gesch, R.W. and Cermak S. 2011. Sowing date and tillage effects on fall-seeded camelina in the northern Corn Belt. Agron. J. 103:980-987.

Gesch, R. W., Archer, D. W., Forcella, F. 2010. Rotational effects of cuphea on corn, spring wheat, and soybean. Agron. J. 102:145-153.

Berti, M., Johnson, B., Gesch, R. and Forcella, F. 2008. Cuphea nitrogen uptake and seed yield response to nitrogen fertilization. Agron. J. 100:628-634.

Seed coatings for delaying emergence of corn and soybean. Even when soil is sufficiently dry, growers avoid sowing corn and soybean in early spring because of the possibility of early-season cold damage to seed and seedlings. ARS researchers in Morris, Minnesota, verified that polymer-based seed coatings prevent germination until soils are warm enough to promote safe emergence. Polymer coatings enable seed planting 2 to 4 weeks earlier than normal while delaying seedling emergence by about 10 days, providing ample time to protect seeds from cold damage. This information and technology are assisting growers, crop advisors, and seed industry personnel in making optimal decisions for spring planting of corn and soybean. The reserachers collaborated with Landec Corp. (http://landec.com/applications/seed-coatings-treatments/) to develop polymer seed coating for "early planting" of corn on more than 1,200 farms covering more than 100,000 acres across the Midwest.

Sharratt, B.S. and Gesch, R.W. 2008. Germination and Emergence of Polymer-coated Corn and Soybean Influenced by Tillage and Sowing Date in the Northern US Corn Belt. Agronomy Journal 100:585-590.

Variable rate fertilizer applications. Fertilizer is a major input cost for almost all farming operations; but not all field zones need the same amount of fertilizer. ARS researchers in College Station, Texas, found that variable rates of fertilizer applied to maize fields based on zonal soil nutrient levels increased grain yield by 11 to 33 percent and decreased input costs by 30 percent over conventional, uniform rate fertilizer application. This strategy reduces the chances of over application of fertilizer, which not only saves farmers money, but also potentially reduces nitrogen and phosphorus run-off pollution of surface or ground water.

Lan. Y., Zhang, S., Li., W., Xu, Y., Hoffmann, W.C, Xu, Y., Ma, C. 2008. Variable rate fertilization for maize and its effects based on the site-specific soil fertility and yield goal. Agricultural Engineering International: the CIGR E-journal. Manuscript IT 08 002. Vol. X. December, 2008.

Management strategy for a new oilseed crop, Lesquerella. Lesquerella is a new oilseed crop being developed for production in the southwestern United States. For maximum yields, growers need to know optimum planting and harvest dates for the crop. ARS researchers in Maricopa, Arizona, evaluated different planting dates (fall, winter, and spring) to assess the effect on reproductive and vegetative growth. Fall planting dates are optimum for maximum yield. The researchers also developed an imaging system using a multi-spectral camera to accurately monitor crop status. The system helps growers to optimize fertilizer application times and harvest dates for lesquerella. The University of Arizona is incorporating these data into guidelines for lesquerella production systems in the southwest.

Dierig, D.A., Wang, G., McCloskey, W.B., Thorp, K.R., Isbell, T.A., Ray, D.T., Foster, M.A. 2011. Lesquerella: new crop development and commercialization in the U.S. Indust. Crops and Prod. 34: 1381-1385.

Thorp, K.R., Dierig, D.A., French, A.N., Hunsaker, D.J. 2011. Analysis of hyperspectral reflectance data for monitoring growth and development of lesquerella. Indust. Crops and Prod.33: 524-531.

Mycorrhizal fungi influence polyphenolics composition in basil. Nutrient management practices indirectly influence plant production of phenolic compounds. Mycorrhizal fungi and subsequent root absorption of nutrients can also affect crop quality components. ARS scientists in Corvallis, Oregon, and Parma, Idaho, found that inoculating basil with arbuscular mycorrhizal fungi increases concentrations of specific polyphenolics and chicoric acid, a putative beneficial component also found in *Echinacea*. This information about the influence of mycorrhizae on plant products and how nutrient management can influence composition of desired phenolics in end-products ultimately might provide consumers access to a less expensive source of chicoric acid than *Echinacea*. This research has stimulated interest from the largest U.S. herb company.

Lee, J. and Scagel, C.F. 2010. Chicoric acid levels in commercial basil (*Ocimum basilicum*) and *Echinacea purpurea* products. *J. Funct. Foods.* 2:77-84.

Lee, J. 2010. Caffeic acid derivatives in dried Lamiaceae and *Echinacea purpurea* products. *J. Funct. Foods.* 2:158-162.

Quantifying maturity genes and temperature effects on soybean seed sugars and minerals. Understanding the interaction between the environmental factors (such as temperature) and soybean maturity genes responsible for seed constituents (sugars and minerals) is important for production of high quality beans. ARS researchers in Stoneville, Mississippi, quantified the effects of temperature, maturity, and genetic background on seed sugars and mineral nutrition on sets of soybean lines that have a common genetic background, but differ in one or more genes for maturity within each set. The contribution of temperature, maturity, and genetic background substantially affects the stability of the constituents, such as mineral nutrients and sugars (sucrose, raffinose, or stachyose). This knowledge is helping breeders to develop soybean germplasm with higher mineral seed content, to more efficiently select for seed sugars, and to breed varieties with higher quality seed.

Bellaloui, N., Smith, J.R., Ray, J.D., Gillen, A.M. 2011. Effect of maturity genotypic background and temperature on seed mineral composition in near-isogenic soybean lines in the early soybean production system. Crop Science. 51:1161-1171.

Bellaloui, N., Smith, J.R., Gillen, A.M., Ray, J.D. 2010. Effect of maturity on seed sugars as measured on near-isogenic soybean (Glycine max) lines. Crop Science. 50:1978-1987.

SUBCOMPONENT 1B: PERENNIAL CROPS

The Perennial Crops Subcomponent focuses on bush, tree, and vine crops. The multi-year aspect of perennial crops brings additional challenges – protection from overwintering cold, alternate bearing, controlling soil pests without damaging the crop, canopy management, additional labor needs for pruning and thinning, and the compounding of positive or negative impacts of management over the long life cycle of the crop. On the positive side, perennial crops provide opportunities to take a long term ecosystem approach to crop production. To impact these systems, ARS researchers developed new strategies and technologies for better management of pests and environmental stresses; developed equipment to mechanize some routine tasks and adapted other equipment for new uses; developed various approaches to managing the canopy environment; and developed improved production systems.

PROBLEM STATEMENT 1B.1: *Develop integrated strategies for the management of pests and environmental factors that impact yield, quality, and profitability of perennial crops.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Greater knowledge about and understanding of how biological processes, crops, and environmental stresses act and interact to affect pest damage, productivity, and production efficiency of select perennial crops.
2. Improved horticultural and pest management tools, strategies, and technologies that increase adaptability, productivity, production efficiency, product quality, profitability and economic viability of select perennial crops.
3. Increased understanding of how soil, water, and nutrients limit perennial cropping system productivity, production efficiency, and/or crop quality for apple, brambles, blueberry, grape, peach, pecan, sugarcane, and exotic tropical/subtropical crops, and how these crops adapt to and utilize limiting resources.
4. Soil, water, or nutrient management technologies and/or strategies that increase productivity, production efficiency, and/or crop quality of apple, brambles, blueberry, grape, peach, pecan, and sugarcane and are effectively integrated into new, existing, or modified cropping systems.
5. Increased knowledge and understanding of how microclimate environments in perennial cropping systems limit production efficiency and crop quality.
6. Microclimate management technologies and strategies that increase production efficiency and crop quality for apple, grape, and peach.
7. Knowledge of impact of pest management strategies on honey bee (*Apis*) and non-*Apis* bee pollinators.

PROBLEM STATEMENT 1B.1 SELECTED ACCOMPLISHMENTS:

Ring nematode reduces grapevine carbohydrate reserves. Management of existing vineyards with high populations of the ring nematode requires better knowledge of whole-plant response to nematode parasitism. ARS researchers in Corvallis, Oregon, found that ring nematode had a greater impact on carbohydrate reserves in vines than on mineral nutrient reserves. Furthermore, vines grown under low light (15 percent sunlight) conditions to further stress vines suffered greater damage due to higher nematode numbers per mass of roots than did plants grown in full sun or those defoliated by 75 percent. Viticultural practices to increase carbohydrate reserves in the vine and roots, such as lower crop loads or earlier harvesting of fruit for sparkling wine, are recommended to reduce the impact of this pest on vine productivity and survival.

Schreiner, R.P., J.N. Pinkerton, and I.A. Zasada. 2012. Delayed response to ring nematode (Mesocriconema xenoplax) feeding on grape roots linked to vine carbohydrate reserves and nematode feeding pressure. *Soil Biol. Biochem.* 45:89-97

Brown marmorated stink bug. The brown marmorated stink bug is a recently introduced invasive pest in the eastern United States that is beginning to cause extensive economic damage.

ARS researchers in Kearneysville, West Virginia, initiated formation of the Brown Marmorated Stink Bug Working Group that brought together research personnel from within ARS, land-grant universities from 10 states, extension personnel, stakeholders, industry representatives, and regulatory officials from APHIS and EPA. This group formulated research, extension, and regulatory priorities for control of the brown marmorated stink bug, and developed coordinated, collaborative, and integrated projects to develop effective monitoring and management tools for this invasive species. Priorities determined by the working group are at: www.northeastipm.org/neipm/assets/File/Priorities-BMSBIPM%20WG-2011.pdf. ARS researchers in Kearneysville found that early season brown marmorated stink bug can inflict substantial injury to peach and apple crops all season long. Sampling techniques were developed to quantify the amount and severity of injury. In addition, methods were developed to establish the number of generations of the insect per year. The researchers demonstrated for the first time that this insect had two complete generations within a year under Kearneysville, West Virginia, conditions. Previously, only a single generation per year had been recorded. In addition, prototype pyramid traps have been developed for trapping adults and nymphs in commercial orchards and other crops.

Leskey, T.C., B.D. Short, S.E. Wright and A. Khrimian. 2012. Development of Behaviorally-Based Monitoring Tools for the Brown Marmorated Stink Bug (Heteroptera: Pentatomidae) in Commercial Tree Fruit Orchards. Journal of Entomological Science (in press).

A natural plant bioregulator controls black pecan aphids and alternate bearing in pecan. Enhanced alternate bearing in pecan, and subsequent reduced profitability, is greatly accentuated by stress factors triggering premature foliar senescence and defoliation. ARS researchers in Byron, Georgia, found that treating canopies with gibberellic acid prevents black pecan aphids from triggering foliar senescence or canopy defoliation. Additionally, the natural product bioregulator functions as an indirect chemical regulator of subsequent year flowering and associated alternate bearing. Efforts are underway by ARS and Valent BioSciences Corp. of Libertyville, Illinois, to optimize the approach for both black pecan aphid control and flowering. This new tool is already being used for aphid control in Georgia and Arizona, and exhibits promise as an effective and novel means of controlling senescence-inducing aphids in other crops.

Cottrell, T.E., Wood, B.W., and Ni, X. 2010. Application of plant growth regulators mitigates chlorotic foliar injury by the black pecan aphid (Hemiptera: Aphididae). Pest Management Sci. 66(11):1236-1242.

Phosphite as a new tool for managing pecan scab disease. There has recently been emergence of scab resistance to certain classes of fungicides used to control this fungal disease in orchards. New chemical controls are increasingly needed for controlling this devastating disease. ARS researchers in Byron, Georgia, found a simple inorganic chemical – phosphate – to be highly efficacious for controlling the pecan scab fungus and disease in orchards. This research led to rapid registration of several phosphite products for use in pecan orchards and is now being added to the disease spray guidelines used by several pecan belt state extension services. Commercial use of phosphite products now stands at roughly 25 percent of the pecan acreage in the southeastern United States in wet years when scab is more prevalent.

Bock, C.H., Brenneman, T.B., Hotchkiss, M.W., Wood, B.W. 2012. Evaluation of a phosphite fungicide to control pecan scab in the southeastern USA. Crop Protection 34: 58-65.

Particle film materials reduce heat stress and increase apple productivity. Heat stress is a limiting factor of plant productivity throughout the world. ARS researchers in Kearneysville, West Virginia, developed a kaolin-based particle film and demonstrated that the reflective nature of the surfaces of plants treated with it can reduce fruit, leaf, and canopy temperature resulting in increased plant productivity. The researchers found that a 3 percent kaolin-based particle film treatment in an irrigated orchard leads to greater light diffusion, which increases photosynthesis and lower canopy temperature and reduces water use. In 'Empire' apple, photosynthesis and productivity increased with particle film and irrigation treatments. This finding broadly impacts apple growers, and by inference, many different crops. The approach and product are now being used in the United States on about 35 percent of apples, 25 percent of pear, 10 percent of walnut, and 5 percent of cherry, citrus, grape, almond, pistachio, melons, and tomato. It is also now being used on approximately 70,000 acres overseas.

Figure 5: ARS scientists found that when a kaolin-based particle film was applied to Empire apples (bottom photo), it reduced heat stress and increased productivity compared to untreated apples (top photo). *Photo by ARS Kearneysville.*

Glenn, D.M. 2009. Particle film mechanisms of action that reduce the effect of environmental stress in 'Empire' apple. J. Amer. Soc. Hort. Sci. 134(3):314-321.

Mechanisms for the size-controlling ability of apple rootstocks. Dwarfing rootstocks have had a major impact on fruit tree management, and while new rootstocks are needed, the mechanisms for the size-controlling effect have been largely unknown. ARS researchers in Kearneysville, West Virginia, partially characterized the biological basis for size-controlling effects of apple rootstocks. Stem hydraulic conductivity was lower while hormone (abscisic acid) concentrations were higher in xylem exudates from dwarfing than in vigorous rootstocks. It is anticipated that characteristics such as these can be traced to molecular markers that can be used by rootstock breeders to develop new dwarf cultivars.

Tworkoski, T.J. and G. Fazio. 2011. Physiological and Morphological Effects of Size-controlling Rootstocks on 'Fuji' Scion. Acta Horticulturae 903:865-872.

New theory for floral regulation in pecan and other temperate zone trees. The plant processes regulating flowering in pecan have heretofore been a mystery, with the relative roles of plant hormones and energy reserves being unknown. ARS researchers in Byron, Georgia, found that development of female flowers is initially regulated by the interplay of at least four classes of hormones within the bud meristem environment during the previous growing season. It is subsequently regulated by non-structural carbohydrate reserves within that same meristem environment early the following spring. A new theory explains how flowering in pecan involves a three-phase process during the 12 months preceding the visual expression of female flowers. This identifies new research avenues for better understanding the specific physiological processes regulating flowering in tree crops, as well as enabling new opportunities for development of horticultural tools and strategies capable of on-farm regulation of flowering within pecan orchards. A gibberellins-based strategy is beginning to be used by pecan farmers in Georgia, Arizona, and Texas to suppress excessive flowering.

Wood, B.W. 2011. Influence of plant bioregulators on pecan flowering and implications for regulation of pistillate flower initiation. HortScience 46(6):870-877.

Management strategies and tools for reducing fruit-drop in pecan. Fruit-drop maladies (i.e., June-drop and water-stage-fruit-split) are major annual problems in certain pecan orchards. ARS scientists in Byron, Georgia, found that June-drop is substantially manageable by either increasing potassium concentration in young developing fruit to greater than or equal to 1.5 percent potassium, or by timely application of aminoethoxyvinylglycine (AVG), an ethylene inhibitor. They also found that water-stage-fruit-split associated drop is reduced by improving tree boron and nickel nutrition, with boron improving the ability of fruit to rapidly adjust turgor pressure, and nickel improving lignification and subsequent shell hardening for withstanding high turgor. These new tools and management strategies are beginning to be used by growers and recommended by extension specialists and consultants to reduce splitting and premature fruit-drop in pecan. New deficiency guidelines for these nutrients are established in extension service guides. AVG (commercially available as ReTain®, Valent BioSciences Corp.) is now beginning to be used in pecan orchards to manage June drop and alternate bearing.

Wood, B.W. 2011. Influence of aminoethoxyvinylglycine (AVG) on yield and quality of nut crops from a commercial pecan orchard. HortScience. 46(4):586-589.

Wood, B. W., Wells, L., Funderburke, F. 2010. Influence of elevating tree potassium on fruit drop and yield of pecan. HortScience. 45(6):911-917.

Wells, M.L., Wood, B.W. 2008. Foliar boron and nickel applications reduce water-stage fruit-split of pecan. HortScience. 43(5):1437-1440.

Trace element linked to nutritional physiology issues affecting crop production. Crop performance is commonly limited by undiagnosed micronutrient or beneficial element nutritional maladies. ARS researchers in Byron, Georgia, found the impact of nutritional physiology of nickel to be underestimated for many crops. Aside from having major effects on nitrogen cycling and usage within the plant, it also potentially affects disease resistance. Also, one or more rare-earth elements exhibit evidence of involvement as either beneficial or essential elements, with these elements being linked to new species development in genus *Carya*. This research is stimulating widespread use of foliar nickel sprays within much (approximately 50 percent) of the U.S. and Mexican pecan acreage. Additionally, nickel usage is beginning in other crop systems – such as daylily, and nationally and internationally on wheat – to protect against rust, or for improvement in grain protein yield and quality. These nickel products solve several production problems on many perennial and annual crops. This work promises to stimulate new research regarding heretofore overlooked biological roles and agricultural relevance of rare-earth elements, which could lead to additional new products and/or management strategies.

Wood, B.W. and L.J. Grauke, 2011. The rare-earth metallome of pecan and other Carya. J. Amer. Soc. Hort. Sci. 136 (6):389-398.

Bai, C., Reilly, C.C., Wood, B.W. 2007. Nickel deficiency affects nitrogenous forms and urease activity in spring xylem sap of pecan. J. Amer. Soc. Hort. Sci. 132(3):302-309.

Water-stress vulnerability of grapevines is lower than thought. Grapevines are typically grown in dry habitats under deficit irrigation to purposefully induce water stress to improve fruit quality, but it is not known if this strategy harms vines. ARS researchers in Davis, California, found that grapevines are not susceptible to significant drought induced vessel blockage when grown under conditions of normal operating water potentials, and the vine repairs the blockages when they do occur. By using High Resolution Computed Tomography, a type of CAT scan, to model the xylem network of grapevines, they were able to describe the mechanism of air bubble blockage repair in grapevines. Researchers worldwide had suspected this mechanism for decades, but had been unable to visualize this process in living plants. This research proves that water stress-induced disruption of xylem vessels is repairable, and it also provides an analytical method for studying these processes in other crops. Growers are beginning to take advantage of this knowledge to impose water stress to enhance fruit quality, while saving water without fear of permanent damage to the water conducting capacity of their vines.

Broderson, C.R., Mcelrone, A.J., Choat, B., Matthews, M.A., Shackel, K. 2010. Dynamics of embolism repair in xylem: in vivo visualizations using High Resolution Computed Tomography. Plant Physiology. 154(3):1088-1095.

Choat B, Drayton W, Broderson C, Matthews MA, Shackel KA, McElrone AJ. 2010. Measurement of vulnerability to water stress-induced cavitation in grapevine: a comparison of four techniques applied to a long-vesseled species**.** Plant Cell and Environment. 33:1502-1512.

Predictive model of grapevine cold hardiness is publicly accessible. The cold hardiness of grapevine buds, particularly *Vitis vinifera*, is of critical interest to growers in the inland northwest and other areas that are subjected to cold winters. Predictions of site-specific values have not existed. ARS researchers in Prosser, Washington, developed a discrete dynamic model of grapevine bud cold hardiness for several economically important *Vitis vinifera* grape cultivars grown in the Northwest. The model is applicable across locales. Public accessibility is provided by Washington State University's AgWeatherNet system that hosts the decision aid and provides input meteorological data. Results provide objective criteria to growers for the management of frost-protection measures and assessing the anticipated extent of bud injury that may follow extreme cold events during the dormant season.

Ferguson, J.C., J.M. Tarara, L.J. Mills, G.G. Grove and M. Keller. 2011. Dynamic thermal time model of cold hardiness for dormant grapevine buds. Annals of Botany. 107:389-396.

Brief exposure to temperature extremes compromises grape quality. Management of vineyard canopy and microclimate play a significant role in the production of high-quality grapes and wine, as the interactions between berry temperature and solar radiation can influence the polyphenolic content of grapes. These natural chemical compounds in grape skins impinge directly on quality and market price of both the grapes and their products. ARS researchers in

Prosser, Washington; Parma, Idaho; and Corvallis, Oregon, determined the deleterious effects of extreme high fruit temperatures and differences in solar radiation on two classes of important antioxidant compounds in grapes. This research showed that management of vineyard canopy and microclimate play a significant role in production of high-quality grapes and wine. The wine industry in the western United States is applying these results to simultaneously halve the manual labor involved in shoot and cluster thinning, and the number of tractor-hours involved in mechanical leaf-pulling to manage the vineyard canopy. Since adopting these results, the wine industry has saved an estimated $9 million in canopy management costs.

Tarara J.M., J. Lee, S.E. Spayd, C.F. Scagel. 2008. Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in merlot grapes. American Society for Enology and Viticulture. 59:235-247.

Managing beneficial arbuscular mycorrhizal fungi in vineyards. Virtually nothing is known about the identity and functional diversity of the arbuscular mycorrhizal fungi that are engaged in symbiosis with grapevines in production vineyards. Also, regulated deficit irrigation is used in vineyards to control canopy growth and improve fruit quality, and little is known about how imposed deficits alter root growth and beneficial mycorrhizal symbionts. ARS scientists in Corvallis, Oregon, found that grapevines are usually colonized by at least eight different AMF taxa, and that four fungi were always found in grape roots, with the community of fungi in roots not changing over the growing season, but differing between soil types (alluvial versus hill soils) and as vines aged. They also found that fine root growth is reduced by 50 percent using two new regulated deficit irrigation strategies, but is countered by greater colonization of roots by AMF fungi. Fifty percent regulated deficit irrigation strategies do not affect yield or quality of grape, even though they reduce whole plant photosynthesis. High quality grapes are potentially produced using less water than current regulated deficit irrigation practice being used by grape farmers, because of greater colonization by symbiotic fungi under drier conditions. Maintaining diverse AMF communities in vineyards might enhance plant tolerance to nutrient and water stress. This research is stimulating work by other researchers on the influence of cover crops on AMF diversity in grapevine roots in California vineyards.

Schreiner, R.P. and K.L. Mihara. 2009. The diversity of arbuscular mycorrhizal fungi amplified from grapevine roots (*Vitis vinifera* L.) in Oregon vineyards is seasonally stable and influenced by soil and vine age. Mycologia. 101:599-611.

Improving phosphorus management in grape vineyards. Foliar application of phosphorus fertilizers, a common practice in western Oregon grape vineyards, substantially contributes to management costs. ARS researchers in Corvallis, Oregon, found that foliar phosphorus application has no effect on growth, yield, fruit quality, or drought stress of vines. The research indicates little benefit accrues from applying phosphorus fertilizers, even in low phosphorus vineyards. Refraining from using phosphorus fertilizers reduces the potential risks of runoff (ground water contamination) and reduced harm to arbuscular mycorrhizal fungi. The researchers also demonstrated that grapevines grown in a red hill soil are exceptionally dependent on arbuscular mycorrhizal fungi to supply enough phosphorus for growth, while vines grown in a more fertile, valley soil acquire enough phosphorus for normal vegetative growth without arbuscular mycorrhizal fungi. Grapevine growth response and phosphorus uptake were not improved when soils were treated with a native arbuscular mycorrhizal fungus as compared to a nonnative arbuscular mycorrhizal fungus. This provides the basis for eliminating application of foliar phosphorus fertilizers in vineyards, thus increasing profitability and potentially negative environmental side effects. It also shows that use of arbuscular mycorrhizal fungi native to a particular soil is not a critical factor for vine establishment. This research facilitated development of guidelines used by LIVE (Low Input Viticulture and Enology), the largest third party organization to certify sustainable vineyard practices in the Pacific Northwest.

Schreiner, R.P. 2010. Foliar sprays containing phosphorus (P) have minimal impact on 'Pinot noir' growth and P status, mycorrhizal colonization, and fruit quality. Hortscience. 45:815–821.

Schreiner, R.P. 2007. Effects of native and nonnative arbuscular mycorrhizal fungi on growth and nutrient uptake of 'Pinot noir' (*Vitis vinifera* L.) in two soils with contrasting levels of phosphorus. Applied Soil Ecology. 36:205-215.

Best irrigation practices developed for blueberry. Most blueberry fields in the United States require irrigation for commercial production, but little information is available on optimum irrigation practices. ARS researchers in Corvallis, Oregon, identified improved irrigation methods and strategies for rapid field establishment of blueberry. The research found that proper drip placement reduces irrigation requirements, maintains higher soil water content, and lowers plant water stress relative to traditional (sprinkler) irrigation. In addition, the research showed drip irrigation reduces prevalence of root rot, and demonstrated that growth and early production are often greatest when plants are drip irrigated as compared to sprinkler irrigation. This research documents the benefits of drip irrigation technology in terms of reduced inputs and improved plant development, and provides growers with accurate information on how much water to apply to blueberry. This research led to almost every new blueberry field in the Pacific Northwest (3,000+ acres since 2008) utilizing drip irrigation, whereas more than 90 percent of fields were previously sprinkler irrigated. Many of the older fields are now being converted from sprinklers to drip.

Bryla, D.R., J.L. Gartung, and B.C. Strik. 2011. Evaluation of irrigation methods for highbush blueberry—I. Growth and water requirements of young plants. HortScience. 46:95−101.

Bryla, D.R., R.G. Linderman, and W.Q. Yang. 2008. Incidence of *Phytophthora* and *Pythium* infection and the relation to cultural conditions in commercial blueberry fields. HortScience. 43:260–263.

Novaluron increases alfalfa leafcutting bee mortality. Novaluron is an insect growth regulator for controlling *Lygus* bugs in alfalfa seed fields, and thought to be safe for bees. However, declining bee populations raises concerns about the effect of this and other pesticides on bees and the crops they pollinate. ARS scientists in Logan, Utah, with their university collaborators, found that novaluron kills alfalfa leafcutting bee eggs. Egg mortality rates are near 100 percent when novaluron is applied to eggs and pollen in laboratory bioassays, but it also kills eggs of adult females who are fed novaluron. In field trials, egg mortality is much greater when adult females forage on pollen, nectar, and leaves sprayed with novaluron than in non-treated alfalfa fields. To lessen the negative impact on these alfalfa pollinators, growers are being encouraged by extension and research workers to either avoid use of novaluron, or to only use it at the end of bee nesting season. This knowledge is now being used by western alfalfa farmers to better preserve important bee pollinators of crops.

Hodgson, E.W., Pitts Singer, T., Barbour, J.D. 2011. Effects of the insect growth regulator, novaluron on immature alfalfa leafcutting bees, *Megachile rotundata*. Journal of Insect Science. 11:43.

PROBLEM STATEMENT 1B.2: *Develop mechanization and automation practices that increase production efficiency.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. New technologies and strategies that provide economically attractive and environmentally sound alternatives to current practices for perennial crops.
2. Identification of the handling and delivery factors that influence the biological impact of application technologies and the associated efficacy of pest management and crop production materials for perennial crops.
3. Technologies and strategies that minimize off-target spray movement during application to perennial crops and reduce worker exposure.
4. Technologies and strategies for assessing factors influencing improvements in automation, control, and efficiency, thus improving delivery and deposition of pesticides and growth regulators.

PROBLEM STATEMENT 1B.2 SELECTED ACCOMPLISHMENTS:

Billet planting of sugarcane is economical. Sugarcane producers prefer to use a chopper harvester, which cuts stalks of seed cane into short pieces (billets) as an alternative to traditional whole-stalk harvesters. However, billet plantings require more seed cane to ensure adequate cane stands and equivalent yields. ARS researchers in Houma, Louisiana, demonstrated that billet planting with sugarcane variety LCP 85-384 is economical and does not negatively influence cane or sugar yields. Growers are beginning to adopt this strategy which can save about $60 per hectare in labor costs and up to $250 per hectare in seed costs.

Johnson, R.M., Viator, R.P., and Richard Jr, E.P. 2011. Effects of billet planting rate and position on sugarcane yields in Louisiana. Journal of the Amer. Soc. Sugar Cane Technol. J. Amer. Soc. Sugar Cane Technol. 31:79-90.

Scanning system developed to optimize pesticide spray applications. Inaccurate application of pesticides on target areas often cause serious spray drift and off-target loss problems, resulting in inefficient pesticide use, food safety concerns, environmental contamination, and hazards to workers. ARS researchers in Wooster, Ohio, developed a portable scanning system and scanning software – DepositScan – for rapid evaluation of deposition quality of pesticide spray applications. Long-term benefits of DepositScan will be to minimize off-target loss, including spray drift, and increase pesticide spray application efficiency and efficacy. The free software is available and can be downloaded at: www.ars.usda.gov/mwa/wooster/atru/depositscan. Since its release in 2009, over 700 copies have been downloaded and used nationally and internationally. Farmers have used it to optimize spraying of pesticides, and extension educators have used it to help train applicators to accurately apply chemicals. Manufacturers have used it to accelerate the process for new pesticide formulations and pesticide spraying equipment, while other researchers in the agriculture, food, paint and coal industries have used it to determine droplet size distributions to improve application technologies in their fields.

Zhu, H., Salyani, M., Fox, R.D. 2011. A portable scanning system for evaluation of spray deposit distribution. Computers and Electronics in Agriculture. 76(1):38-43.

Development of variable-rate air-assisted nozzles. Precision sprayers that match spray outputs to target are needed to reduce pesticide use and minimize off-target loss. The variable-rate spray nozzle is one of the most important components for achieving high sprayer performance. ARS researchers in Wooster, Ohio, developed air-assisted, five-port nozzles for the variable-rate spray applications. They determined the magnitude of influence of spray parameters on droplet size distributions while the nozzles were performing the variable-rate function. The newly developed nozzles have the reliable performances required for precision spray applications, and are being used for development of new variable-rate, air-assisted sprayers to achieve a reliable spray technology synchronizing spray outputs with canopy size structures in real-time.

Figure 6: ARS researchers field-test air-assisted, five-port nozzles for variable-rate spray applications. *Photo by ARS Wooster.*

Gu, J., Zhu, H., Ding, W., Jeon, H.Y. 2011. Droplet size distributions of adjuvant-amended sprays from an air-assisted five-port PWM nozzle. Atomization and Sprays. 21 (3):263–274.

Management of citrus greening via proper sprayer setup and compliance with insecticide labels. The Asian citrus psyllid is the vector of the pathogen that is suspected of causing Huanglongbing (HLB, or citrus greening disease) on citrus trees in Florida and Texas. Many insecticides, when applied properly, are effective at suppressing or eliminating the psyllids in groves. ARS scientists in College Station, Texas, conducted three sprayer evaluation clinics in Florida, and evaluated 40 sprayers for use against the psyllid. Sprayers were initially run at the user settings to determine the droplet size of the spray and then adjusted to comply with a special exemption product label. These results provided applicators, growers, and extension agents who work with citrus applicators with guidelines to ensure spray systems are operated in compliance with label restrictions. This effort is saving Florida growers at least $25 million a year, and ensures that applications are in line with label guidelines, thus minimizing drift issues.

Hoffmann, W. C., Fritz, B. K., Martin, D. E., Atwood, R., Hurner, T., Ledebuhr, M., Tandy, M., Jackson, J. L., Wisler, G. 2010. Evaluation of low-volume sprayers used in Asian citrus psyllid control applications. Horttechnology, 20(3), 632-639.

New technology enables growing trailing blackberries without low-temperature injury. Trailing blackberries developed by ARS scientists in Corvallis, Oregon, are susceptible to low temperature injury and are not grown commercially in the central or eastern United States. A variety of techniques, such as rowcovers, cold frames, greenhouses, and high tunnels, have been used to modify the growing environment for berry crops, but none has been shown to reduce winter injury in trailing blackberries. ARS researchers in Kearneysville, West Virginia, used a novel trellis system with a long rotating cross-arm to position trailing blackberry canes close to the ground. This approach, combined with rowcover application, is a cost-effective method for protecting trailing blackberries from cold temperatures and desiccating winds; thus, enabling trailing blackberries to be grown in the eastern United States. Since trailing blackberries ripen earlier than other blackberries, they are useful for growers in the eastern United States interested in early season blackberry. This research is currently being commercialized by Trellis Growing System, Inc. and was nominated for an Excellence in Technology Transfer Award from the Federal Laboratory Consortium.

Takeda, F. and Phillips, J. 2011. Horizontal cane orientation and rowcover application improve winter survival and yield of trailing 'Siskiyou' blackberry. HortTechnology. 21(2)*:170*-175.

New and efficient mechanical thinning equipment for high-density peach production systems. Reducing the number of fruit per tree is necessary to attain marketable size peach fruit, but thinning is a costly and labor intensive operation. ARS researchers in Kearneysville, West Virginia, designed a single spiked drum shaker that is small, lightweight, and readily adapted to forklift machines commonly found in commercial orchards. This thinning device has drawn interest from researchers and peach grower groups in Pennsylvania, California, and New York.

Figure 7: An ARS researcher tests a thinning device for high-density peach orchards. *Photo by ARS Kearneysville.*

Miller, S.S., Baugher, T.A., Schupp, J.R., Wolford, S.D. 2011. Performance of mechanical thinners for bloom or green fruit thinning in peaches. HortScience. 46 (1):43-51.

Mechanized hedge pruning as a light management tool for pecan. Orchard crowding, with associated light stress, loss of nutmeat yield, and accentuated alternate bearing, is a major problem for pecan farmers in the southeastern United States. ARS researchers in Byron, Georgia, building on previous ARS work in the mechanized hedge-pruning of orchards in the relatively high-light U.S. southwest, introduced a relatively low-light compatible approach to hedging for southeastern United States. Results support the notion that modified mechanical hedge pruning can be beneficial in relatively low-light environments. In addition to widespread adoption of mechanical hedging in the southwestern United States, Mexico, and Australia (about 75, 50, and 50 percent of acreage, respectably) the approach is now beginning to be used by several large farming enterprises within the southeast (on approximately 6,000 acres) to manage canopies and reduce alternate bearing.

Wood, B.W. 2009. Mechanical hedge pruning of pecan in a relatively low-light environment. HortScience. 44(1):68-72.

A new continuous vine yield monitoring system. Vineyard managers need an improved method for monitoring crop-load in grape vineyards for facilitating thinning, irrigation, and yield. ARS researchers in Prosser, Washington, found that a continuous monitoring system in vineyard trellises (i.e., the trellis tension monitor) provides estimates of grapevine yields that are more accurate than those compiled by the juice processing industry using their static sample approaches. Growers can apply this technology for shoot thinning, confirmation of desired levels of fruit thinning, and initiation of deficit irrigation. It can be used by juice processors or wineries as an adjunct decision aid for fruit thinning and timing of supplemental hand sampling for traditional yield estimation, or as a stand-alone, remote yield estimation technique. Harvest scheduling alone is estimated to cost U.S. wineries upwards of $10 million annually, while the cost associated with wine pricing decisions, which are based on yield estimates, exceed $30 million annually.

Tarara, J.M., P.E. Blom, B. Shafii, W.J. Price, and M. Olmstead. 2009. Modeling seasonal dynamics of canopy and fruit growth in grapevine for application in trellis tension monitoring. HortScience. 44:334-340.

Sugarcane yield monitor predicts field cane yields. Louisiana sugarcane producers continue to search for ways to increase yields and profitability. One way to increase profitability is to accurately predict and map cane yields at harvest so that transportation costs are minimized and in-field variability is more effectively managed. In a cooperative research effort, ARS researchers in Houma, Louisiana, and their colleagues at Kansas State University, developed and validated an optical yield monitor for predicting cane yields under field harvest conditions. The yield monitor is insensitive to variety and harvester speed, and requires minimal maintenance. This technology allows sugarcane producers to map within field variability, identify areas requiring additional inputs, and maximize transportation efficiency.

Price, R.R., Johnson, R.M., Viator, R.P., Larsen, J., Peters, A. 2011. Fiber optic yield monitor for a sugarcane chopper harvester. Transactions of the ASABE. 54(1):31-39.

PROBLEM STATEMENT 1B.3: *Develop perennial crop production systems that are productive, profitable, and environmentally acceptable.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Perennial crop production systems with enhanced productivity, profitability, and sustainability.
2. Improved crop production systems for new varieties or cultivars for suitability in niche sites or markets.

PROBLEM STATEMENT 1B.3 SELECTED ACCOMPLISHMENTS:

Cultivation affects sustainability of sugarcane yields. In Louisiana, sugarcane farmers typically cultivate cane three to six times during each production year of the 4-year crop cycle. Eliminating cultivation passes during one or more years of a crop cycle may reduce production costs without affecting yield. ARS researchers in Houma, Louisiana, compared conventional tilling cultivation to an alternative no-cultivation system and found that in both the plant-cane and first-ratoon production years conventional cultivation increased sugar yields. However, in the second-ratoon crop, cultivation did not affect yields. In the third-ratoon crop, increased sugar yield was noted when the fields were not tilled for that season. This research demonstrated that conventional tilling is beneficial in the first 3 years of the crop cycle, and not needed in the fourth. This information enables growers to eliminate cultivation during the third-ratoon crop year without compromising 4-year yield, thus reducing input costs by $100 per hectare. This new strategy is now being implemented by Louisiana sugar cane producers.

Viator, R.P., Johnson, R.M., Richard Jr, E.P. 2010. Effects of cultivation frequency on sugarcane yields. Sugar Cane International. 28(6):259-265.

Off-season long-cane blackberry production. U.S. blackberry growers want to expand market share by entering specific niches. ARS scientists in Kearneysville, West Virginia, used a unique trellis and cane training system to propagate single-cane blackberry plants which can be manipulated to produce off-season fruit that commands a higher price. The new propagation system increases plant output five- to seven-fold over the current commercial propagation technique. The long-cane plants can be established in a warm area, such as southern Florida, in late winter to obtain a crop in March and April. For late season fruit production, plants are held in cold storage until summer and then grown in a warm environment so the fruit matures from August to October. This new propagation method is efficient for producing a large number of blackberry plants that can be manipulated to produce fruit in the off-season and is therefore useful to both growers and nurserymen looking for off-season production systems.

Takeda, F. and Soria, J. 2011. Method for producing long-cane blackberry plants HortTechnology. 21*:*563-568.

Increasing plant diversity increases ecosystem services in orchards. Orchard-level management experiments that evaluate pesticides often do not consider effects beyond the targeted pests, missing potentially important effects on ecosystem services provided by the orchard. ARS researchers in Kearneysville, West Virginia, evaluated biological control in apple and peach orchards – with and without flowering plants – and interplanting of peach trees with apple trees. Although biological control of targeted aphids and bud moth did not increase, population levels of other pests and the percentage of fruit damaged by several insect pests were reduced by increasing plant diversity of the orchard ecosystem. Increased diversity of the orchard vegetation structure suppressed pest damage through complex functional interactions, not only by direct predator-prey or parasitoid host interactions. The ecosystem service of pest regulation was achieved indirectly through subtle changes in ecosystem processes, but was only detected by using a holistic approach to evaluating orchard-level experiments. This knowledge is useful to horticulturists and growers developing new sustainable orchard management systems.

Brown, M.W. 2012. Role of biodiversity in integrated fruit production in eastern North American orchards. Agricultural and Forest Entomology, 14:89-99.

High density peach production system developed with 'pillar' growth types. The lack of dwarfing rootstocks for peach has led to cultural and genetic approaches that reduce tree size and vegetative growth to establish high-density plantings. ARS researchers in Kearneysville, West Virginia, evaluated the interactions of ground cover management and pruning strategies with tree densities and compared the productivity of a standard peach architecture with 'pillar' peach architecture. The use of sod management does not reduce pruning time and costs. However, high density plantings, particularly with trees possessing a pillar growth habit, have greater economic returns than do low density plantings of either growth habit. Because the pillar peach tree demonstrates potential for significant horticultural and economic benefit in high density peach production systems, this concept is stimulating considerable world-wide research as a prerequisite to adoption by peach growers.

Glenn, D.M., T. Tworkoski, R. Scorza, and S.S. Miller. 2012. Long-term effects of peach production systems for standard and pillar growth types on yield and economic parameters. HortTechnology. 22:17-21.

Tworkoski, T., R. Scorza, and D.M. Glenn. 2009. Leaf N and P in different growth habits of peach: Effects of root system morphology and transpiration. J. Applied Hort. 11:95-98.

Viability of litchi and rambutan production. Knowledge of whether the fruit of rambutan and litchi serve as hosts to the West Indian fruit fly is critical to increasing the production and trade of those commodities. ARS researchers in Mayagüez, Puerto Rico, found no fruit flies from a large sampling of mature fruit collected from fields. Moreover, 12 day-old female flies exposed to ripe litchi and rambutan fruit did not result in viable larvae. This research indicates that rambutan and litchi fruit exported from Puerto Rico do not pose a risk of transporting the West Indian fruit fly to destination countries, and prompted APHIS to reevaluate their risk assessment. This led to an October 2011 decision by APHIS to allow movement of rambutan from Puerto Rico into the continental United States. As a result, Puerto Rican growers enjoy an expanded market for their fruit in the United States.

Figure 8: Puerto Rico farmers are able to move the fruit of ramutan to the continental United States, thanks to research by ARS scientists. *Photo by ARS Mayagüez.*

Goenaga, R.J. 2011. Dry matter production and leaf elemental concentrations of rambutan grown on an acid Ultisol. Journal of Plant Nutrition. 34:753-761.

Jenkins, D.A., and R. Goenaga. 2008. Host status of litchi and rambutan to the West Indian fruit fly (Diptera: Tephritidae). Florida Entomologist. 91(2):228-231.

Improving the soil health of cacao plantations. Soils of old cacao plantations are degraded due to many years of intensive cultivation, insufficient fertilization, and soil erosion. These plantations need floor management practices that correct these problems. ARS researchers in Beltsville, Maryland, found that legume cover crops substantially increased soil organic matter content and plant-available phosphorous in cacao agroforestry systems, improving soil fertility and reducing soil degradation. They also found that in cacao agroforestry systems litter management is critical for maintaining healthy soil fauna communities and improving cacao production potential. Additionally, the researchers determined that genotypes of cacao differ in how they affect population dynamics and species richness and diversity of soil rhizosphere microfauna, with microfaunas potentially influencing growth and development of cacao grown under different management systems. This information is part of a new strategy (i.e., legume cover crops, better adapted genotypes, and better litter management) that is beginning to be used by Andean cacao growers to improve sustainability and yields in plantations with highly degraded soils.

Hall, H., Y. Li, N. Comerford, E. A. Gardini, L. Z. Cernades, V. C. Baligar, and H. Popenoe. 2010. Cover crops alter phosphorus soil fractions and organic matter accumulation in a Peruvian cacao agroforestry system. Agroforest Syst. 80:447-455.

Moço, M. K. S., E. F.Gama-Rodrigues, A. C. Gama-Rodrigues, R. C. R Machado, and V. C. Baligar. 2010. Relationships between invertebrate communities, litter quality and soil attributes under different cacao agroforestry systems in the south of Bahia, Brazil. Applied Soil Ecology, 46:347-354.

SUBCOMPONENT 1C: GREENHOUSE, HIGH TUNNEL, AND NURSERY PRODUCTION SYSTEMS

This Subcomponent focuses on fruit trees or woody ornamental nursery crops grown in the field or in containers, as well as greenhouse production of floral crops. Challenges for this crop sector include managing water and nutrient, availability of substrates for containerized production, high energy demands of greenhouse systems, the diversity of crops, improving vase-life of cut flowers, and hitting specific market windows, such as Mother's Day. To address these challenges, ARS researchers developed new strategies and technologies to improve water, nutrient, and pest management; developed technologies to detect disease and track insects; developed a software package to improve greenhouse production systems; explored alternative substrate materials; and developed postharvest handling strategies for cut flowers.

PROBLEM STATEMENT 1C.1: ***Develop integrated strategies for the management of pests and environmental factors that impact yield, quality, and profitability of greenhouse, high tunnel, and nursery production systems.***

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Improved pest and pathogen control strategies for both within-season and post-harvest application.
2. New knowledge of the interaction between plant nutrition, genetic composition, and pest susceptibility.
3. Better understanding of how to effectively and economically treat pathogens in recycled water.

PROBLEM STATEMENT 1C.1 SELECTED ACCOMPLISHMENTS:

Environmentally friendly strategies for controlling diseases in ornamental crops. Many diseases plague the production of ornamentals, and producers need better and more environmentally friendly approaches for managing these diseases. ARS researchers in Poplarville, Mississippi, developed methods to eliminate *Rhizoctonia* species from azalea stems collected for propagation. They found that submerging stem cuttings in 122°C water for 21 minutes eliminates the pathogen from stems. The approach is also being successfully used for blueberry propagators in the southeast. They also found that hydrogen dioxide controls daylily rust, a foliar disease, when applied to plants 3 to 5 times per week. Hydrogen dioxide is applied through irrigation systems at several greenhouse propagation facilities in Florida, Texas, and California, for general control of foliar diseases on annual and perennial flowering plants. These approaches are potential components of an integrated disease management strategy using environmentally friendly products versus using standard fungicide products.

Copes, W. E. and Blythe, E. K. 2009. Chemical and hot water treatments to control *Rhizoctonia* AG P infesting stem cuttings of azalea. Hortscience. 44(5):1370–1376.

Copes, W. E. 2009. Concentration and intervals of hydrogen dioxide applications to control *Puccinia hemerocallidis* on daylily. Crop Protection. 28:24-29.

Predisposition of trees to infection by Phytophthora syringae. Disease caused by *Phytophthora syringae* is common on bare root deciduous nursery stock in the Pacific Northwest and requires intensive cultural and chemical management. It is unknown whether the increased incidence of *P. syringae* during the dormant period is due more to the wet-cold environment, the dormancy status of the tree, or the influence of common autumn spray practices on susceptibility. ARS researchers in Corvallis, Oregon, found that susceptibility of nursery trees to *P. syringae* is not the same in actively growing and dormant trees and sprays with urea, fungicides, and defoliants alter tree susceptibility. Regardless of tree growth stage, environmental conditions after exposure to the pathogen, particularly temperature, are important for disease development. Additionally, spraying trees in the autumn with urea, defoliants, or fungicides influenced tree nitrogen (N) status but the effects on N status are unrelated to susceptibility to *P. syringae*. These results enable nursery managers and extension personnel in areas infested with *P. syringae* to make better disease management decisions and highlight the importance of inspection and treatment of both dormant and actively growing trees to prevent or reduce the spread of plant diseases in nursery stock. These results are being used by bareroot nursery crop producers to develop better treatment protocols and optimize autumn sprays to benefit both early harvest and prevention of contamination and/or infection by *P. syringae* in the field or in storage.

Laywisadkul, S., Scagel, C.F., Fuchigami, L.H., R.G. Linderman. 2010. Tree growth stage and environment after pathogen inoculation alters susceptibility of pear trees to *Phytophthora* canker. Open Hort. J. 3:1-10

Reducing nitrogen increases cold hardiness of nursery trees. Stem and bud dieback due to winter injury causes economically important losses in nursery tree production. ARS researchers in Corvallis, Oregon, found that both nitrogen rate and nitrogen source influences cold tolerance of buds and stems of nursery trees. Trees possessing a similar nitrogen status withstand different levels of cold depending on rate or form of nitrogen fertilizer used during production. Results have been provided to nurserymen as new guidelines for developing and optimizing nitrogen management strategies for nursery production of trees in climates prone to winter injury.

Scagel C.F., Regan, R.P., and G. Bi. 2010**.** Bud necrosis of green ash nursery trees is influenced by nitrogen availability and fertilizer type. HortTechnology. 20:206-212.

Excess nitrogen increases Botrytis problems. Applied nitrogen is often the nutrient that is varied the most during production to control growth or provide a last opportunity to "green up" plants before shipment. ARS researchers in Wooster, Ohio, investigating the interaction between nitrogen supply and susceptibility to the *Botrytis cinerea* fungal pathogen found that as nitrogen supply exceeded 200 parts per million, the risk of plants succumbing to Botrytis rot increased. This research documented severe penalties to crop production if excess nitrogen fertilizer was used, and provided guidelines for reducing disease outbreak through changes in fertility management. Many growers are now cutting back on their nitrogen use rates, especially prior to plant shipment. This strategy has provided growers an additional tool to combat post-production losses of product.

Pitchay, D.S., J. Frantz, J.C. Locke, Krause, C.R. 2007. Impact of nitrogen supply on uptake, utilization, growth, and development of begonia and New Guinea impatiens, and susceptibility of begonia to *Botrytis cinerea*. J. Amer. Soc. Hort. Sci. 132:193-201.

Horticultural crops benefit from improved silicon nutrition. Silicon was believed to only have beneficial effects on specific groups of plants, such as grasses (rice, wheat, sugarcane) or from the Cucurbitacea family (e.g. pumpkin, squash, cucumber). All other crops were believed to be unresponsive to feeding with silicon. ARS researchers in Wooster, Ohio, found that crops have measurable changes in response to stress (drought, metal toxicity, virus infection, or fungal pathogens) when fed silicon. The researchers also improved detection methods for determining optimal silicon concentrations within plants and in soilless substrate systems. They better identified the role of silicon in certain crops and better assessed how to effectively deliver silicon to target plants. Inclusion of silicon in production systems of certain floricultural crops improves plant ability to withstand stress from a variety of sources (both biotic and abiotic) that reduces the need for applying some chemicals and improves efficacy of others (e.g., copper-containing pesticides). These results enable growers to utilize novel fertility management practices to decrease losses caused by biotic or abiotic stress, and to develop methods to supply silicon in different production systems. For floriculture growers, the work is triggering small-scale, on-site evaluations. In addition to the benefit for ornamental crops, a supplier of field-agriculture materials has refined a 'lime + silicon' product for pH management that improves drought tolerance and resistance to lodging, and increases yields in soybean and corn. Many growers now rely upon its use for pH management and other beneficial effects.

Ranger, C., A.P. Singh, J.M. Frantz, L. Canas, J.C. Locke, M.E. Reding, and N. Vorsa. 2009. Influence of silicon on resistance of *Zinnia elegans* to *Myzus persicae* (Hemiptera: Aphididae). Env. Entomol. 38:129-136.

Frantz, J.M., J.C. Locke, L. Datnoff, M. Omer, A. Widrig, D. Sturtz, L. Horst, C.R. Krause. 2008. Detection, distribution, and quantification of silicon in floricultural crops utilizing three distinct analytical methods. Comm. Soil Sci. Plant Analysis. 39:2734-2751.

Li, J., S. Leisner, J.M. Frantz. 2008. Alleviation of copper toxicity in *Arabidopsis thaliana* by silicon addition to hydroponic solutions. J. Amer. Soc. Hort Sci. 133:670-677.

New irrigation approach for controlling boron and calcium problems. Stunted and abnormal growth in production of greenhouse-produced ornamentals is typically attributed to insufficient calcium. ARS scientists in Toledo, Ohio, and their university colleagues found that the cause of distorted plant growth in several floriculture species is typically not due to calcium, but rather to a boron deficiency stunting growth. This knowledge eliminates the necessity for adding significant amounts of calcium while correcting a major problem with small amounts of boron. The boron deficiency is generally triggered by excessive irrigation relative to root substrate volume and lack of environmental conditions that encourage water uptake and transpiration. Greenhouse operators are now aware of how to better manage irrigation using a transpiration-based control system instead of reliance on timers that lead to water logging, boron deficiency, and stunted growth of floriculture crops. Among others, the largest floriculture facility in the United States uses this research to reduce losses due to either boron or calcium disorders.

Krug, B.A., B.E. Whipker, W.C. Fonteno, I. McCall, and J. Frantz. 2011. Incidence of boron deficiency in bedding plants caused by drought stress or abscicic acid application. Acta Hort. 891:141-147.

Krug, B.A., B.E. Whipker, J. Frantz, and I. McCall. 2009. Characterization of calcium and boron deficiency and the effects of temporal disruption of calcium and boron supply on pansy, petunia, and gerbera plugs. HortScience. 44:1566-1572.

Improving waste-water quality for recycling in greenhouse production systems. Water quality is often a limiting factor in production of ornamentals, and the water's ongoing quality characteristics when recycled within a facility are of utmost importance for overall profitability. Many filtration approaches and treatment systems exists, but they have not been evaluated and compared for effectiveness. ARS funded research at the University of Florida that evaluated several of the most common filtration systems, and all were found to be more porous than previously believed, enabling passage of particulate matter and pathogens through expanded pores. Additionally, the water treatments of ozone and chlorination were evaluated for efficacy in reducing pathogens, as well as their effects on micronutrient delivery compounds, e.g., chelates. This work improved the water quality systems of several large ornamental growers, resulting in reduced pesticide use, increased profits, and reduction of labor. The information is available (http://watereducationalliance.org/default.asp) through the Water Education Alliance Web site and has been shared in numerous trade journal articles and grower-focused workshops. An example of the practical benefits of this research is illustrated by a Florida company that had experienced severe crop loss due to Ceratocystis being spread through its irrigation system. Incorporating research results, including irrigation flow, filtration, and copper ionization, resulted in labor and crop savings of more than $108,000 in its first year, far more than the installation and maintenance costs of the system upgrades.

PROBLEM STATEMENT 1C.2: *Develop sensors and automation technologies for greenhouses, high tunnel, and nursery production systems.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. New sensors for rapidly and economically monitoring plant growth and stress in greenhouses, high-tunnels, and nurseries with minimal labor.
2. Optimal production practices that reduce wastewater and nutrient use and lower production cost in greenhouses, high-tunnels, and nurseries.
3. New automatic irrigation control systems for optimal nursery and greenhouse irrigation practices.
4. Insect tracking technology in protected environments and nurseries.
5. Improved understanding of insect dispersal and behavioral patterns to aid the development of efficacious management strategies and improve production efficiency.
6. Scientific information for engineers, plant pathologists, entomologists, horticulturists, and chemists to determine the most important factors of sprayer operating conditions, formulation properties, plant structures, and weather conditions for protected horticulture production.
7. New sensors or new applications for existing sensor technology to assess coverage of sprays.
8. New or adapted agrochemical application equipment for use in the greenhouse, high-tunnel, or nursery environment.
9. Improved pest management strategies arising from existing and new spray techniques.
10. Guidelines for nursery and greenhouse growers enabling optimal pesticide spray and delivery practices that enhance efficacy and reduce production costs with minimal environmental impact from agrichemicals.

PROBLEM STATEMENT 1C.2 SELECTED ACCOMPLISHMENTS:

Detecting onset of a root pathogens in geranium. Many greenhouse production practices use non-selective preventative applications of pesticide to reduce or eliminate the chance of encountering root pathogens, while other approaches wait until visible symptoms of the disease appear. ARS researchers in Toledo, Ohio, utilized off-the-shelf infrared temperature sensors to identify the onset of disease in geranium by detecting differences in leaf temperature. Leaves heated up relative to a control indicating lower water use by the plant, suggesting a problem with root health. The use of the technology could identify the start of the disease one week earlier than visible symptoms appear. This demonstrates that a non-destructive approach could be used to target pesticide use more effectively, and reduce crop loss by earlier detection of the stress. While there is no direct commercial application of this system as yet, coupling the approach to other non-destructive tools and monitoring approaches promises to allow for more efficient targeting of problem areas in production.

Omer, M., J.C. Locke, J.M. Frantz. 2007. Using leaf temperature as a nondestructive procedure to detect root rot stress in geranium. HortTechnology. 17:532-536.

Moisture availability in soilless substrates. Irrigation management is critical to the future of the nursery industry. Until now, measuring water availability in soilless substrates has been very difficult and time consuming. ARS researchers in Wooster, Ohio, developed a new method for measuring water content in soilless substrates at low tensions that enables better characterization of water buffering potential of soilless substrates. The researchers created a chart known as the Moisture Characteristic Curve that is used to accurately program irrigation controllers to improve irrigation precision and reduce water waste. These results are being adopted by scientists at Oregon State University and Ohio State University, and are used to analyze novel substrates being developed by scientists at Auburn University, Kansas State University, and other ARS scientists in Fort Pierce, Florida.

Altland, J.E., J.S. Owen, Jr., and W. Fonteno. 2010. Developing moisture characteristic curves and their descriptive functions at low-tensions for soilless substrates. J. Amer. Soc. Hort. Sci. 135(6):563-567.

Harmonic radar unit developed for tracking insects. Every year, insect pests cause substantial economic losses to agricultural and forest crops. ARS researchers in Wooster, Ohio, developed entomological harmonic radar tracking systems as an alternative technology to study behavior, population dynamics, and movement of insects. The system is miniaturized by using patch antenna transponders to improve dipole or monopole antenna transponders for tracking insects in areas where sources of electricity or transportation vehicles are unavailable. The system offers a unique combination of portability, low power, and small tag design to improve harmonic conversion efficiency. The technology is used by entomologists as an educational material possessing great potential for tracking agricultural and forest insects and even animals upon full commercial fabrication of miniaturized patch antennas.

Zhu, H., Psychoudakis, D., Brazee, R.D., Thistle, H.W., Volakis, J.L. 2011. Patch antenna harmonic radar tracking system for small insects. Trans. ASABE. 54(1):355-362.

Water-resistant insect trap for containerized production systems. Early detection of insect outbreaks is needed for effective chemical control of multigenerational pests, such as the strawberry rootworm beetle, a major root and leaf pest of potted azaleas in large production nurseries. While sticky traps are commercially available for monitoring strawberry rootworm beetles, these cardboard traps are not durable enough to withstand daily application of irrigation water in a nursery. ARS researchers in Poplarville, Mississippi, developed a lightweight water-resistant trap that collects the strawberry rootworm beetle as well as other pest species. Incorporation of a light emitting diode increases trap catch by three- to seven-fold for nocturnal strawberry rootworm beetle. This trap provides nursery managers with a routine monitoring device for detecting early outbreaks of strawberry rootworm beetle and other leaf beetle pests, reduces the cost of labor and insecticides, and eliminates the need for the destructive sampling of plants. Illuminated trap stations are being used to monitor and control both diurnal and nocturnal leaf beetle pests at several nurseries. For just one nursery, insecticide usage was reduced by 50 percent, a saving of approximately $2,200. A patent application has been submitted for the trap device.

Sampson, B. Insect monitoring method and apparatus, Docket # 0033.12, application #61576457.

Dispersion of pesticide droplets affects pesticide application efficiency. Although numerous studies have been reported on methods to maximize deposition and coverage of droplets on target surfaces, current application technologies are still highly inefficient. This can lead to excessive amounts of pesticides being applied with greater cost and increased contamination of the environment. ARS scientists inWooster, Ohio, determined effects of individual variables including spray adjuvant, drift retardant, droplet size, and relative humidity on the dispersion of single droplets deposited on waxy and hairy leaf surfaces. The information from this research has assisted pesticide formulators to develop better products that can maximize uptake by leaves, as well as allowed spray applicators, extension educators, and researchers to maximize efficacy and minimize chemical use. This information is used as training materials by numerous associations including American Association of Pesticide Safety Educators (AAPSE) and Ontario Ministry of Agriculture for maximizing pesticide application efficiency and safeguarding the environment.

Xu, L., Zhu, H., Ozkan, H.E., Bagley, W.E., Krause, C.R. 2011. Droplet evaporation and spread on waxy and hairy leaves associated with type and concentration of adjuvants. Pest Management Science. 67(7):842-851.

Half-rate pesticide use. Pesticide applications are critical to ensure healthy, unblemished ornamental nursery plants. Conventional spray application practices recommend the modification of carrier volume for preparations of spray mixtures, but not the amount of active ingredients per unit area. ARS researchers in Wooster, Ohio, demonstrated that growers can use their existing spray equipment to reduce pesticide and water use by 50 percent by properly changing spray nozzles at no extra cost and still achieve effective pest and disease control. Other benefits include increased operational efficiency and reduced costs for energy consumption and new equipment. By using the half-rate practice, growers reported savings of over $200-$500 per acre. This technology is being widely used by nursery growers and received the Federal Laboratory Consortium's Excellence in Technology Transfer award for 2011.

Zhu, H., Zondag, R.H., Krause, C.R., Merrick, J., Daley, J. 2011. Reduced use of pesticides for effective controls of arthropod pests and plant diseases. Journal of Environmental Horticulture. 29(3):143-151.

Improved spray delivery of pesticides to mature poinsettias. ARS researchers in Wooster, Ohio, evaluated the foliar pesticide deposit characteristics in a mature poinsettia canopy when applied by handgun and boom delivery systems in a greenhouse production system. All systems tested had difficulty treating the underside of leaves in the poinsettia canopy. Air-assisted, boom delivery produced the most uniform deposits, which could result in more predictable insect control, however, droplet size decreased with increasing nozzle pressure in the handgun systems. Air entrainment aided delivery in the handgun applications, as well as the air-assist boom systems. This research demonstrated more efficient methods for putting pest management materials where they will provide the most impact and that could lead to reductions

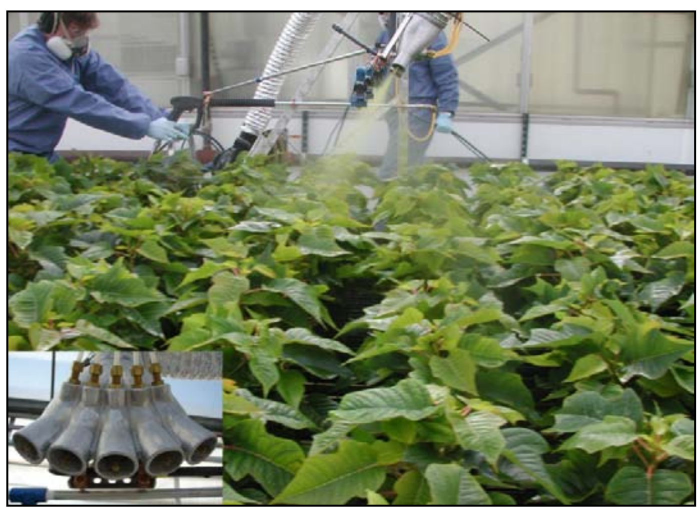

Figure 9: ARS researchers test an air-assisted system for delivering pesticides to poinsettia grown in greenhouses. *Photo by ARS Wooster.*

in pesticide use as a result of more efficient delivery. This supports use of conventional greenhouse spray technology that utilizes air movement to increase deposits and air-assist technology that moves foliage to improve spray deposits and pest control. Using these methods will enable producers to better match the specific pest management need with the pesticide application options they have available.

Derksen, R.C., Ranger, C.M., Canas, L.A., Zhu, H., Krause, C.R. 2010. Greenhouse evaluation of air-assist delivery parameters for mature poinsettias. Applied Engineering in Agriculture. 26(6):947-953.

Variable-rate sprayer developed for nursery liners. Pesticide applications on ornamental nursery tree liners with conventional sprayers for control of pests and diseases are excessive. ARS researchers in Wooster, Ohio, developed a real-time, variable rate experimental sprayer – where spray outputs coincided with canopy sizes – to reduce pesticide usage. The sprayer reduces the average application rates by up to 75 percent and demonstrates that pesticide usage can be greatly reduced when variable rate spray applications are determined by canopy sizes. The potential use of this variable rate sprayer can extend to other fruit crops, including vineyards. Field trials of the sprayer by a leading commercial nursery in Oregon are leading to grower use of the new spray application technologies for improving pesticide use efficiency and safeguarding the environment.

Jeon, H.Y., Zhu, H. 2012. Development of variable-rate sprayer for nursery liner applications. Accepted for publication by Transactions of the ASABE.

Jeon, H.Y., Zhu, H., Derksen, R.C., Ozkan, H.E., Krause, C.R. 2011. Evaluation of Ultrasonic Sensors for the Variable Rate Tree Liner Sprayer Development. Computers and Electronics in Agriculture. 75(1):213-221.

Application of chemical and microbial pesticides through drip irrigation systems. Physical properties of designated pest management agents, especially microbial products are highly variable. Specific evaluation of deliverability for these products applied through drip irrigation systems with flow characteristics was lacking. ARS researchers in Wooster, Ohio, investigated distribution uniformity and recovery rate of chemical and microbial control agents with different physical properties discharged from emitters at various flow capacities throughout drip lines. The pest management agents included a water soluble chemical used to track flow, a suspendable microbial bio-insecticide and a suspendable microbial bio-fungicide, and microbial entomopathogenic nematodes. The researchers demonstrated that drip irrigation could be an alternative method to apply these products, however, their distribution uniformity and recovery rate throughout the drip line varied with the physical properties of the individual product formulation and emitter capacity. This work is now enabling nurseries with drip irrigation systems to apply these products through drip lines as an alternative strategy, resulting in efficient application of pesticides and reduction of a grower's capital investment.

Wang, X., Zhu, H., Reding, M.E., Locke, J.C., Leland, J.E., Derksen, R.C., Spongberg, A.L., Krause, C.R. 2009. Delivery of chemical and microbial pesticides through drip irrigation systems. Applied Engineering in Agriculture. 25(6):883-893.

Application system for entomopathogenic nematodes. Root-feeding larvae are important pests of crops, and biological control agents that offer safer and environmentally friendly advantages have been promoted as an alternative approach to conventional pesticides. Entomopathogenic nematodes when protected within desiccated insect cadavers remain more viable as a control measure of root-feeding larvae than nematodes applied in a water-based solution. ARS researchers in Wooster, Ohio, developed a delivery system based on the crop seed planter concept to apply irregular-shaped, fragile, desiccated cadavers carrying entomopathogenic nematodes into the soil. This inexpensive system was able to dispense the cadavers at predictable rates and depths, and will be a feasible and effective technique to apply biological insecticides for control of soil pests under less than perfect field conditions. The system is being used by university researchers to effectively control white grubs and black vine weevils in nurseries and to reduce nursery production costs associated with damages of stocks by root-feeding insects.

Zhu, H., Grewal, P.S., Reding, M.E. 2011. Development of a desiccated cadaver delivery system to apply entomopathogenic nematodes for control of soil pests. Applied Engineering in Agriculture. 27(3):317-324.

PROBLEM STATEMENT 1C.3: *Develop decision support systems optimized for greenhouse, nursery, and high tunnel production systems.*

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Improved computer decision support aids optimized for greenhouses, high tunnels, and nursery production.
2. Optimized structure design based on location.

PROBLEM STATEMENT 1C.3 SELECTED ACCOMPLISHMENTS:

Virtual Grower 3.0 release for greenhouse management. Growers of greenhouse crops face many complex, interrelated systems on a daily basis wherein one decision influences others in sometimes counterintuitive ways. Virtual Grower software developed by ARS researchers in Wooster, Ohio, allows users to build virtual greenhouses with many different types of materials, select from different fuel types, simulate heating needs and costs, and see the impact of those decisions on the growth and development of commonly grown greenhouse crops. The new version of this program adds supplemental lighting, several more crop species, the ability to add more fuels and materials for testing, improves calculations for energy curtains, and real-time weather calls in which the next 2 days of weather at a grower's U.S. site can be simulated within the model. The software assists both large and small growers in identifying energy (and money) saving strategies in their operations, improves efficient scheduling of crops, and helps growers obtain energy efficiency improvement grants through various funding sources. To date, more than 12,000 copies of the software have been downloaded or distributed around the

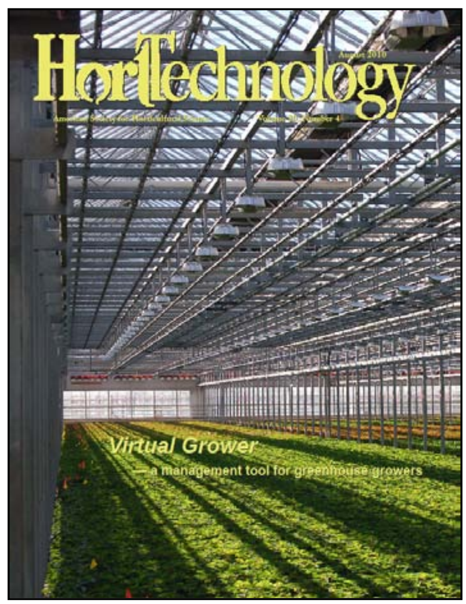

Figure 10: ARS' Virtual Grower decision support software was featured on the cover of HortTechnology in 2010.

world. Virtual Grower was selected as the winner of the Federal Laboratory Consortium's Excellence in Technology Transfer award for 2012. The software is used in dozens of university courses on greenhouse management every year. In Ohio, Virtual Grower has identified savings of over $500,000 annually in five facilities of various sizes. Implementation of those strategies paid for themselves within a year. Virtual Grower (available in English, Spanish, and French versions) can be downloaded free of charge at www.virtualgrower.net .

Frantz, J.M. 2011. Elevating carbon dioxide in a commercial greenhouse reduced overall fuel carbon consumption and production cost when used in combination with cool temperatures for lettuce production. HortTechnology. 21:647-651.

Frantz, J.M., Hand, B., Buckingham, L., Ghose, S. 2010. Virtual Grower: software to calculate heating costs of greenhouse production in the U.S. HortTechnology. 20:778-785.

Energy-efficient management of greenhouse temperature. Energy for heating is a significant expense in the production of greenhouse bedding plants. ARS researchers in Toledo, Ohio, and their university colleagues characterized how a variety of annual bedding plant species grow and develop in response to a range of greenhouse temperatures. Species-specific models were generated that predict the effect of temperature on time-to-flower, enabling greenhouse growers to predict crop timing at different temperatures so as to meet market dates. Growers can use that information with the 'Virtual Grower' computer program to identify production temperatures that consume the least amount of energy using their greenhouse characteristics and location. As a result, growers can potentially lower their energy bill up to 20 percent and improve scheduling accuracy. This information has been disseminated to greenhouse growers at regional and national grower meetings and through a 12-part "Energy-Efficient Annuals" series that appeared in Greenhouse Grower magazine in both print and on their Web site. Growers in northern climates, where heating and lighting represent the largest expenses of crop production, after labor, have implemented these strategies and have reported reduced production times and lower energy expenses.

Blanchard, M.G., E.S. Runkle, and J.M. Frantz. 2011. Energy-efficient greenhouse production of *Petunia* and *Tagetes* by manipulation of temperature and photosynthetic daily light integral. Acta Hort. 893:857-864.

PROBLEM STATEMENT 1C.4: *Develop improved crop production systems for high quality greenhouse, high tunnel, and nursery crops*.

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. New or modified substrate components for floriculture and ornamental production and materials for potted production.
2. Improved production systems for greenhouse, nursery, and high-tunnel production.
3. Production methods for new high-quality product lines that command higher prices/create new niches in the floriculture, nursery, organic, and greenhouse-produced vegetable marketplace.
4. Guidance to improve vase-life of flower species.
5. Production systems for evaluation of new and improved crop varieties for suitability in the greenhouse, high-tunnel, and nursery industries.

PROBLEM STATEMENT 1C.4 SELECTED ACCOMPLISHMENTS:

Guidelines for container production of ornamental crops using WholeTree substrates. There is a continuing need for greater utilization of renewable natural resources in the production of containerized ornamental crops. Container substrates are a vital part of commercial ornamental crop production and account for up to 9 percent of direct costs. ARS researchers in Poplarville, Mississippi, developed guidelines for irrigation and nutrient management for container production of ornamental crops using WholeTree substrates (sustainable alternatives made of pine trees). Using these guidelines, a large greenhouse and a large nursery operation in the southeastern United States have implemented the use of substrates composed of 30 and 80 percent WholeTree mix, respectably, for production of numerous annual, perennial, and woody crops. As research on irrigation and nutrient inputs for WholeTree substrates continues, results will enable increased commercial demand.

Murphy, A., C.H. Gilliam, G.B. Fain, H.A. Torbert, T.V. Gallagher, J.L. Sibley, S.C. Marble, and A.L. Witcher. 2010. Extending pine bark supplies with Wholetree and clean chip residual substrates. Journal Environ. Hort. 28:217-223.

Witcher, A.L., G.B. Fain, E.K. Blythe, and C.T. Pounders. 2011. Nitrogen form affects pH and EC of whole pine tree substrate and growth of petunia. Journal Environ. Hort. 29:213-219.

Switchgrass substrate for nursery and ornamental production. Pine bark is currently used as the primary potting substrate for the nursery industry, but its cost is increasing, its availability decreasing, and it must be transported from the southern United States over long distances. ARS researchers in Wooster, Ohio, developed a new potting substrate comprised primarily of switchgrass, a biofuel crop that can be grown and harvested locally. In tests, this substrate performed as well as traditional pine bark-based nursery substrates. Successful adoption of switchgrass substrate could decrease industry's reliance on pine bark, and subsequently lower substrate cost. Newly developed substrates are being adopted by several nursery producers on a trial basis. This research is a national priority for the American Nursery Landscape Association, and successful implementation is estimated to save up to 66 percent in potting mix costs for container nursery producers.

Altland, J.E. and C. Krause. 2010. Modification of switchgrass substrate pH using compost, peatmoss, and elemental sulfur. HortTechnology. 20:950-956.

Novel growth substrates developed for floriculture production. Floriculture production needs a better means to mitigate the effect of biotic and abiotic stress induced by multi-day lack of soil hydration and nutrient availability. ARS researchers in Toledo, Ohio, developed a bi-layer hydrogel to separate the swelling requirement from that of low dehydration rates and mechanical strength, providing a soft inner layer surrounded by a hard outer layer. Additionally, a material made from polyethylene was evaluated as a potentially reusable substrate for containerized floriculture production. The polyurethane coated gels produce excellent results, maximizing water absorption of the inner layer, while retaining sufficient compressive strength and reduced dehydration time of over a week. These hydrogels assist in not only more water efficient production strategies, but also in improving nutrient delivery in containerized plant production. The polyethylene holds promise for seedling germination because of its convenient-to-use design, but was not able to hold sufficient water when mixed with peat-based substrates. A version of the polyethylene material is being used as a hydroponic substrate.

Kim, S., G. Inyer, A. Nadarajah, A. Spongberg, and J.M. Frantz. 2010. Polyacrylamide hydrogel properties for horticultural applications. International Journal of Polymer Analysis and Characterization. 15:307-318.

Nutritional requirements for optimal growth and photographic keys for nutrient stress of floricultural crops. There are hundreds of floricultural crops on the market today and all have unique nutrition requirements and responses to nutritional stress. Learning how to fertilize these crops and recognize signs of nutritional stress is done primarily through trial and error, resulting in production inefficiencies and crop loss. ARS researchers in Toledo, Ohio and their university colleagues evaluated several commonly grown herbaceous ornamentals for appropriate nutrient supply rates and documented visual deficiency and toxicity symptoms of mineral nutrients. These photographic keys and elemental recommendations were combined into grower-friendly keys and used to hold hands-on grower workshops in nutrient diagnostics. Now, species-specific books are being developed with this information to assist in fertility management. Workshops and information exchange help growers identify nutrient disorders. This information results in less crop loss and guidance in correcting fertility management mistakes. Some large germplasm suppliers have adapted the photographic guides for their how-to-grow guides for specific germplasm for distribution to hundreds of growers nationally.

Jeong, K.Y., B.E. Whipker, I. McCall, C.C. Gunter, and J. Frantz. 2011. Characterization of nutrient disorders of pot rose ‘Karina Parade.’ Acta Hort. 891:125-133.

Davis, K.I., C.E. Niedziela Jr., M.R. Reddy, B.E. Whipker, and J.M. Frantz. 2011. Nutrient disorder symptomology and foliar concentrations of *Clerodendrum thomsoniae*. J Plant Nutrition. 34:1079-1086.

The influence of supplemental carbon dioxide on abiotic stress for crops. Use of supplemental carbon dioxide is not only a potential production practice in protected horticultural environments, but rising carbon dioxide is a long-term likelihood in field production practices. The influence of carbon dioxide on plant growth is well documented, but its influence over how plants exhibit and respond to stress is less well documented. ARS researchers in Toledo, Ohio, determined the influence of carbon dioxide on fertility demand of some floricultural crops, as well as the timing of onset, severity of nutritional disorder symptoms, and the influence of carbon dioxide on other abiotic stress (ozone, light, temperature). Generally, carbon dioxide could alleviate some stress (light and temperature extremes), exacerbate others (ozone), and change the apparent demand for nutrients. This information can be used to alter production practices and recommendations for those who utilize carbon dioxide supplementation, while providing information on what to anticipate in a future, high- carbon dioxide world. Commercial floriculture facilities are exploring its use in seedling or plug production.

Mishra, S., S.A. Heckathorn, J.M. Frantz. 2011. Elevated CO_2 affects plant responses to variation in boron availability. Plant & Soil. 350:117-130.

Frantz, J.M. and P. Ling. 2011. Growth and partitioning of *Petunia* × *hybrida* Vilm. are influenced by altering light, CO_2, and fertility. HortScience. 46:228-235.

Timing of nutrient application affects fertilizer use for container-grown nursery plants. ARS researchers in Corvallis, Oregon, found that fertilizer uptake efficiency of container-grown *Rhododendron* is low until July, indicating that fertilizer application prior to this time may not be effectively taken up by plants. Additionally, nitrogen application rates are not proportionally related to uptake of other nutrients, and nitrogen deficiency decreases a plant's ability to take up certain nutrients. These results can be used to improve efficiency of nutrient use and decrease fertilizer use in production of container-grown nursery crops by providing growers and fertilizer manufacturers with information on how to optimize fertilizer application based on rate, timing, method of nitrogen application, and cultivar.

> Scagel C.F., G. Bi, L.H. Fuchigami, and R.P, Regan 2011. Nutrient uptake and loss by containter-grown deciduous and evergreen Rhododendron nursery plants. HortScience. 46:296-305.

Spraying hydrangea leaves in the autumn alters defoliation efficiency, growth, and flowering characteristics. Chemical defoliation and growth regulators commonly used during the production of florists' hydrangea can decrease product quality. ARS researchers in Corvallis, Oregon, determined optimal concentrations for use of defoliants on hydrangea at different times in the autumn and found spraying foliage with urea in the autumn can ameliorate some of the negative effects of defoliants and growth regulators on performance during forcing. These results may be used by growers and extension personnel to develop alternative nitrogen management strategies for production of herbaceous perennial nursery crops that improve product quality, decrease production costs, and encourage use of environmentally sustainable practices. This research is stimulating activity by woody and herbaceous nursery crop producers for using foliar urea to improve product quality.

> Bi, G., and C.F. Scagel. 2009. Effects of fall applications of chemical defoliants, urea, and gibberellic acid on defoliation in the fall and plant performance of hydrangeas during forcing. HortScience. 44:1604-1607.

Use of thidiazuron to extend vase life. Leaf yellowing, a symptom of aging, is a significant quality problem in a wide range of potted plants, and also reduces the quality, value, and vase life of cut flowers. ARS researchers in Davis, California, found that leaves on thidiazuron-treated potted plants, such as tulip, cyclamen, poinsettia, and geranium remain dark green for more than a month, while leaves on the untreated plants display yellowing or fall off during the same time period. Thidiazuron also delays leaf yellowing and flower senescence in alstroemeria, stock, and lilies, and extends the life of Iris and Bird-of-Paradise flowers. The approach is receiving great commercial interest among California floral producers and registration of the product is being pursued.

> Macnish, A.J., C.-Z. Jiang and M.S. Reid. 2010. Treatment with thidiazuron improves opening and vase life of iris flowers. Postharvest Biology & Technology 56: 77-84.

Chemical compounds for controlling Botrytis infection. Infection by the fungus *Botrytis cinerea* is one of the most common pathogen problems in postharvest ornamentals. ARS researchers in Davis, California, identified several highly promising fungistatic compounds, such as a chlorine-based oxidizer (e.g. bleach), as having potential to control Botrytis disease on cut rose flowers. They also found that the efficacy of fungicides to prevent Botrytis infection on rose flowers was greatest when fungistatic compounds were applied approximately 6 hours after harvest. These results highlight the potential of a simple and safe biocide and the importance of treating the fungus at its most vulnerable development stage for reducing postharvest *Botrytis* infection on rose flowers. Several California potted plant growers are interested in using the technology.

Macnish, Andrew J., Kristy L. Morris, Annemarie de Theije, Manon G.J. Mensink, Henry A.M. Boerrigter, Michael S. Reid, Cai-Zhong Jiang, Ernst J. Woltering. 2010. Sodium hypochlorite: A promising agent for reducing Botrytis cinerea infection on rose flowers. Postharvest Biology and Technology. 58:262-267.

An alternative postharvest handling strategy developed for cut flowers. Immediate postharvest hydration is conventionally considered to extend the postharvest life of flowers by reducing desiccation. ARS researchers in Davis, California, found that dry-handled flowers show less transportation damage (largely petal bruising), presumably because of reduced turgor and total volume. Despite substantial loss of water during transport, dry-handled flowers rehydrate fully, and performed at least as well in the vase as flowers handled according to the standard protocol. The technology is being commercially evaluated by a large commercial rose producer in Ecuador that ships to the United States.

Macnish, A.J., A. deTheije, M.S. Reid and C.-Z. Jiang. 2009. An alternative postharvest handling strategy for cut flowers – dry handling after harvest. Acta Hort. 847:215-221.

COMPONENT 2: Bees and Pollination

Bees play a clear and vital role in agricultural and wild ecosystems by providing pollination services to plants. In the United States, bees are vital to the production of more than 90 crops, including almond, alfalfa, apples, cherries, melons, and berries. Commercially managed bees, such as the honey bee (*Apis mellifera*), the alfalfa leafcutting bee (*Megachile rotundata*), and bumble bees (*Bombus* spp.), are the nation's principal pollinators. The honey bee is particularly versatile, pollinating a variety of crops worth billions of dollars, and producing other economically important products such as honey, wax, and bee pollen. The use of other kinds of managed bees (non-*Apis* bees) for pollination has been growing for certain specialty crops, especially alfalfa seed, canola, hybrid seed production, and covered crops (such as in greenhouses and covered row crops). Many native bees provide pollination services for native plant communities, which is crucial to the restoration of damaged ecosystems.

For those reasons, the research under this component of NP 305 focuses on the health and production issues associated with the use of bees in agriculture. It is divided into two Subcomponents, each with two Problem Statements: Subcomponent 2A highlights the issues facing honey bees (*Apis*) and Subcomponent 2B deals with the issues facing non-*Apis* bees.

The NP 305 Action Plan identified 36 Anticipated Products which were expected to result from research expressed in the various Problem Statements under the two Subcomponents. These Anticipated Products now serve to help measure the national program's progress during the past 5 years in meeting the needs of crop researchers and producers. Under each of the Problem Statements, the report will list the accomplishments that highlight our progress in meeting the Anticipated Products for that Problem Statement. Because of the nature of the research, many accomplishments may contribute to more than one Anticipated Product.

Honey bee research is conducted at seven ARS locations, each specializing in a different aspect: bee breeding (Baton Rouge, Louisiana); bee disease (Beltsville, Maryland); bee integrated pest management (Weslaco, Texas); bee health (Tucson, Arizona); semiochemical communication (Gainesville, Florida); cell culture (Fort Pierce, Florida), and, bee physiology (Fargo, North Dakota). ARS also has a laboratory in Logan, Utah, that specializes in management of non-*Apis* bees. RNAi technology for bee health is now being developed at several laboratories, especially Fort Pierce, Beltsville, Gainesville, and Weslaco.

SUBCOMPONENT 2A: HONEY BEES [*APIS*]

An extremely important crop production system, bees are threatened by a myriad of problems, including invasive pests and pathogens, pesticide exposure, loss of habitat, and poor nutrition. These factors, individually and in combination, threaten the long-term viability of bee industries, and the agriculture of crops dependant on bee pollination.

However, since 2006, a new malaise has stricken the industry – Colony Collapse Disorder (CCD) – and devastated the hives of many commercial beekeepers. A recent and very serious threat to the survival of the honey bee industry, CCD is defined by the sudden dwindling of bees coming out of overwintering, with a queen, some brood, and a few nurse bees remaining in the hive, but at levels below that needed (10,000 bees) for colony survival. If allowed to progress unchecked, CCD has significant consequences for crops such as almond that are almost entirely dependent on the honey bee for pollination.

The strength of ARS research is that it is well positioned to address multi-faceted problems, such as CCD, for which no single cause has been determined. ARS scientists have long conducted research on these and other problems inflicting honey bee survival, and have developed extensive capacity and expertise of international renown.

PROBLEM STATEMENT 2A.1: ***Improving honey bee health.***

National coordination of the Federal research response to Colony Collapse Disorder. ARS national program leaders and scientists, recognizing the significance of CCD to American agriculture, mobilized Federal, State, university, and private researchers to define a coordinated, collaborative research approach to determine the causes and potential remedies for CCD. These efforts led to the formation of the Federal CCD Steering Committee, co-chaired by ARS and NIFA and composed of representatives of five USDA agencies and the U.S. Environmental Protection Agency (EPA). To help define the needs and coordinate the research going forward, ARS organized a 2-day CCD Workshop of 66 apiculture experts from government, university, and industry in April 2007 to identify research gaps and priorities, as well as measures required to address these needs. Based on information gathered at the workshop, the Steering Committee identified critical research and response needs and developed and published a CCD Action Plan (www.ars.usda.gov/is/br/ccd/ccd_actionplan.pdf) in June 2007.

The Action Plan strategy for addressing the CCD crisis at that time involved four main components: 1) Survey and data collection; 2) Analysis of samples; 3) Hypothesis-driven research; and 4) Mitigation and preventative action. The research tied to this Action Plan is dedicated to resolving this issue, while simultaneously improving pollinator health. ARS national program staff is planning a second CCD Workshop for October 2012 to review progress and determine new research goals for the coming years. The Workshop discussion will be the basis for the revision of the CCD Action Plan in 2013.

Many organizations, public and private, in addition to those represented on the Steering Committee, are involved in the work to address the CCD problem. While causation by a single factor has not been nullified as yet, research by ARS scientists and others increasingly point to there being many causes with many factors interacting.

Soon after the development of the CCD Action Plan, ARS started working with collaborators to determine the rate of honey bee colony losses in the United States by conducting a large survey during the fall-winter periods of 2007-2011. The overall losses were determined to be due to a variety of causes and remained steady during this time period, averaging about 30 percent for each fall-winter period. Some large commercial beekeepers were economically devastated by CCD.

ARS researchers also conducted a descriptive epidemiological study describing the level of pests and other pathogens present in CCD versus non-CCD colonies. Researchers documented high pathogen loads in colonies suffering from CCD, suggesting that CCD is an interaction between pathogens and other factors. These findings prompted ARS scientists, in collaboration with their university colleagues, to conduct a genomic meta-analysis of the samples, which established a link between a new virus, Israeli acute paralysis virus and CCD. However, because ARS scientists had done a broad survey of the bee sample collection long before CCD, they were able to determine that Israeli acute paralysis virus had been in the country long before the appearance of CCD. While Israeli acute paralysis virus may not be the cause of CCD, these research efforts were nevertheless fundamental to beginning a process of delineating the cause(s).

Following the Israeli acute paralysis virus findings, the newly invasive fungus *Nosema ceranae* emerged as a suspected cause of CCD in Europe, particularly in Spain. However, ARS researchers – despite finding that *N. ceranae* has almost entirely displaced the closely related fungus *N. apis* in the United States – found only a weak association between the incidence of *N. ceranae* and CCD. However, ARS researchers did find increased titers of *Nosema* spores in adult honey bees exposed to low levels of imidacloprid (an insecticide). Together with a growing body of evidence from university laboratories, this antagonism reinforces the hypothesis that multiple factors play a role in CCD.

ARS also focused on general bee health and vigor, initiating a 5-year Areawide Program (*Improving Honey Bee Health, Survivorship and Pollination Availability*) in 2008. This program demonstrated good bee management practices to maintain healthy bees despite the pressures of CCD. This program used ARS-developed technologies such as varroa mite-resistant bee strains, improved feeding supplements for building colonies early in the spring, and developed biorational miticides based on both beta plant acids and bee pheromones. Generally, beekeepers that followed this regimen had sustainable bee operations.

Overall, countering the effects of biological and environmental factors on the health and well-being of the honey bee colony requires a sustained, comprehensive, multi-disciplinary effort, especially given the broad scope of these factors. Progress in honey bee research has been accelerated by greater use of genomics and molecular markers, microarrays, and other molecular strategies such as RNAi, a trend that will increase over the next few years. ARS scientists helped lead the sequencing of the honey bee genome in a large international effort, and lead the successful sequencing of key pathogens (*Paenibacillus larvae*, *Ascosphaera apis, N. apis,* and *N. ceranae*) and pests (varroa mite). Newly hired ARS scientists are now beginning to use the honey bee genome in marker-assisted selection to improve bee lines. ARS findings such as heritable traits for immunity to *P. larvae* encourage this strategy.

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Traps, lures, soft pesticides, and other IPM tools for management of bee pests and protection of hive products.
2. Bee cell cultures for bee virus isolation, diagnosis, and study.
3. Supplements that can be added to larvae grafted into cells to be reared into queens that will enhance feeding by nurse bees.
4. Dietary supplements for queen-rearing and drone production colonies.

5. Resistance management programs, especially for varroa.
6. Methodologies for minimizing bee exposure to insecticides.
7. Increased knowledge about the role of chronic pesticide exposure and other environmental stresses on bee health, and role of stress in promoting CCD.
8. Better pollen and nectar substitute diets for improved strength of colonies for early season crops, such as almond.
9. New control strategies and products for management of nosema.
10. Nutritional supplements to reduce the occurrence and impact of pathogens and mites.
11. Tailored nutrition management systems based on monitoring the quality of forage, *e.g.*, as affected by weather conditions.
12. Information for plant breeders on the nutritional characteristics desired for healthy bees.
13. Better understanding of the roles of non-pathogenic bacteria in maintaining bee health.

PROBLEM STATEMENT 2A.1 SELECTED ACCOMPLISHMENTS:

Elucidating the chemistry of host finding by the varroa mite. Varroa mites, the most serious pests of honey bees and the major cause of hive loss in the United States, are extremely difficult to control with pesticides and therefore alternative strategies of control must be developed. The varroa mite parasitizes honey bees, transmits viruses, and likely contributes significantly to CCD. ARS scientists in Gainesville investigated the semiochemical communication system used by varroa mites to invade honey bee larval cells and identified two chemicals that might be useful in controlling the mites. One of the chemicals identified attracts mites into empty cells and keeps them from leaving, while the other repels the mites. ARS research documented that these attractants can be used to cause phoretic mites to leave adult bees, and that communication in mites can be disrupted by flooding the hive environment with the chemicals. This research served as the foundation for a patent filing (September 2011 - log #273867) for the use of these compounds in controlling varroa mites.

Lures and traps developed for the small hive beetle. The small hive beetleinfests bee hives, destroying the nest, killing the brood, and driving away the bees. To facilitate its invasion, the small hive beetle carries yeast that grows on pollen in the hive and emits an odor that is highly attractive to fellow beetles, setting off a large influx of beetles into the hive. Using lures based on these aromatic compounds, ARS scientists in Gainesville developed three different types of traps: a trap for placing inside the hives to capture beetles; another for placing at the entrance to trap beetle larvae as they exit to pupae in the soil; and a third for placement in the bee yard to monitor beetle populations. Use of these trapping technologies has been shown to reduce honey bee colony loses due to the small hive beetle. The traps have not as yet been commercialized, but the Gainesville laboratory has been supplying cooperators with all necessary plans and protocols, and the traps are currently in use in both the United States and Canada.

Teal, P.E.A., Torto, B., Tumlinson, J.H., Boucias, D.G. In hive trap and attractant composition for the control of the small hive beetle, *Aethina tumida*. U. S. Patent 7,309,274. Issued 2007.

Torto, B., Boucias, D.G., Arbogast, R.T., Tumlinson, J.H., Teal, P.E. 2007. Multitrophic interaction facilitates parasite-host relationship between an invasive beetle and the honey bee. Proceedings of the National Academy of Sciences. 104(20):8374-8378.

Movement of the small hive beetle worldwide. Small hive beetles have spread to Australia and North America in the past 15 years. Along with economic impacts on queen rearing and colony development, these beetles are now regulated to avoid their spread into Europe, affecting U.S. queen exportations. Genetic analyses by ARS scientists in Beltsville revealed the origins of two new populations of the small hive beetle in Australia and Canada. These beetles left sub-Saharan Africa at least twice, and continue to spread to countries that do not accept bee importations (e.g., Australia). Genetic results suggest a need for improved vigilance of bee and beetle movement, and will show over time whether specific races of this beetle have higher impacts on bees. APHIS is aware of these beetle movements, but no action is warranted since the beetles are already well established in the United States. There, however, continue to be some border concerns, and regulation for specific states (i.e., Hawaii).

Lounsberry, Z., S. Spiewok, S. F. Pernal, T. S. Sonstegard, W. M. Hood, J. Pettis, P. Neumann, and J. D. Evans. 2010. Worldwide diaspora of *Aethina tumida* (Coleoptera: Nitidulidae), a nest parasite of honey bees. Annals of the Entomological Society of America 103: 671-677.

Remediation of bee nesting materials through irradiation and ozone fumigation. It is not uncommon for beekeepers to transfer comb from one hive to another, even from dead colonies to new ones. ARS scientists in Beltsville demonstrated that this practice decreases the chances of survival in the new colony, presumably due to pathogen or pesticide transfer. After 9 months, 70 percent of colonies with gamma irradiated comb survived, compared to 30 percent survival of colonies receiving untreated combs. This demonstrates that comb re-use can negatively impact colony survival and that comb remediation techniques are necessary.

In addition, ARS scientists in Logan demonstrated that ozone can break down pesticides, kill insect pests, and kill pathogen spores when used at very high concentrations. The research showed that ozone is effective against wax moths and small hive beetles at 920 milligrams ozone/cubic meter. However, ozone was only effective against foulbrood spores when used at 8,560 milligrams ozone/cubic meter for 3 days in combination with high temperature (122^{o}F) and high humidity. These results indicated that ozone might be developed as a fumigant to decontaminate honey bee supers, honey comb, and alfalfa leafcutting bee nesting boards, but it cannot be used on the bees themselves, and beekeepers may not be able to realistically achieve the conditions necessary to kill all diseases.

James, R. R. 2011. The potential of ozone as a fumigant to control pests in honey bee hives. J. Econ. Entomol. 104(3): 353-399.

vanEngelsdorp, D., Speybroeck, N., Evans, J.D., Nguyen, B., Mullin, C., Frazier, M., Frazier, J., Cox-Foster, D., Chen, Y., Tarpy, D., Haubruge, E., Pettis, J.S., Saegerman, C. 2010. First analysis of risk factors associated with bee colony collapse disorder by classification and regression trees. Journal of Economic Entomology. 103:1517-1523.

New medium for the development of bee cell cultures. A stable cell culture method is needed to enable the purification and production of host-dependent pathogens, such as nosema and viruses, and reveal their biology. ARS scientists in Fort Pierce developed a new medium and used it to produce cell lines from honey bee larvae and pupae, and from alfalfa leafcutting bee eggs. For both bee species, cell lines survived for up to a year, an important step towards permanent establishment. Multiple cell types were observed in culture, including fibroblast-like and epithelial-like monolayers.

Hunter, WB. 2010. Medium for development of bee cell cultures (*Apis mellifera*: Hymenoptera: Apidae). In Vitro Cell. Dev. Biol. Animal 46:83-86.

RNAi technology – a new strategy for controlling infectious diseases and parasites of bees. Israeli acute paralysis virus, a pathogen suspected of being linked to CCD, is a single-stranded, RNA virus with no DNA stage. ARS scientists in Fort Pierce, in collaboration with university, industry (Beeologics), and military partners, have developed a new control strategy that uses RNA interference (RNAi) technology to protect bees against Israeli acute paralysis virus infections. In efficacy tests conducted in bee colonies in two different climates (Florida and Pennsylvania), no bees were infected when colonies exposed to the virus were fed the new RNAi-based drug via a sugar solution. This technique not only shows potential for controlling Israeli acute paralysis virus, and thus perhaps reducing CCD, but it could be adapted to target and control other bee pests as well. World-wide, this was the first large-scale field proof-of-concept use of RNAi for bee disease control.

Additionally, ARS scientists in Beltsville showed in laboratory assays that *Nosema* was vulnerable to an RNAi control strategy.

In related work, the genome of the varroa mite was sequenced, revealing potential weak points in mite biology (defensive proteins and proteins used in chemical mitigation) and candidates for novel control, such as RNAi. ARS scientists in Beltsville led both the genome description and follow-up work that identified microbes and other novel candidates for mite control. This information was used in Gainesville by ARS researchers to identify and sequence two vitellogenin genes responsible for varroa egg development and documented physiological interactions with honey bees that induce up-regulation of the genes in the mites. The researchers have now used RNAi to down-regulate vitellogenin genes (publication in preparation), and plan to use this technology to develop novel methods for pest control by inhibiting reproduction.

Cornman, S. R., M. C. Schatz, S. J. Johnston, Y. Chen, J. Pettis, G. Hunt, L. Bourgeois, C. Elsik, D. Anderson, C. M. Grozinger, and J. D. Evans. 2010. Genomic survey of the ectoparasitic mite *Varroa destructor*, a major pest of the honey bee *Apis mellifera*. BMC Genomics 11:602.

Hunter, W, Ellis, J, vanEngelsdorp, D, Hayes, J, Westervelt, D, Glick, E, Williams, M, Sela, I, Maori, E, Pettis, J, Cox-Foster, D, Paldi, N. 2010. Large-Scale Field Application of RNAi Technology Reducing Israeli Acute Paralysis Virus Disease in Honey Bees (*Apis mellifera*, Hymenoptera: Apidae). PLoS Pathology 6(12): e1001160.

Paldi, N., E. Glick, M. Oliva, Y. Zilberberg, L. Aubin, J. Pettis, Y. Chen, and J. D. Evans. 2010. Effective gene silencing in a microsporidian parasite associated with honeybee (*Apis mellifera*) colony declines. Applied and Environmental Microbiology 76: 5960-5964.

Bees with varroa sensitive hygiene trait resistance against varroa mite commercialized. To expand the use of bees with desired traits such as varroa resistance, there is need to find the genes conferring the resistance and then introducing (introgressing) the genes into bee stock with other desired traits. ARS scientists in Baton Rouge showed that bees with the trait of suppressed mite reproduction achieved resistance by removing mites from developing brood in capped cells;

thus, the trait was renamed varroa-sensitive hygiene (VSH). VSH bee colonies tend to uncap more infested cells, reduce mite infestation, and reduce mite fertility. Together, these factors confer strong resistance to varroa mites. In a 3-year field test, VSH bee colonies required less treatment against varroa than did Italian-based control stock, and had honey yields that were comparable to that of Italian colonies. The genetic trait for VSH has now been introgressed into bee lines favored by beekeepers, and bees with the VSH trait have now been released by ARS to industry as publically available breeding stock and are widely commercialized. It is estimated that at least 25 percent of the honey bee queens now being sold contain the VSH trait. This success in VSH research and development resulted in one of the top U.S. awards for technology transfer, a Federal Laboratory Consortium Award for Excellence in Technology Transfer in 2012 for ARS.

Figure 11: Two worker bees with the varroa sensitive hygiene trait detecting varroa mites and removing them from the colony. *Photo by Robert Danka – ARS.*

Harbo, J.R., Harris, J.W. 2009. Responses to varroa by honey bees with different levels of varroa sensitive hygiene. Journal of Apicultural Research 48(3):156-161

Villa, J.D., Danka, R.G., Harris, J.W. 2009. Simplified methods of evaluating colonies for levels of varroa sensitive hygiene (VSH). Journal of Apicultural Research 48(3):162-167

Ward, K., Danka, R.G., Ward, R. 2008. Comparative Performance of Two Mite-Resistant Stocks of Honey Bees (Hymenoptera: Apidae) in Alabama Beekeeping Operations. Journal of Economic Entomology. 101(3):654-659.

Russian honey bee lines resistant against varroa mite, tracheal mites, and small hive beetle commercialized. ARS researchers in Baton Rouge have focused on breeding bees resistant to the varroa mite, which prompted the discovery of honey bees in Russia with some resistance to the mite. After importation to the United States, the bees were intensively selected to produce a commercially desirable varroa-resistant stock. The bee also was found to be very resistant to tracheal mites and American foulbrood, and somewhat resistant to *nosema*, and to harbor fewer small hive beetles than Italian bee colonies. Varroa mite population growth rates in Russian colonies were evaluated over three seasons and found to be consistently lower than in Italian colonies (70-fold). Mite infestation levels were lower in both worker and drone brood cells and the phoretic (non-reproductive) stage of the mites was extended in the Russian colonies. There are two mechanisms of resistance: Russian bees uncapped and removed varroa from infested brood cells, and removed the mites through frequent auto-grooming. Tracheal mite resistance is dependent on a few major dominant genes interacting with minor genes. These advances in understanding resistance mechanisms makes it possible to phenotype breeding stock and, potentially, to develop marker-assisted breeding. ARS lines of Russian bees have now been transferred and are being used by the bee industry, with 14 commercial bee breeders having certified pure Russian stock. The demand is high for these bees and the breeders have reported that their anticipated production is sold out a year or more in advance. Other queen producers also sell Russian queens and several commercial honey producer/pollinators have bought queens and are selecting their own breeding stock from these. Commercial adoption is reasonably strong and is accelerating. Although resistance to beetles is not sufficient to entirely prevent infestation, Russian queens clearly play multiple roles in an integrated strategy that controls multiple hive pests, while reducing pressure to use miticides, thereby functioning as an integral part of a pesticide resistance management program. Beekeepers that use production Russian honey bees can control varroa by very infrequent use of "soft" chemicals, such as thymol, have no need to control tracheal mites, and yet can have colonies that will exceed standards for pollination and produce exceptional honey crops.

Villa, J.D., Rinderer, T.E. 2008. Inheritance of resistance to *Acarapis woodi* (Acari: Tarsonemidae) in crosses between selected resistant Russian and selected susceptible U.S. honey bees (Hymenoptera: Apidae). Journal of Economic Entomology 101(6):1756-1759(4).

De Guzman, L.I., Frake, A.M., Rinderer, T.E. 2008. Detection and removal of brood infested with eggs and larvae of small hive beetles (*Aethina tumida* Murray) by Russian and Italian honey bees. Journal of Apicultural Research and Bee World 47(3):216-221.

De Guzman, L. I., Rinderer, T. E., and Frake. A. M. 2007. Growth of *Varroa destructor* (Acari: Varroidae) populations in Russian honey bee (Hymenoptera: Apidae) colonies. Ann. Entomol. Soc. Am.: 100: 187-195.

Genome of the honey bee pathogen Nosema ceranae sequenced. The prevalence and impact of nosema disease has increased dramatically in the past few years. To better understand how *Nosema ceranae*, a key fungal suspect in CCD, affects bees and to provide insights and tools for industry and researchers seeking to minimize the disease, ARS researchers in Beltsville led a collaborative project to sequence and describe the genome of this microbe. From the genome, molecular markers are being used to investigate fungal vulnerabilities, including finding RNAi targets for control. Also, the fungus was found to have a compact genome, relying on its bee host to provide critical proteins. This suggests another means of control – interrupting the fungus' relationship with its bee host.

Paldi, N., E. Glick, M. Oliva, Y. Zilberberg, L. Aubin, J. Pettis, Y. Chen, and J. D. Evans. 2010. Effective gene silencing in a microsporidian parasite associated with honeybee (*Apis mellifera*) colony declines. Applied and Environmental Microbiology 76: 5960-5964.

Cornman, R. S., Y. P. Chen, M. C. Schatz, C. Street, Y. Zhao, B. Desany, M. Egholm, S. Hutchison, J. S. Pettis, W. I. Lipkin, and J. D. Evans. 2009. Genomic analyses of the microsporidian *Nosema ceranae*, an emergent pathogen of honey bees. PLoS Pathogens 5(6):e1000466.

Pathology and spread of Nosema disease. Believed to be a new invasive pathogen, *Nosema ceranae* was actually in the United States as early as 1984, and its geographic range is much more extensive than previously thought, almost completely displacing *N. apis*. ARS scientists in

Beltsville found that *N. ceranae* proliferates in more honey bee tissues than *N. apis*, invading the host well beyond the gut wall, whereas *N. apis* is most prevalent in the gut. Microarray analysis revealed that nosema infection alters bee nutrition and behavioral maturation, as expected, but also that the parasite displayed an ability to suppress bee immune response after invasion. This knowledge is being used in breeding bees for resistance.

Chen, Y., J. D. Evans, L. Zhou, H. Boncristiani, K. Kimura, T. Xiao, A. M. Litkowski, and J. S. Pettis. 2009. Asymmetrical coexistence of *Nosema ceranae* and *Nosema apis* in honey bees. Journal of Invertebrate Pathology 101:204-209.

Chen, Y. P., J. D. Evans, C. Murphy, R. Gutell, M. Zuker, D. Gundensen-Rindal, and J. S. Pettis. 2009. Morphological, molecular, and phylogenetic characterization of *Nosema ceranae*, a microsporidian parasite isolated from the European honey bee, *Apis mellifera*. Journal of Eukaryotic Microbiology 56(2):142-147.

Bee health reduced by pesticides (including sub-lethal doses), pesticide interactions, and pathogens. ARS scientists and their university collaborators conducted an extensive survey to determine the levels of pesticide contamination in honey bee colonies in the United States. The survey documented high levels of a broad range of pesticides (98 in all) in the beeswax and pollen of both dying and healthy colonies, revealing the complexity of potential interactions of this kind. These pesticides have served as leads for more intensive, detailed studies of pesticide exposure and effects on bee health. Furthermore, the study highlighted the persistence of some products used to control hive pests, especially varroa mites. Pesticides, particularly the sub-lethal effects of pesticides and their synergistic interactions with other mortality factors, are prime suspects in CCD causation. While there is still little published evidence in support of such claims, the following results of ARS research supports the need to continue this line of inquiry:

- A fungicide commonly used by almond growers (Vanguard) was found by ARS scientists in Weslaco to interact with another varroa control chemical (Hivastan, fenpyroximate), to increase bee mortality. These results support findings at universities that fungicide-pesticide interactions can overload cytochrome p450 detoxification mechanisms in bees, and suggests that one or the other product (fungicide or miticide) should not be used during bloom.
- ARS scientists in Beltsville tested the interaction between a widely used neonicotinoid pesticide (imidacloprid) and the common gut pathogen nosema. Honey bee adults exposed to sub-lethal doses of imidacloprid developed higher titers of nosema spores than did non-exposed bees. The research determined that queen rearing was negatively affected when bees are fed pollen contaminated with fungicides and pesticides. The studies revealed that queen emergence rates are reduced and the incidence and titers of viruses are greater when contaminated pollen is fed to queen rearing colonies. If, as the literature suggests, sub-lethal exposures to pesticides affect insect immunity, these environmental toxins might affect honey bee colony collapse, thus adding important evidence to the growing consensus that maladies, such as CCD, might be the result of synergisms between multiple factors.

Pettis, J. S., D. van Engelsdorp, J. Johnson, G. Dively 2012. Pesticide exposure in honey bees results in increased levels of the gut pathogen *Nosema.* Naturwissenschaften 99:153-158.

Mullin, C., Frazier, M., Frazier, J.L., Ashcraft, S., Simonds, R., van Engelsdorp, D., Pettis, J.S. 2010. High levels of Miticides and Agrochemicals in North American Apiaires: Implications for honey bee health. PLoS One 5(3): e9754. DOI:10.1371.

Eischen, F. A., Graham, R. H., and Rivera. P. 2009. A simulation of conditions associated with a bee kill during fenpyroximate (Hivastan) application in California, 21 April – 4 June, 2009. A report submitted to Central Life Sciences (Wellmark).

New varroa mite treatments developed based on beta plant-acids. Beekeepers need new, effective miticides for control of varroa, ones that can be used to reduce development of resistance to currently used synthetic miticides, and ones that can be used by organic growers and that are environmentally benign. ARS scientists in Tucson used plant acids to create a highly effective varroa mite treatment. These plant acids are food grade compounds and are on the FDA's 'generally recognized as safe' (GRAS) list. A cardboard delivery system dispersed the compounds adequately throughout the colony within 48 hours, without causing adult or immature bee mortality. The bees remove the delivery device when the product is gone. The plant acids did not disrupt queen egg laying or colony growth, and did not accumulate in wax comb. When the beta acids were found in honey, the levels were tolerable (less than 100 parts per billion). A product was developed under a cooperative research and development agreement and is in commercial production under the name HopGuard® http://betatechopproducts.com/products/varroa-mite-control). This research was recognized with Federal Laboratory Consortium Award of Excellence in Technology and Transfer and an ARS Technology Transfer Award. The product is currently available in 23 states under Section 18 registration. To date, more than 14,000 HopGuard® kits have been sold; enough to treat more than 350,000 colonies. A manuscript is in review.

Protein supplement is comparable to feeding pollen. Several protein supplements are available commercially, and beekeepers use these supplements to feed their colonies when flowering plants are unavailable. ARS scientists in Tucson, in collaboration with industry and ARS scientists in Baton Rouge and Beltsville, developed and tested the protein supplement diet MegaBee (also called the Tucson Diet) that has now been commercialized (www.megabeediet.com/index.html). MegaBee was found to be comparable to naturally collected pollen in attractiveness to bees, consumption rates, and in stimulating colony growth. However, it was not known whether pollen substitutes are as entirely nutritious as pollen. ARS scientists also found that bees fed a MegaBee diet, as they aged, had significantly greater protein concentrations, hypopharyngeal gland (where brood food is produced) development, and immune response than occurred in bees fed only sugar syrup. ARS scientists at Tucson also developed a candy board formulation as a palatable, but less expensive method than the standard patty for feeding MegaBee pollen substitute to bees. The candy board stimulated brood production and colony growth to levels comparable to the patty, and at lower cost. These results suggest that, indeed, the MegaBee protein supplement is comparable to bee pollen and can sustain colony growth and health during intervals when pollen is unavailable.

In related work, ARS researchers found a reduction in deformed wing virus titers in bees fed either pollen or MegaBee. Virus titers increased in worker bees over the same time interval when fed a diet without protein. Results suggest a connection between diet, protein levels, and immune response, and indicate that colony losses might be reduced by alleviating protein stress through supplemental feeding. This information has been transferred to beekeepers through a report in the *American Bee Journal* and through presentations to beekeeper groups.

DeGrandi-Hoffman, G., and Y. Chen. 2010. Why supplemental feeding can help reduce colony losses. Amer. Bee J. 1500: 1157-1160.

DeGrandi-Hoffman, G., Chen, Y., Huang, E., Huang, M. 2010. The effect of diet on protein concentration, hypopharyngeal gland development and virus load in worker honey bees (*Apis mellifera* L.). J. Insect Physiol. 56: 1184-1191.

DeGrandi-Hoffman, G., Wardell, G., Ahumada-Segura, F., Rinderer, T.E., Danka, R.G., Pettis, J. 2008. Comparisons of pollen substitute diets for honey bees: consumption rates by colonies and effects on brood and adult populations. Journal of Apicultural Research 47(4):265-270.

Sucrose is a better nectar substitute than high fructose corn syrup. Beekeepers commonly feed honey bee colonies either high fructose corn syrup or sucrose (sugar water) as a substitute for nectar when flowering plants are not available. ARS scientists in Tucson found that colonies fed during the winter with sucrose syrup had greater brood production in the spring than colonies fed corn syrup. A high rate of brood production in the spring is important because it means that the bees were able to build large colonies early in the season, and were thus better able to pollinate early season crops such as almonds, and were more likely to maximize their honey production. In related work, ARS scientists found that when corn syrup is stored at high temperatures in certain types of metal tanks, hydroxymethylfurfural will form. This compound is toxic to bees, shortening bee longevity and compromising comb building. Shortened worker longevity could reduce the length of time colonies are able withstand winter conditions and precipitate colony collapse if the winter is too long. Beekeepers have now changes practices to avoid storage of corn syrup at high temperatures, and are mixing the syrup with sucrose to help reduce the build-up of furfurals.

Sammataro, D. and M. Weiss. 2012. Comparison of productivity between honey bee colonies (*Apis mellifera*) supplemented with sucrose or high fructose corn syrup (HFCS). J. Insect Scence, in press.

Leblanc, B.W., Eggleston, G., Sammataro, D., Cornett, C., Dufault, R., Deeby, T.A., St Cyr, E.L. 2009. Formation of Hydroxymethylfurfural in Domestic High Fructose Corn Syrup and Its Toxicity to the Honey Bee (*Apis mellifera*). Journal of Agricultural and Food Chemistry 57:7369-7376.

PROBLEM STATEMENT 2A.2: *Pollination of crops.*

Honey bees are essential as pollinators for approximately one-third of the crops in the United States. A single colony is often moved several times to pollinate several different crops during the same year, beginning in early spring and ending in late summer. Some crops are not good sources of nectar and pollen for honey bees (e.g., melons, cucumbers, and blueberries), and thus the colonies can become smaller and weaker during the time they are situated near these crops. If the colonies become too weak, they cannot be used for pollinating other crops, and must be moved to a place where they can obtain better forage or be merged to achieve populations large enough to survive the winter. Weakened colonies can also become highly susceptible to mortality due to predation, pests, and parasites that further decrease population growth rates. ARS researchers worked to develop ways to alleviate some of these problems associated with using honey bees to provide pollination services.

ANTICIPATED PRODUCT IN NP 305 ACTION PLAN:

1. Recommendations on how to manage colonies introduced to crops that cause nutritional stress during pollination.

PROBLEM STATEMENT 2A.2 SELECTED ACCOMPLISHMENTS:

Varroa-resistant honey bee lines performed well during pollination service. While new bee lines are bred for resistance to parasites or diseases, they must be tested to ensure that they have good pollination and honey production characteristics. Bees with VSH varroa resistance were tested by ARS researchers in Baton Rouge for two seasons in a commercial migratory beekeeping operation that focused on crop pollination, and were found to perform well in terms of survival, colony size, and resistance to varroa mites. The bee colonies used were created from VSH queens that were outcrossed (i.e., matings were not controlled), a method used by most large-scale beekeepers, and used for spring pollination of almonds in California, followed by apples in New York, low-bush blueberries in Maine, and cranberries in Massachusetts. A significant extension of this research was propagation of the best surviving VSH colonies to form a breeding population that had enhanced genetics for both mite resistance and desired behaviors for crop pollination. These bees are now being marketed by a partner (Glenn Apiaries), and the use of this breeding material should improve adoption of mite-resistant bees by commercial beekeepers that pollinate crops.

Danka, R. G**.,** L. I. de Guzman, T. E. Rinderer, H. A. Sylvester, C. M. Wagener, A. L. Bourgeois, J. W. Harris and J. D. Villa. Functionality of varroa-resistant honey bees (Hymenoptera: Apidae) when used in migratory beekeeping for crop pollination. J. Econ. Entomol. 105: In press.

Feeding pollen in winter produces larger colonies for almond pollination. Having large colonies in February for almond pollination is a difficult challenge for beekeepers since colonies naturally tend to decrease during the winter. ARS scientists found that continual feeding of protein enriched with pollen beginning in late autumn produces colonies that far exceed the sizes necessary for almond pollination. This effect is enhanced if beekeepers use 8-frame equipment, the smaller commercially used hive size. Although it is widely known that feeding protein helps build large colonies, the advantages of enhancing the protein with pollen and providing continual food through the winter are novel. These feeding techniques are useful for all beekeepers that pollinate almonds and those that require large colonies early in the spring for the production and sale of colonies and queens.

Rinderer, T.E., de Guzman, L. I., Frake, A. M., Stelzer, J. A. Bourgeois, A. L., Wagnitz, J. 2012. The effects of pollen-enriched pollen substitute on winter cluster size and the prevalence of *Nosema ceranae* in Russian honey bee colonies. In press. Science of Bee Culture.

Rinderer, T.E., De Guzman, L.I., Bourgeois, A.L., Frake, A.M. 2010. The effects of hive size, feeding, and *Nosema ceranae* on the size of winter clusters of Russian honey bee Colonies. Science of Bee Culture. 2(1):1-6. Supplement to Bee Culture. 138(3):1-6.

PROBLEM STATEMENT 2A.3: ***Developing and using new research tools: genomics, genetics, physiology, germplasm preservation, and cell culture.***

The U.S. beekeeping industry faces numerous challenges that may be addressed by traditional genetic approaches and with emerging, molecular-based technologies, based on the recently sequenced honey bee genome. Using genomics, scientists can link genes with desired traits, using adjoining markers that indicate important genes or even variants within genes themselves that have a direct impact on health or behavior. This technology allows marker-assisted breeding to speed the development of new lines useful to the beekeeper. Once the markers are identified, preserving germplasm is central to efforts to improve honey bee stock. The ability to preserve desired bee lineages – as sperm, eggs, or embryos – could provide beekeepers with more time to assess the traits of their bees before making breeding decisions. Long-term preservation offers an opportunity to keep desired traits indefinitely and to transfer these traits among bee breeders.

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Molecular markers for identifying desirable traits and for certifying bee stock, and for bee stocks resistant to parasites and pathogens.
2. Molecular marker-assisted selection techniques for breeding bees with desirable traits.
3. Diagnostic tests for determining the disease status of bees and risk analysis tools for evaluating disease treatment options.
4. Quick-tests of the level of stress on a colony to allow effective treatment to be implemented before economic damage occurs.
5. Stable cryopreservation methods for honey bee sperm, eggs, and embryos.
6. A technique for preserving sperm viability during artificial insemination.
7. Direct assay for inbreeding risk at the sex determination locus.
8. Ability to assess breeder-queen genetic traits prior to production.

PROBLEM STATEMENT 2A.3 SELECTED ACCOMPLISHMENTS:

Honey bee genome sequenced. Genomic analyses provide tools for mitigating honey bee susceptibility to pathogens and chemicals, resolve questions about breed identities, and allow for the identification of markers and causes of bee behaviors and resistance traits. The honey bee genome sequence was completed after an enormous effort by the scientific community. ARS researchers in Beltsville and Weslaco were instrumental in the conception and completion of this sequencing, including coordination of efforts to identify genes related to bee health. This accomplishment has already led to new projects that explore bee health, behavior, and physiology, which in turn, will improve beekeeping and pollination. The genome paper has been the most-cited bee work since 2007, and has led directly to a genetic revolution in studies of bee behavior, physiology, and disease resistance. Striking differences between honey bees and other insects in genomic diversity related to detoxification and disease resistance may explain why bees are so vulnerable to pesticides and pathogens. Knowing these genetic vulnerabilities can drive management and breeding schemes, respectively. With the discovery that genome sequences for immune proteins in the honey bee, wasps, and aphids co-occur, researchers have a new tool to investigate and strengthen bee immunity. The honey bee genome sequence is maintained at BeeBase, and resources are mirrored at several web portals in the United States (including GenBank) and internationally.

Evans, J.D., Spivak, M. 2010. Socialized Medicine: Individual and communal disease barriers in honey bees, *Journal Invert. Pathol.* 103, S62-S72.

Aronstein, K.A., .Daniel, K.D., Saldivar, E. 2010. Transcriptional responses in honey bee larvae infected with chalkbrood fungus. BMC Genomics, 11:391,

Johnson, R.M., Evans, J.D., Robinson, G.E., Berenbaum, M.R. 2009. Changes in gene expression relating to Colony Collapse Disorder in honey bees, *Apis mellifera. Proceedings of the Natl. Academy of Sciences,* 106 (35) 14790-14795.

Genetic markers developed to identify quality parentage of Russian bees. The maintenance of selected lines can be impaired when drones from unselected bees intrude and mate with selected queens. It is important to assess whether selected bee lines have pure matings and maintain desirable traits. For selected lines, DNA markers can be identified and used to determine parentage and to maintain line integrity. ARS researchers in Baton Rouge developed genetic markers (using microsatellites and SNPs) to identify Russian bee parentage of the recently released 18 Russian honey bee lines. These markers were used to evaluate the quality of commercially marketed queens, and the ARS researchers determined that a very high proportion of these queens were mated with Russian drones. That finding means the consumer was purchasing a queen that would produce Russian workers and not hybrids. This result documents that the producers of Russian queens are controlling the quality of the stock they produce. These markers were also used to evaluate the spread of genes from Russian bee lines into feral honey bee populations. The invasion of varroa mite into the United States has caused a decline in feral honey bee populations, bees that used to provide pollination services. ARS scientists have determined that feral population in areas near Russian apiaries are now predominantly Russian in parentage, presumably due to natural selection for bees resistant to varroa. Thus, genetic lines with varroa resistance may also help feral honey bee populations rebound and increase pollination.

Sylvester, H.A., Bourgeois, A.L., De Guzman L.I., Rinderer, T.E. 2011. Presence of Russian honey bee genotypes in swarms in Louisiana, Notes Science of Bee Culture 3(1):9-10, supplement to Bee Culture 139(3).

Bourgeois, A.L., Sheppard, W.S., Sylvester, H.A., Rinderer, T.E. 2010. Genetic stock identification of Russian honey bees. Journal of Economic Entomology. 103(3):917-924.

A genetic mechanism for resistance to chalkbrood disease. When chalkbrood infections go unchecked in a honey bee colony, the overall health and productivity is greatly decreased. Identifying the genetic bases for resistance to the fungus will be useful for breeding improved resistance into bee populations. ARS scientists in Baton Rouge found a statistically significant association between larval resistance to chalkbrood and a single genomic locus. This research indicates that selective breeding for larval resistance, in concert with breeding for chalkbrood resistance in adults bees by hygienic behavior, holds promise that chalkbrood could become a negligible disease among managed colonies.

Holloway, B., Sylvester, H. A. Bourgeois, L., Rinderer, T. E. 2012. Association of single nucleotide polymorphisms to resistance to chalkbrood in *Apis mellifera*. Journal of Apicultural Research. In Press.

A heritable resistance to Nosema ceranae was found in Russian honey bees. Chemical control of *N. ceranae* is both very temporary and costly. Genetic control would be ideal, but genetic variance in resistance to the parasite had not been documented. ARS scientists in Baton Rouge found that honey bee patrilines (workers with the same father) in Russian colonies vary in their response to *N. ceranae*. This is the first time that varied resistance to the pathogen has been found in honey bees. Together with progress on the genetics of varroa resistance, this finding opens the way to use a unique (sub-family membership) marker-assisted breeding programs to produce a line of honey bees highly resistant to both varroa mites and nosema.

Bourgeois, A.L., Rinderer, T.E., Sylvester, H. A., Holloway, B., Oldroyd, B.P. 2012. Patterns of *Apis mellifera* infestation by *Nosema ceranae* support the parasite hypothesis for the evolution of extreme polyandry in eusocial insects. Apidologie , DOI: 10.1007/s13592-012-0121-5.

Immune response in honey bees found to be partially heritable and amenable to selection. Honey bees combat the bacterial pathogen *Paenibacillus larvae* with immunity proteins found across insect species. ARS scientists in Beltsville developed and used a four-generation mating scheme to assess heritability and variation in a honey bee immune trait, the production of the key antimicrobial peptide called abaecin. When individual larvae were challenged with *P. larvae*, abaecin levels were shown to be a selectable trait. Thus, this and likely other immune response traits are amenable to selection that could improve bee health. These efforts, along with experimental studies of social and solitary bees in the field, indicate that bee immunity is also aided by other potentially selectable traits. These results can be applied to the development of breeding programs for resistance to pathogens through bee sociality and improved immune responses.

Evans, J. D., and M. Spivak. 2010. Socialized medicine: Individual and communal disease barriers in honey bees. Journal of Invertebrate Pathology 103: S62-S72.

Simone, M., J. D. Evans, and M. Spivak. 2009. Resin collection and social immunity in honey bees. Evolution 63: 3016-3022.

Honey bee responses to fungal diseases. To combat bee disease, information is needed on mechanisms of pathogen invasion. Using a genome-wide approach, ARS researchers in Weslaco identified a large set of genes in the honey bee fungal pathogen *Ascosphaera apis,* the cause of chalkbrood disease, to be responsible for pathogen reproduction and host invasion. A wide variety of molecules found in this study are well-known target sites of anti-fungal drugs currently used in treatments of animal diseases, and thus can be tested against the fungus. The researchers found evidence to support the theory that activation of disease defenses in the honey bee negatively affects most of the bee's biological functions, including its nutritional status and response to pesticide poisoning. This finding supports the need to consider the interaction of multiple mortality factors in bee disease.

Aronstein, K.A., Murray, K.D. 2010. Chalkbrood disease in honey bees. J. Invertebr. Pathol.103 (SUPPL. 1):20-29,

Aronstein, K.A., Daniel Murray, K.D., Saldivar, E. 2010. Transcriptional responses in honey bee larvae infected with chalkbrood fungus**.** Biomed Central (*BMC) Genomics***,** 11:391,

The genomes of two honey bee pathogens sequenced. Chalkbrood and American foulbrood are actionable diseases, which present regulatory and management costs to U.S. beekeepers. ARS researchers in Beltsville and Weslaco, with their collaborators at the Baylor College of Medicine, sequenced the genome of *Paenibacillus larvae* (American foulbrood) and *Ascosphaera apis* (chalkbrood). This genome sequence information has led to several studies of virulence factors in *P. larvae*, and of markers for population and virulence determination in *A. apis*. Genomic information for both pathogens is available for analysis in Genebank (US-NIH) and at the BeeBase Pathogen Database (http://hymenopteragenome.org/beebase/?q=bee_pathogens).

Chan, Q. W. T., R. S. Cornman, I. Birol, N. Y. Liao, S. K. Chan, T. R. Docking, S. D. Jackman, G. A. Taylor, S. J. M. Jones, D. C. de Graaf, J. D. Evans, and L. J. Foster. 2011. Updated genome assembly and annotation of *Paenibacillus larvae*, the agent of American foulbrood disease of honey bees. BMC Genomics 12:450.

Aronstein, K., K. Murray, E. Saldivar. 2010. Transcriptional responses in honey bee larvae infected with chalkbrood fungus. BMC Genomics 11:391.

Molecular assay developed to differentiate, detect, and quantify two nosema parasites of honey bees. *Nosema ceranae* is an emergent pathogen whose prevalence has increased dramatically in recent years. Assessment of both presence and quantity of infestation levels of both *N. apis* and *N. ceranae* was needed to assist beekeepers in proper management of infected colonies. A genetic assay was developed by ARS scientists in Beltsville and Baton Rouge that simultaneously detects and quantifies both *N. ceranae*, a new invasive pathogen, and differentiates it from *N. apis*, a long-established pathogen of honey bees in the United States. The assay detects infections associated with greater than 10 pathogen spores per bee, and may be used in place of laborious microscopic examination. The assay is being used to assess the variation in *N. ceranae* titer levels during natural infections and for identification of genetically resistant subfamilies within single colonies. This information will be useful for understanding colony level resistance to nosema infestation and for improving resistance in breeding stocks.

Bourgeois, A.L., Rinderer, T.E., Beaman, G.D., Danka, R.G. 2010. Genetic detection and quantification of *Nosema apis and N. ceranae* in the honey bee. Journal of Invertebrate Pathology. 103:53-58.

Chen, Y., J. D. Evans, L. Zhou, H. Boncristiani, K. Kimura, T. Xiao, A. M. Litkowski, and J. S. Pettis. 2009. Asymmetrical coexistence of *Nosema ceranae* and *Nosema apis* in honey bees. Journal of Invertebrate Pathology 101: 204-209.

Improved detection of nosema and chalkbrood diseases in bee hives. Among numerous honey bee diseases, nosemosis is one that presents special concerns for beekeepers by threatening to deplete essential pollinators in the United States and around the world. Significantly, nosemosis caused by *Nosema ceranae* does not produce clear clinical signs of the disease; therefore a simple and robust detection method must be at the forefront of the disease management program. A new diagnostic tool was developed by ARS scientists in Weslaco for quick, reliable detection of nosema infections in honey bee samples. The test is based on an antigen capture assay that detects a nosema spore wall protein. Both a reliable field diagnostic tool and a high-throughput laboratory test (ELISA) have been developed based on this technique. ARS also has developed a PCR-based diagnostic method for chalkbrood in bees that can differentiate among 10 different species of chalkbrood pathogens. These methods provide tools to scientists for assessing the disease status of bees, and can be particularly useful for experiments designed to evaluate the effects of environmental factors on disease susceptibility in bees.

Aronstein, K.A., Eduardo Saldivar, E., Webster, T.C. 2011. Evaluation of *Nosema ceranae* spore-specific polyclonal antibodies. Journal of Apicultural Research 50(2):145-151.

Genetics of antibiotic resistance discovered for American foulbrood pathogen. American foulbrood is one of the most devastating diseases of the honey bee and results in massive losses of bee colonies. ARS scientists in Beltsville discovered a small circular plasmid (pMA67) in *Paenibacillus larvae* that carries a gene for oxytetracycline resistance (TetL), explaining the rapid rise of *P. larvae* resistance to this class of antibiotics. This plasmid is useful as a diagnostic marker, including those in quick tests for American foulbrood disease. ARS scientists also discovered several additional plasmids in *P. larvae* that can be used to move genes into the bacterium for purposes of finding bacterial pathways that might be exploited in American foulbrood control. Because plasmids often contain genes directly involved in pathogen virulence, there may be important information in these plasmids that reveal how the bacterium invades the bee, bacterial abilities that can be countered in future control strategies. This research has attracted attention among scientists in the United States, Canada, and Europe, who request samples of the plasmid and publication reprints to aid in their work in using the plasmid – with a florescent marker – to study pathogenicity genes active in the bee host.

Murray, K. D. and Aronstein, K. A. 2008. Transformation of the gram-positive pathogen, Paenibacillus larvae, by electroporation. Journal of Microbiological Methods. 75:325-328.

Murray, K. D. and Aronstein, K. A. 2007. Analysis of pMA67, a predicted rolling-circle replicating, mobilizable, tetracycline-resistance plasmid from the honey bee pathogen, Paenibacillus larvae. Plasmid 58:89-100.

Tools developed for tracking and understanding CCD. Efforts to improve bee health have been hampered by an inability to accurately assess the incidence and prevalence of diseases caused by viruses and other pathogens. ARS scientists in Beltsville developed improved methods for collecting honey bee populations in the field, collecting embryos from established colonies, and shipping samples to laboratories such that they arrived in a condition adequate for conducting tests. The researchers also improved processes for carrying out controlled experiments on adult bees using sterile cups, extracting and stabilizing RNA, and developing high-throughput genetic screens for viruses and other pathogens. These methods are being used in U.S. surveys to establish cell lines and other genetic techniques, and to better determine how pathogens and environmental factors may interact and affect bee health.

Dainat, B., J. D. Evans, Y. P. Chen, and P. Neumann. 2011. Sampling and RNA quality for diagnosis of honey bee viruses using quantitative PCR. Journal of Virological Methods 174: 150-152.

Evans, J. D., Y. P. Chen, G. Di Prisco, J. Pettis, and V. Williams. 2009. Bee cups: Single-use cages for honey bee experiments. Journal of Apicultural Research 48: 300-302.

Van Engelsdorp, D., J. D. Evans, C. Saegerman, C. Mullin, E. Haubruge, B. K. Nguyen, M. Frazier, J. Frazier, D. Cox-Foster, Y. Chen, R. Underwood, D. R. Tarpy, and J. S. Pettis. 2009. Colony collapse disorder: a descriptive study. PLoS ONE 4(8):e6481.

SUBCOMPONENT 2B: NON-*APIS* BEES

North America is the native home to a great diversity of bees, with nearly 4,000 species, and all are non-*Apis* bees. Some solitary bees and bumble bees are already used for crop pollination, and others play a critical role in maintaining native flowering plants that form the basis of our wildland ecosystems. The solitary bees nest in domiciles; bumble bees, which are social, nest in small containers. The contribution of non-*Apis* bees to plant and crop production is often under-recognized by most agronomists. For example, alfalfa seed production is almost entirely dependent on alfalfa leafcutting bees. Approximately 200,000 gallons (valued at approximately $20 million) of alfalfa leafcutting bees are imported annually into the United States from Canada because U.S. seed farmers are unable to produce enough bees, yet cannot produce seed without them. This equates to almost as many bees as the number of honey bees brought into almonds every year, and at a greater cost per acre ($500-600 per acre for alfalfa vs. $300 per acre for almonds). To maintain the productivity and the health of these bees and expand their use in crop production, a greater understanding of the physiologies and behaviors are needed, especially for those species that are of greatest interest to agriculture, such as the alfalfa leafcutting bee (*Megachile rotundata*), the alkali bee (*Nomia melanderi*), the blue orchard bee (*Osmia lignaria*), and bumble bees (*Bombus* spp.).

PROBLEM STATEMENT 2B.1: *Management for crop pollination.*

If non-*Apis* bee species are to play a greater role in crop production, more information is needed on their stewardship – including their habitat requirements, husbandry, handling and over-winter storage, disease and health issues (chalkbrood disease and unknown causes of immature mortality) – and the role that chemical cues play in finding nests or appropriate forage. While some of these areas of concern have received much study in the honey bee, less has been done on the various non-*Apis* bee species.

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Better management practices for non-*Apis* bees, including recommendations for bee cell handling and stocking densities, use of chemical lures as establishment cues for nesting and thus retention of foragers in the field, and safe, easy-to-use, and effective integrated pest management strategies for parasites and diseases.
2. An evaluation of the host range of the *Ascosphaera* (chalkbrood) in bees.
3. Identification of genetic markers for chalkbrood resistance in bees.
4. Management protocols and nesting materials for managing promising native *Osmia* bee species to better pollinate select field crops, particularly native seeds crops and cane fruits.
5. Recommendations for use of the blue orchard bee in California almonds and other tree crops, including acceptable bee biotype sources, and use of flowering plants to ranch the bees.
6. A western bumble bee species that can be used for commercial pollination of enclosed crops in the West.
7. Identification of the prevalence and occurrence of bumble bee diseases and parasites.
8. Determination of the feasibility of managing bumble bees for pollination of field crops.

PROBLEM STATEMENT 2B.1 SELECTED ACCOMPLISHMENTS:

Nest establishment cues discovered for alfalfa leafcutting bees and blue orchard bees. Alfalfa leafcutting bees and blue orchard bees can be readily used as pollinators because they nest together, making it possible to manage populations large enough to be sufficient for agricultural pollination. ARS scientists in Logan and Fargo identified the chemical cues that attract the bees to nest in a particular place based on nesting establishment cues found in old nests. The scientists developed artificial nest attractants based on some of these compounds and have established an agreement with a company to develop this product commercially. The product will allow farmers to use new or cleaned nesting materials, yet still attract the bees to nest in the desired locations. The first field trials have proved the concept to be promising.

Pitts-Singer, T.L. 2007. Olfactory response of megachilid bees, *Osmia lignaria*, *Megachile rotundata* and *M. pugnata*, to individual cues from old nest cavities. Environmental Entomology. 36: 402-408.

Control strategies for chalkbrood in alfalfa leafcutting bees. Chalkbrood is the single most important disease affecting alfalfa leafcutting bees. ARS scientists in Logan determined that chalkbrood prevalence can be reduced by treating alfalfa leafcutting bee cocoons with a fungicide when the bees are brought out of cold storage in the early summer, but prior to incubation for field release. In addition, the researchers showed that high concentrations of ozone are effective as a disinfectant for chalkbrood spores in nesting boards. This method could replace the currently used compounds, paraformaldehyde and methyl bromide, both of which are considered environmental hazards. Seed producers have been unable to control this disease in the field, and combining cocoon treatments and nesting board disinfection provides the most substantial control yet offered, reducing chalkbrood as much as 50 percent.

James, R. R. 2011. Chalkbrood transmission in the alfalfa leafcutting bee: the impact of disinfecting bee cocoons in loose cell management systems. Environ. Entomol. 40(4): 782-787.

Huntzinger, C.I., James, R.R., Bosch, J., and Kemp, W.P. 2008. Laboratory bioassays to evaluate fungicides for chalkbrood control in larvae of the alfalfa leafcutting bee, *Megachile rotundata* (Hymenoptera: Megachilidae). J. Econ. Entomol. 101: 660-667.

Immunity related genes in alfalfa leafcutting bees. Immune systems are poorly understood for any bee, yet knowledge about how bees resist infectious disease could lead to the development of new drugs and methods for disease control. ARS scientists in Logan, with their university collaborators, conducted the first analysis of immunity-related genes in a solitary bee, the alfalfa leafcutting bee, and identified 116 genes. Like honey bees, alfalfa leafcutting bees were found to have fewer immune response pathways than other insects. ARS researchers also found that alfalfa leafcutting bees exposed to temperature stress, either chilling or overheating (20°C and 35°C), were more resistant to chalkbrood as the stressful temperatures increased the expression of immune response genes, resulting in fewer infections. This finding identified immune responses in this bee and the relationship between stress and disease, contributing to the development of better methods for maintaining healthy bees.

Xu, J., and James, R.R. 2012. Temperature stress affects the expression of immune response genes in the alfalfa leafcutting bee, *Megachile rotundata*. J. Insect Molec. Biol. DOI 10.1111/j.1365-2583.2012.01133.x.

Xu, J., and James, R.R. 2009. Genes related to immunity as expressed in the alfalfa leafcutting bee, *Megachile rotundata*, during pathogen challenge. J. Insect Molec. Biol. 18 (6): 785-794.

A new bee identified to pollinate cane berry fields. Cane berries, such as raspberries and Logan berries, are not good forage for honey bees, but these crops still need to be pollinated. A manageable native bee, *Osmia aglaia*, was identified by ARS scientists in Logan as a good berry pollinator. The researchers were able to develop methods for its use, including new portable nesting shelters, and they demonstrated methods for propagating and deploying the bees. Successful field testing and modifications were conducted over 4 years. Populations increased 2- to 3-fold per year in commercial berry fields using nesting materials that are readily available to growers. This bee is now being used on Oregon and California farms.

Figure 12: With inadequate visits from pollinating insects, raspberry fruits are small and malformed, left. Pollination by the solitary bee *Osmia aglaia* regularly sets well-formed large raspberries, such as seen on the right. *Photo by James Cane – ARS*.

Cane, J.H. 2008. An effective, manageable bee for pollinating *Rubus* cane fruits, *Osmia aglaia*. Acta Horticul. (ISHS). 777:459-464.

Blue orchard bees as a supplement to honey bees for almond pollination. A combination of the devastating effects of CCD and an increase in almond acreage has affected the availability of honey bees to pollinate this crop. An ARS economic analysis of pollination fees for California almonds and sweet cherries showed that the recent sharp increase in honey bee pollination fees was caused by a dramatic increase in almond and cherry acreage during a period when honey bee colonies in the United States declined. ARS scientists in Logan demonstrated in commercial orchards that blue orchard bees are very effective pollinators for almonds, with costs and yields similar to those obtained with honey bees. Methods developed by ARS for propagating and releasing the bees on large farms include a field incubation box, small nesting shelters, protocols for temperature regulation, and the identification of flowering plants useful for bee propagation. Blue orchard bees are currently being used on a trial basis by some almond growers, including by the largest producer in the United States, and a new organization – the Orchard Bee Producers Association – has formed by the new blue orchard bee producers.

Ward, R. A. Whyte, and R. R. James. 2010. A tale of two bees: Looking at pollination fees for almonds and sweet cherries. Amer. Entomol. 56(3):170-177.

Pitts-Singer, T. L., Bosch, J., Kemp, W. P. and Trostle, G. T. 2008. Field use of an incubation box for improved emergence timing of *Osmia lignaria* populations used for orchard pollination. *Apidologie* 39: 235-246.

Western bumble bee species developed as greenhouse pollinators. Bumble bees are used to pollinate greenhouse crops because they are well adapted to greenhouse environments and more cost effective than hand pollination. Unfortunately, no Western bumble bees are commercially available. ARS scientists developed rearing, queen production, and nest establishment techniques for four Western bumble bee species. Queen production rates were more than doubled, and nest-establishment rates increased up to four-fold. Making a Western bumble bee species available to western growers will reduce the risks associated with introducing non-native species, such as the accidental introduction of exotic diseases that could potentially cause the decline or demise of wild bees in the region. Three commercial bumble bee production companies (two of which supply over 90 percent of all commercial bumble bees) are either producing a western species, or evaluating their capacity to do such.

Strange J.P. 2010. Nest initiation in three North American bumble bees (*Bombus*): Gyne number and presence of honey bee workers influence establishment success and colony size. *Journal of Insect Science,* available online: insectscience.org/10.130

PROBLEM STATEMENT 2B.2: *Bee biodiversity and contribution to land conservation.*

Sustainable pollination services by native bees in natural landscapes are critical for affordable native plant seed for re-vegetation after wild fires and overgrazing activities. The need to facilitate conservation of bee biodiversity and develop pollinators for land restoration is rooted in expanding our knowledge of bee systematics in agriculture and natural systems.

ANTICIPATED PRODUCTS IN NP 305 ACTION PLAN:

1. Knowledge of the pollination needs of each wildflower species identified for use in restoration efforts, and development of practical systems for growers to use to multiply pollinators for producing seed.
2. Assessment of the status of *Bombus occidentalis* populations and other native bumble bees.
3. Generic/subgenera revision of Anthidiini trap-nesting bees.
4. Revision and Web-based identification tool for Nearctic *Osmia* (which includes the blue orchard bee).
5. Full digitization of the U.S. National Pollinating Insects Collection.
6. Processes for obtaining key pollinators for crop use.

PROBLEM STATEMENT 2B.2 SELECTED ACCOMPLISHMENTS:

Native bees assist efforts to restore damaged Federal lands. Native pollinators provide an important ecological service for native plants in wildlands. Land managers in the western United States need affordable native plant seed for re-vegetation efforts after wild fires and overgrazing by livestock. ARS scientists in Logan experimentally characterized the pollination needs of 12 western wildflower seed crops desired for Great Basin rehabilitation, surveyed bee faunas regionally, and made progress toward practical pollinator management for U.S. growers of these specialty seed crops. The researchers demonstrated that without pollinators, 11 of the wildflower species set little if any seed, and native bees are prevalent pollinators of 11 of these plant genera.

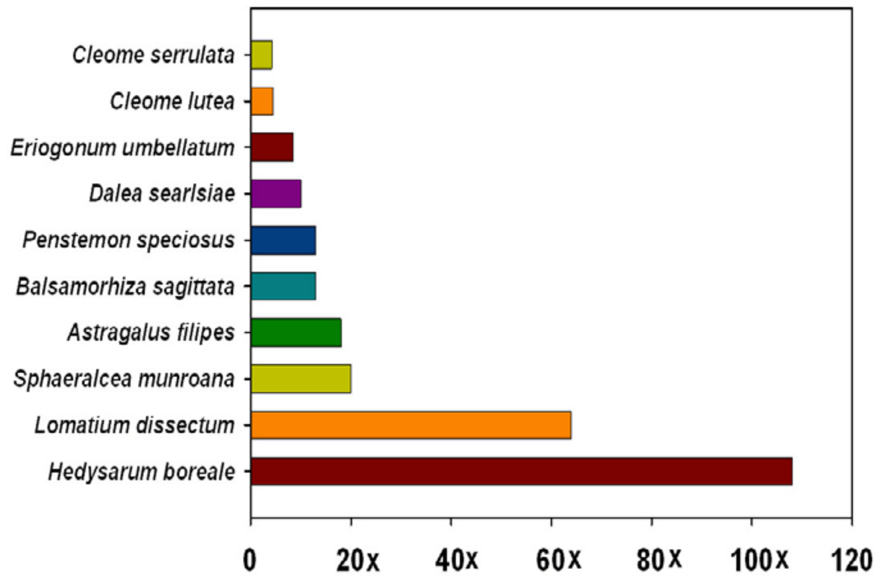

Figure 13: *Reproduction gain with pollinators* – Bees are key pollinators for all of the Great Basin wildflowers whose seed is wanted by Federal agencies involved in rangeland restoration. The graph demonstrates how many fold the various wildflower plant species seed production increases in the presence of pollinators. Without pollinators, growers will produce little or no seed for everything other than the *Cleome* species.

Some plants are pollinated by *Osmia* bees that are potentially manageable; and others host only ground-nesting floral specialists that are difficult to manage. Only two plant genera were readily pollinated by honey bees or alfalfa leafcutting bees in field trials. ARS scientists obtained the native *Osmia* bees from the wild, evaluated their biologies, developed protocols for managing them on a commercial scale, and established start-up populations for distribution to growers. This research was part of a high profile, multi-agency, Federal research program that has allowed seed growers to produce these native plant seeds. Growers from six states have requested the pollination protocols for producing seeds.

Cane, J. H. 2011. Meeting wild bees' needs on rangelands. Rangelands 33(3):27-32.

Cane, J. H. 2011. Specialist *Osmia* bees forage indiscriminately among hybridizing *Balsamorhiza* floral hosts. Oecologia 167(1):107-116.

Bumble bee declines documented on a continent-wide scale. Bumble bee specialists have noticed declines in bumble bees, but have not been able to clearly document such events in the United States. ARS scientists in Logan and collaborators at the University of Illinois and the Illinois Natural History Survey developed new methods for conducting field surveys of these bee populations. Using data from the labels on bees in insect collections, they modeled the historic geographic range of five bumble bee species, and applied that information to a 3-year field survey to evaluate the current ranges and abundance. *Bombus occidentalis*, in particular, was found to have declined significantly in both abundance and range. The researchers used microsatellite markers to identify genetic bottlenecks, or reduced gene flow, in bumble bee populations, and found species in decline to have lower genetic diversity than species not in decline. This method documented species declines without having to monitor populations over many years, by which time it may be too late for recovery efforts. To understand the role of diseases and parasites in these population declines, the researchers conducted a nationwide survey of the two key bumble bee pathogens *Nosema bombi* and *Crithidia bombi*. Disease prevalence was greater in declining species than in stable species. These pathogens were found to infect a broad host range and to be geographically widespread. These results have been used by conservation agencies to list *B. occidentalis* as threatened, and *B. franklini* as possibly extinct.

Cordes N., Huang W.-F., Strange J.P., Cameron S.A., Griswold T.L., Lozier J.D., and Solter, L. F. 2012. Interspecific geographic distribution and variation of the pathogens *Nosema bombi* and *Crithidia species* in United States bumble bee populations. J. Invertebrate Pathology. 109:209-216.

Cameron S.C., Lozier J.D, Strange J.P., Koch J.B., Cordes N., Solter L.F., Griswold T.L. 2011. Recent widespread population declines of some North American bumble bees: Current status and causal factors. Proceedings of the National Academy of Science. 108: 662-667.

Revisions and Web-based identification tools developed for Nearctic bees. The *Osmia* are an unusually large group of bees with over 350 species. These bees are important pollinators in ecosystems, and several species have been developed for use on farms. Currently, only a handful of bee taxonomists are competent to provide identifications, hampering progress in field ecology studies. To reduce this research bottleneck, ARS scientists in Logan and their collaborators improved the taxonomy, and then created Web-based identification tools. The researchers also collaborated with university scientists in developing a DNA-based taxonomic revision. Several new species were discovered, with one species having a wider distribution than previously thought. The Web-based identification tools are included within the DiscoverLife Web site (www.discoverlife.org/mp/20q) to contribute to this broad effort to improve species identifications in ecological studies.

Rightmyer, M.G., M. Deyrup, J.S. Ascher & T. Griswold. 2011. *Osmia* species (Hymenoptera, Megachilidae) from the southeastern United States with modified facial hairs: taxonomy, host plants, and conservation status. ZooKeys 148: 257–278.

Largest collection of bees in the world. ARS houses the U.S. National Pollinating Insects Collection in Logan, one of the largest collections of bees in the world containing approximately 1.1 million specimens. This reference collection is visited and used by scientists from all over the world on a weekly basis. Data from the insect labels, including the identity, date and time of collection, host plant, and gender has been entered into a specimen-level relational database for 874,548 specimens. This pollinator data was made available to the scientific community and land managers via the Global Biodiversity Information Facility (GBIF, www.gbif.org) and Discover Life (www.discoverlife.org/) Web sites. Species names are linked to higher level taxonomic categories (family, subfamily, and tribe). Location data is geo-referenced, allowing for spatial analyses of pollinators (e.g., as for the bumble bee decline accomplishment above). The ARS dataset is included within the larger, cooperative research tools of GBIF and DiscoverLife, making it broadly available to the scientific community.

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APPENDIX 1

National Program 305 – Crop Production

ACCOMPLISHMENT REPORT 2007 – 2011

Research Projects in National Program 305*
[By Action Plan Component]

Component 1: Integrated Sustainable Crop Production Systems

1275-21000-266-00D
SUSTAINABLE PRODUCTION SYSTEMS FOR TROPICAL TREE CROPS – Virupax Baligar (P) and Ronald Collins; Beltsville, Maryland

1931-21000-018-00D
NOVEL PRODUCTION SYSTEMS FOR SMALL FRUITS – Fumiomi Takeda (P); Kearneysville, West Virginia

1931-21000-019-00D
INTEGRATED ORCHARD MANAGEMENT AND AUTOMATION FOR DECIDUOUS TREE FRUIT PRODUCTION – Thomas Tworkoski (P), David Glenn, Stephen Miller, and Tracy Leskey; Kearneysville, West Virgina

3607-21000-014-00D
CROP PROTECTION AND PRODUCTION STRATEGIES FOR HORTICULTURAL CROPS – Richard Derksen (P), James Altland, and Charles Krause; Wooster, Ohio

3607-21000-015-00D
DEVELOP MANAGEMENT TOOLS FOR EARLY STRESS DETECTION AND EFFICIENT AGROCHEMICAL UTILIZATION FOR PROTECTED HORTICULTURE CROPS – Jonathan Frantz (P), James Altland, James Locke, and Charles Krause; Wooster, Ohio

3607-21620-008-00D
BIOLOGICAL, MICROCLIMATE, AND TRANSPORT PROCESSES AFFECTING PEST CONTROL APPLICATION TECHNOLOGY – Heping Zhu (P), Charles Krause, and Michael Reding; Wooster, Ohio

3645-21220-004-00D
NEW CROPS AND MANAGEMENT STRATEGIES TO IMPROVE CROPPING EFFICIENCY IN SHORT-SEASON HIGH-STRESS ENVIRONMENTS – Russell Gesch (P) and Frank Forcella; Morris, Minnesota

5306-21000-019-00D
IMPROVING POSTHARVEST LIFE OF POTTED PLANTS AND CUT FLOWERS THROUGH USE OF MOLECULAR AND APPLIED TECHNOLOGIES – Cai-Zhong Jiang (P); Davis, California

5358-21000-041-00D
Vineyard Management Practices and the Quality of Grapes and Grape Products in the Pacific Northwest – Julie Tarara (P), Krista Shellie, Lee Jungmin, Robert Martin; Corvallis, Oregon

* For the sake of consistency, NP 305 projects are organized in Appendix 1 and 2 according to the ARS project number used to track projects in the Agency's internal database. A (P) after a scientist's name indicates the project's principal investigator.

5358-21000-042-00D
DETERMINING IMPACT OF SOIL ENVIRONMENT AND ROOT FUNCTION ON HORTICULTURAL CROP PRODUCTIVITY AND QUALITY – Carolyn Scagel (P), David Bryla, Roger Schreiner, and Robert Martin; Corvallis, Oregon

6202-22000-028-00D
AERIAL APPLICATION RESEARCH FOR EFFICIENT CROP PRODUCTION – Wesley Hoffman (P), Yubin Lan, John Westbrook, Bradley Fritz, and Daniel Martin; College Station, Texas

6222-21220-003-00D
ORGANIC AND REDUCED INPUT FRESH MARKET SPECIALTY CROP PRODUCTION SYSTEMS FOR THE SOUTHERN GREAT PLAINS –Vincent Russo (P) and Charles Webber III; Lane Oklahoma.

6402-22000-059-00D
PESTICIDE APPLICATION TECHNOLOGIES FOR SPRAY-DRIFT MANAGEMENT, MAXIMIZING IN-FIELD DEPOSITION, AND TARGETED SPRAYING – Steven Thomson (P) and Yanbo Huang; Stoneville, Mississippi

6402-22000-072-00D
DEVELOPMENT OF SUSTAINABLE INTEGRATED CROP MANAGEMENT SYSTEMS FOR THE MID-SOUTHERN UNITED STATES – Krishna Reddy (P), Herbert Bruns, and William Pettigrew; Stoneville, Mississippi

6404-21430-001-00D
PRODUCTION MANAGEMENT RESEARCH FOR HORTICULTURAL CROPS IN THE GULF SOUTH – Warren Copes (P), James Spiers, Barbara Smith, Blair Sampson, and Stephen Stringer; Poplarville, Mississippi

6410-12210-001-00D
NEW AND IMPROVED CULTURAL PRACTICES FOR SUSTAINABLE SUGARCANE PRODUCTION AND ENVIRONMENTAL PROTECTION – Richard Johnson (P), Edward Richard Jr., and Ryan Viator; Houma, Louisiana

6606-21220-011-00D
PECAN CULTIVATION AND DISEASE MANAGEMENT – Bruce Wood (P) and Clive Bock; Byron, Georgia

6635-21000-050-00D
DEVELOPMENT OF INTEGRATED SYSTEMS FOR SUBTROPICAL/TROPICAL FRUIT CROP PRODUCTION – Richard Goenaga (P) and David Jenkins; Mayagüez, Puerto Rico

Component 2: Bees and Pollination

1275-21000-090-00D
MANAGING DISEASES AND PESTS OF HONEY BEES TO IMPROVE QUEEN AND COLONY HEALTH – Jay Evans (P), Miguel Corona, Jeffery Pettis, and Yanping Chen; Beltsville, Maryland

5342-21000-015-00D
IMPROVE NUTRITION FOR HONEY BEE COLONIES TO STIMULATE POPULATION GROWTH, INCREASE QUEEN QUALITY, AND REDUCE THE IMPACT OF VARROA MITES – Gloria Hoffman (P), Kirk Anderson, Mark Carroll, and Diana Sammataro; Tucson, Arizona

5428-21000-013-00D
BEE DIVERSITY AND THE DEVELOPMENT OF HEALTHY, SUSTAINABLE BEE POLLINATION SYSTEMS – Rosalind James (P), James Cane, Theresa Pitts Singer, James Strange, and Terry Griswold; Logan, Utah

6204-21000-010-00D
PESTS, PARASITES, DISEASES AND STRESS OF MANAGED HONEY BEES USED IN HONEY PRODUCTION AND POLLINATION – Katherine Aronstein (P), Steven Cook, Frank Eischen, and William Meikle; Weslaco, Texas

6413-21000-012-00D
BREEDING, GENETICS, STOCK IMPROVEMENT AND MANAGEMENT OF RUSSIAN HONEY BEES FOR MITE AND SMALL HIVE BEETLE CONTROL AND POLLINATION – Thomas Rinderer (P); Baton Rouge, Louisiana

6413-21000-013-00D
DEVELOPMENT AND USE OF MITE RESISTANCE TRAITS IN HONEY BEE BREEDING – Robert Danka (P), Beth Holloway, Joseph Villa, Thomas Rinderer, Jeffrey Harris, and Anita Bourgeois; Baton Rouge, Louisiana

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Appendix 2

National Program 305 – Crop Production

Accomplishment Report 2007 – 2011

Publications by Research Project

1275-21000-090-00D
Managing Diseases and Pests of Honey Bees to Improve Queen and Colony Health – Jay Evans (P), Miguel Corona, Jeffery Pettis, and Yanping Chen; Beltsville, Maryland

Boncristiani, H., Underwood, R., Schwarz, R., Evans, J.D., Pettis, J., vanEngelsdorp, D. 2012. Direct effect of acaricides on pathogen loads and gene expression levels of honey bee *Apis mellifera*. J. Insect Physiol. DOI:10.1016/j.jinsphys.2011.12.011.

Dainat, B., Evans, J.D., Chen, Y.P., Laurent, G., and Neumann, P. 2012. Dead or alive: Deformed wing virus and *Varroa destructor* reduce the life span of winter honey bees. Applied Environ. Microbiol. 78:981-987.

Dainat, B., Evans, J.D., Chen, Y. P., Laurent, G., and Neumann, P. 2012. Predictive makers of honey bee colony collapse, PLoS One. 7(2):e32151.

Pettis, J.S., D. vanEngelsdorp, J. Johnson, G. Dively 2012. Pesticide exposure in honey bees results in increased levels of the gut pathogen *Nosema*. Naturwissenschaften. 99:153-158.

Zhang, X., He, S.Y., Evans, J.D., Pettis, J., Yin, G.F., and Chen, Y.P. 2012. New evidence that deformed wing virus and Black queen cell virus are multi-host pathogens, J. Invert Pathol. 109:156-159.

Antúnez, K., M. Anido, D. Arredondo, J.D. Evans, P. Zunino. 2011. *Paenibacillus* larvae enolase as a virulence factor in honey bee larvae infection. Veterinary Microbiology 147:83-89.

Dainat, B., Evans, J.D., Chen, Y., Neumann, P. 2011. Sampling and RNA quality for successful diagnostics using quantitative PCR. Journal of Pest Science. 174:150-152.

Chan, Q., Cornman, R.S. Birol, I. Liao, N. Chan, S. Docking, T.R. Jackman, S. Taylor, G. Jones, S. de Graaf, D. Evans, J.D. Foster, L. 2011. Updated genome assembly and annotation of *Paenibacillus larvae*, the agent of American foulbrood disease of honey bees. BMC Genomics. 12:450.

Chen, Y.P., Evans, J. D., and Pettis, J. S. 2011. The presence of Chronic Bee Paralysis Virus infection in honey bees (*Apis mellifera* L.) in the U.S. Journal of Apicultural Research. 50:85-86.

di Prisco, G., X. Zhang, F. Pennacchio, E. Caprio, J. Li, J.D. Evans, G. DeGrandi-Hoffman, M. Hamilton, Y.P. Chen 2011. Dynamics of persistent and acute deformed wing virus infections in honey bees, *Apis mellifera*. Viruses. 3:2425-2441.

Evans, J.D. 2011. Managed pollinator CAP coordinated agricultural project - Genetic toolkits for bee health. American Bee Journal 151:351-353.

Evans, J.D., Schwarz, R.S. 2011. Bees brought to their knees; microbes affecting honey bee health, Trends in Microbiology. 12:614-20.

James, R.R. 2011. The potential of ozone as a fumigant to control pests in honey bee hives. J. Econ. Entomol. 104(3):353-399.

Robinson, G.E., K.J. Hackett, M. Purcell-Miramontes, S.J. Brown, J.D. Evans, M.R., Goldsmith, D. Lawson, J. Okamuro, H.M. Robertson, and D.J. Schneider 2011. Creating a buzz about insect genomes. Science. 331:1386.

Antúnez, K., Evans, J.D., Zunino, P. 2010. Secreted and immunogenic proteins produced by the honey bee bacterial pathogen, Paenibacillus larvae. Veterinary Microbiology. 141:385-389, 2010.

* For the sake of consistency, NP 305 projects are organized in Appendix 1 and 2 according to the ARS project number used to track projects in the Agency's internal database. A (P) after a scientist's name indicates the project's principal investigator.

Boncristiani, H., Li, J.L., Evans, J.D., Chen, Y.P. 2010. Scientific note on PCR inhibitors in the compound eyes of honey bees, *Apis mellifera*. Apidologie. 42:457-460.
Chen, Y., Huang, Z.Y. 2010. *Nosema ceranae*, a newly identified pathogen of *Apis mellifera* in the U.S. and Asia. Apidologie. 41:364-374.
Cornman, R.S., Schatz, M.C., Johnston, S.J., Chen, Y., Pettis, J.S., Hunt, G., Bourgeois, A.L., Elsik, C., Anderson, D., Grozinger, C.M., Evans, J.D. 2010. Genomic survey of the ectoparasitic mite *Varroa destructor,* a major pest of the honey bee *Apis mellifera*. Biomed Central (BMC) Genomics. 11:602.
di Prisco, G., Pennacchio, F., Emilio, C., Boncristiani, H., Evans, J.D., Chen, Y.P. 2010. *Varroa destructor* is an effective vector of Israeli Acute Paralysis Virus in honey bees, *Apis mellifera*, J. General Virology, 92:151–155.
Ellis, J., Evans, J.D., Pettis, J.S. 2010. Colony losses, managed colony population decline, and Colony Collapse Disorder in the United States, J. Apicultural Res. 49(1):134-136.
Evans, J.D., Spivak, M. 2010. Socialized Medicine: Individual and communal disease barriers in honey bees. Journal Invert. Pathol. 103:S62-S72.
Evans, J.D., Boncristiani Jr., H.F., Chen, Y. 2010. Scientific note on mass collection and hatching of honey bee embryos. Apidologie. 41:654-656.
Frazier, M., Muli, E., Conklin, T., Schmehl, D., Torto, B., Frazier, J., Tumlinson, J., Evans, J.D., Raina, S. 2010. A Scientific note on varroa mites found in East Africa; Threat or Opportunity. Apidologie. 41:463-465.
Genersch, E, Evans, J.D., Fries, I. 2010. Honey bee disease overview, Journal Invert. Pathol. 103:S2-S4.
Gerardo, N.M., Altincicek, B., Anselme, C., Atamian, H., Barribeau, S.M., De Vos, M., Duncan, E.J., Evans, J.D., Gabaldon, T., Ghanim, M., Heddi, A., Kaloshian, I., Latorre, A., Monegat, C., Moya, A., Nakabachi, A., Parker, B.J., Perez-Brocal, V., Pignatelli, M., Rahbe, Y., Ramsey, J., Spragg, C., Tamames, J., Tamarit, D., Tamborindeguy, C., Vilcinskas, A. 2010. Immunity and defense in pea aphids, *Acyrthosiphon pisum*. Genome Biology. 11:R21.
Hayes, J., Pettis, J., vanEngelsdorp, D., Rennich, K., Snyder, R.O.B., Andee, M., Patel, N., Roccasecca, K., Rice, N., Lopez, D., Evans, J., Levi, V. 2010. The national honey bee disease and pest survey: 2009-2010 pilot study. American Bee Journal. 150:1033-1035.
Hunter, W, Ellis, J, vanEngelsdorp, D, Hayes, J, Westervelt, D, Glick, E, Williams, M, Sela, I, Maori, E, Pettis, J, Cox-Foster, D, Paldi, N. 2010. Large-Scale Field Application of RNAi Technology Reducing Israeli Acute Paralysis Virus Disease in Honey Bees (*Apis mellifera*, Hymenoptera: Apidae). PLoS Pathology 6(12):e1001160.
International Aphid Genomics Consortium 2010. Genome sequence of the Pea Aphid Acyrthosiphon pisum: Adaptation to host plants and symbiotic bacteria, Plos Biology. 8(2):e1000313. 2010.
Lounsberry, Z.T., Spiewok, S., Pernal, S., Sonstegard, T.S., Hood, M.W., Pettis, J.S., Neumann, P., Evans, J.D. 2010. Worldwide diaspora of *Aethina tumida* (Coleoptera: Nitidulidae), a nest parasite of honey bees. Annals of the Entomological Society of America. 103:671-677.
Mullin, C., Frazier, M., Frazier, J.L., Ashcraft, S., Simonds, R., vanEngelsdorp, D., Pettis, J.S. 2010. High levels of Miticides and Agrochemicals in North American Apiaires: Implications for honey bee health. PLoS One 5(3):e9754. DOI:10.1371.
Paldi, N., Glick, E., Oliva, M., Zilbeberg, Y., Aubin, L., Pettis, J.S., Chen, Y., Evans, J.D. 2010. Effective gene silencing of a microsporidian parasite associated with honey bee (*Apis mellifera*) colony declines. Applied and Environmental Microbiology. 76:5960-5964.
Pettis, J.S., Delaplane, K. 2010. Coordinated responses to honey bee decline in the USA. Journal of Economic Entomology. 41:256-263.
vanEngelsdorp, D., Speybroeck, N., Evans, J.D., Nguyen, B., Mullin, C., Frazier, M., Frazier, J., Cox-Foster, D., Chen, Y., Tarpy, D., Haubruge, E., Pettis, J.S., Saegerman, C. 2010. First analysis of risk factors associated with bee colony collapse disorder by classification and regression trees. Journal of Economic Entomology. 103:1517-1523.
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Werren, J.H., Richards, S., Desjardins, C.A., Niehuis, O., Gadau, J., Colbourne, J.K., Elsik, C.G., Murphy, T., Worley, K.C., Zdobnov, E.M., Evans, J.D., Dang, P.M., Hunter, W.B. 2010. Functional and evolutionary insights from the genomes of three parasitoid *Nasonia* species. Science. 327:343-348.

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SUSTAINABLE PRODUCTION SYSTEMS FOR TROPICAL TREE CROPS – Virupax Baligar (P) and Ronald Collins; Beltsville, Maryland

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INTEGRATED ORCHARD MANAGEMENT AND AUTOMATION FOR DECIDUOUS TREE FRUIT PRODUCTION – Thomas Tworkoski (P), David Glenn, Stephen Miller, and Tracy Leskey; Beltsville, Maryland

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CROP PROTECTION AND PRODUCTION STRATEGIES FOR HORTICULTURAL CROPS – Richard Derksen (P), James Altland, and Charles Krause; Wooster, Ohio

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DEVELOP MANAGEMENT TOOLS FOR EARLY STRESS DETECTION AND EFFICIENT AGROCHEMICAL UTILIZATION FOR PROTECTED HORTICULTURE CROPS – Jonathan Frantz (P), James Altland, James Locke, and Charles Krause; Wooster, Ohio

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BIOLOGICAL, MICROCLIMATE, AND TRANSPORT PROCESSES AFFECTING PEST CONTROL APPLICATION TECHNOLOGY – Heping Zhu (P), Charles Krause, and Michael Reding; Wooster, Ohio

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NEW CROPS AND MANAGEMENT STRATEGIES TO IMPROVE CROPPING EFFICIENCY IN SHORT-SEASON HIGH-STRESS ENVIRONMENTS – Russell Gesch (P) and Frank Forcella; Morris, Minnesota

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IMPROVING POSTHARVEST LIFE OF POTTED PLANTS AND CUT FLOWERS THROUGH USE OF MOLECULAR AND APPLIED TECHNOLOGIES – Cai-Zhong Jiang (P); Davis, California

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IMPROVE NUTRITION FOR HONEY BEE COLONIES TO STIMULATE POPULATION GROWTH, INCREASE QUEEN QUALITY, AND REDUCE THE IMPACT OF VARROA MITES – Gloria DeGrandi-Hoffman (P), Kirk Anderson, Mark Carroll, and Diana Sammataro; Tucson, Arizona

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Vineyard Management Practices and the Quality of Grapes and Grape Products in the Pacific Northwest – Julie Tarara (P), Krista Shellie, Lee Jungmin, Robert Martin; Corvallis, Oregon

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5428-21000-013-00D

BEE DIVERSITY AND THE DEVELOPMENT OF HEALTHY, SUSTAINABLE BEE POLLINATION SYSTEMS – Rosalind James (P), James Cane, Theresa Pitts Singer, James Strange, and Terry Griswold; Logan, Utah

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AERIAL APPLICATION RESEARCH FOR EFFICIENT CROP PRODUCTION – Wesley Hoffman (P), Yubin Lan, John Westbrook, Bradley Fritz, and Daniel Martin; College Station, Texas

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PESTS, PARASITES, DISEASES AND STRESS OF MANAGED HONEY BEES USED IN HONEY PRODUCTION AND POLLINATION – Katherine Aronstein (P), Steven Cook, Frank Eischen, and William Meikle; Weslaco, Texas

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ORGANIC AND REDUCED INPUT FRESH MARKET SPECIALTY CROP PRODUCTION SYSTEMS FOR THE SOUTHERN GREAT PLAINS –Vincent Russo (P) and Charles Webber III; Lane Oklahoma.

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PESTICIDE APPLICATION TECHNOLOGIES FOR SPRAY-DRIFT MANAGEMENT, MAXIMIZING IN-FIELD DEPOSITION, AND TARGETED SPRAYING – Steven Thomson (P) and Yanbo Huang; Stoneville, Mississippi

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DEVELOPMENT OF SUSTAINABLE INTEGRATED CROP MANAGEMENT SYSTEMS FOR THE MID-SOUTHERN UNITED STATES – Krishna Reddy (P), Herbert Bruns, and William Pettigrew; Stoneville, Mississippi

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NEW AND IMPROVED CULTURAL PRACTICES FOR SUSTAINABLE SUGARCANE PRODUCTION AND ENVIRONMENTAL PROTECTION – Richard Johnson (P), Edward Richard Jr., and Ryan Viator; Houma, Louisiana

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BREEDING, GENETICS, STOCK IMPROVEMENT AND MANAGEMENT OF RUSSIAN HONEY BEES FOR MITE AND SMALL HIVE BEETLE CONTROL AND POLLINATION – Thomas Rinderer (P); Baton Rouge, Louisiana

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DEVELOPMENT AND USE OF MITE RESISTANCE TRAITS IN HONEY BEE BREEDING – Robert Danka (P), Beth Holloway, Joseph Villa, Thomas Rinderer, Jeffrey Harris, and Anita Bourgeois; Baton Rouge, Louisiana

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DEVELOP AND TRANSFER IRRIGATED AND NON-IRRIGATED PEANUT MANAGEMENT TECHNOLOGIES SYSTEMS AND TECHNOLOGY – Ronald Sorenson (P); Dawson, Georgia

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DEVELOPMENT OF INTEGRATED SYSTEMS FOR SUBTROPICAL/TROPICAL FRUIT CROP PRODUCTION – Richard Goenaga (P) and David Jenkins; Mayagüez, Puerto Rico

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ENHANCING THE SUSTAINABILITY OF COTTON PRODUCTION IN THE SOUTHEAST USA – Philip Bauer (P); Florence, South Carolina

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Appendix 3

National Program 305 – Crop Production

Accomplishment Report 2007 – 2011

Selected Supporting Information and Documentation for Accomplishments and Impact of NP 305 Research

Relationship of National Program 305 to the ARS Strategic Plan:

Outputs of NP 305 research support the actionable strategies associated with the performance measure shown below from the *ARS Strategic Plan for 2007- 2011*, Strategic Goal 2, Enhance the Competitiveness and Sustainability of Rural and Farm Economies; Objective 2.2: *Increase The Efficiency Of Domestic Agricultural Production And Marketing Systems*. (www.ars.usda.gov/SP2UserFiles/Place/00000000/ARSStrategicPlan2006-2011.pdf).

> **Performance Measure 2.2.3:** Expand, maintain, and protect our genetic resource base, increase our knowledge of genes, genomes, and biological processes, and provide economically and environmentally sound technologies that will improve the production efficiency, health, and value of the Nation's crops.
>
> > **Target**: New technologies developed and used by ARS customers to increase production efficiency and enhance the economic value and quality of U.S. crop production while decreasing the environmental footprint of production systems.

Planning and Coordination – Selected NP 305 Workshops and Stakeholder Gatherings:

- NP 305 Customer and Stakeholder Workshop, February 20-22, 2007; Stuart, Florida
- Colony Collapse Disorder Strategy Meeting (and Action Plan Development), April 23-April 24, 2007; Beltsville, Maryland
- Colony Collapse Disorder Steering Committee Conference Calls; Quarterly: June 2007-September 2011

Patents:

There were 22 patents issued from 2007-2011; Listed by title, inventor.

2011
- Peanut scavenger, Russell Nuti
- Specific light-based visual cues for the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål) and uses thereof, Tracy Leskey
- Biocontrol of varroa mites, William Meikle

2010
- Control of plant senescence, Cai Zhong Jiang
- Method to train an invertebrate to detect a concentration range of a compound, Dawn Olson

- Process for the off-season production of blackberries, Fumiomi Takeda
- Baculovirus for control of honey bee parasitic mites, Jay Evans
- Native bacteria for control of honey bee parasitic mites, Jay Evans
- An intelligent vertical boom spraying system, Heping Zhu
- Funnel bioassay cage, Bradley Fritz
- An interrogation measurement system and method providing accurate permittivity measurements via ultra-wideband removal of spurious reflectors, Mathew Pelletier

2009

- Cross-linked biofiber products and processes for their manufacture, Gregory Holt
- New method for preventing flower induction in strawberry plants for reducing or eliminating fungal infection in nursery fields, Fumiomi Takeda
- Indian meal moth attractant, Peter Teal
- Methods for controlling weeds including kudzu, William Molin
- Methods for attracting honey bee parasitic mites, Peter Teal
- Real time volatile organic compound analyzer, Yubin Lan
- Terrestrial arthropod trap, Peter Teal
- Overhead optical yield monitor for sugarcane chopper harvesters, Richard Johnson

2008

- Ascarosides as nematode sex pheromones, Peter Teal
- Cyclodextrin as carriers of miticidal agents for mite control in honey bees, Blaise le Blanc

2007

- An in-hive trap and lure for control of the small hive beetle, *Aethina tumida*, Peter Teal

EXTERNAL AWARDS:

Peer-reviewed research grants and stakeholder awards are a useful indicator of the quality and value of the NP 305 program. From 2007 to 2011, NP 305 National Program scientists were awarded 97 grants and awards that complemented and enhanced the objectives of the NP 305 Action Plan. Table 1, below, shows that the largest portion of external funding sources was from industry (43.3 percent) – evidence that the research is valued by stakeholders. University grants were the second largest number, and usually involved cooperative research projects jointly conducted with university partners. ARS scientists were also successful in competing for grants from other Federal sources (25 total).

External Grant Sources for National Program 301 Projects - 2007-2011

UNIVERSITY	GOVERNMENT						INDUSTRY	NON-PROFIT & TRUST	OTHER
	APHIS	CREES	FS	NIFA	OTHER FEDERAL	STATE/ LOCAL			
20	5	3	6	5	6	2	42	6	2

Table 1. Peer-reviewed research grants and awards given to NP 305 project scientists from 2007-2011.