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Introduction

National Program (NP) 305, Crop Production, supports research that develops knowledge, strategies, systems, and technologies that contribute to greater cropping efficiency, productivity, quality, marketability, and protection of annual, perennial, greenhouse, and nursery crops while increasing environmental quality and worker safety.

The Nation's rural economic vitality depends on the ability of growers to produce and market agricultural products – including food, fiber, flowers, industrial products, and fuels – profitably, while at the same time enhancing the natural resource base upon which crop production depends. This future financial success depends on increasing productivity, accessing new markets for specialized products, developing technologies to provide new opportunities for U.S. farmers, and utilizing tools and information to mitigate risks and enable rapid adjustments to changing market conditions. The farm sector has great and varied needs driven by a wide variety of resource, climatic, economic, and social factors, thus requiring an equally diverse array of solutions.

Contemporary cropping enterprises are complex and depend on highly integrated management components addressing crop production and protection, resource management, mechanization, and automation. U.S. annual, perennial, and greenhouse (protected systems) crop production are all based on the successful integration of these components. The development of successful new production systems requires a focus on new, as well as traditional crops; the availability and implementation of improved models and decision aids; cropping systems that are profitable and productive; production methods fostering conservation of natural resources; efficient and effective integrated control strategies for multiple pests; improved methods, principles, and systems for irrigation; improved mechanization, and reduced inputs while sustaining or increasing yield and quality. Production systems must better address the needs of small, intermediate, and large farming enterprises, including those using field-, greenhouse-, orchard-, and vineyard-based production platforms, through conventional, organic, or controlled environment strategies. Additionally, adaptation and/or development of technologies are required to ensure a sustainable and profitable environment for production agriculture. 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.

In addition, declining honey bee (Apis) populations and honey production require special attention. Over the past several years, a myriad of pests and potentially adverse cultural and pest management practices have been threatening many of the bee species required for pollination of a multitude of crops. Also, as new crops or niches are introduced, there is an increasing need for non-Apis bee pollinators for specific crops or protected environments.

NP 305 draws heavily on other ARS National Programs, universities, and industries in adapting and incorporating technologies, approaches, and strategies that enable the advancement of the Nation's agricultural industry and enhanced international competitiveness. In 2007, NP 305 held a customer/stakeholder workshop and used the input from the workshop to develop a new 5-year Action Plan. In 2008, new 5-year project plans based on the Action Plan were written for each of

the NP 305 projects and reviewed by external review panels through the Office of Scientific Quality Review (OSQR). Project plans were revised based on review panel comments. Once the project plans were approved by OSQR, the new projects were initiated. ARS thanks the many customer/stakeholders and the review panel members for the input that resulted in excellent project plans to address high priority research needs. Links for the Action Plan and list of new projects can be found at the NP 305 homepage at http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=305.

Below are NP 305 accomplishments from fiscal year 2008. Even though much of this research was conducted under the old project plans, the results are presented under the components and problem areas of the new action plan illustrating the transition from the old action plan to the new. The report below is not intended to be a progress report describing all the on-going research conducted during the fiscal year, but rather a listing of accomplishments, some of which are based on multiple years of research. As a result, not all research projects will reach an "accomplishment" endpoint each year.

ARS welcomes your input regarding our on-going research programs. If you have any questions as you read the report below, please do not hesitate to contact either the co-leaders for NP 305, Kevin Hackett (Kevin.Hackett@ars.usda.gov) or Sally Schneider (Sally.Schneider@ars.usda.gov) or the researchers conducting the work.

Component 1: Integrated Sustainable Crop Production

Subcomponent 1A: Annual Cropping Systems

Problem Statement 1A.1:
Develop Integrated Strategies for Soil, Water, and Nutrient Management for Optimal Yield and Economic Returns in Annual Cropping Systems.

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.

Problem Statement 1A.3:
Decision Support Systems to Optimize Pest Management.

Problem Statement 1A.4:
Develop Crop Production Systems that are Productive, Profitable, and Environmentally Acceptable.

Subcomponent 1B: Perennial Crops

Problem Statement 1B.1:
Develop Integrated Strategies for the Management of Pests and Environmental Factors that Impact Yield, Quality, and Profitability of Perennial Crops.

Problem Statement 1B.2:
Develop Mechanization and Automation Practices that Increase Production Efficiency.

Problem Statement 1B.3:

Develop Perennial Crop Production Systems that are Productive, Profitable, and Environmentally Acceptable.

Subcomponent 1C: Greenhouse, High Tunnel, and Nursery Production Systems

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.

Problem Statement 1C.2:
Develop Sensors and Automation Technologies for Greenhouses, High Tunnel, and Nursery Production Systems.

Problem Statement 1C.3: Develop Decision Support Systems Optimized for Greenhouse, Nursery, and High Tunnel Production Systems.

Problem Statement 1C.4: Develop Improved Crop Production Systems for High Quality Greenhouse, High Tunnel, and Nursery Crops.

Component 2: Bees and Pollination.

Subcomponent 2A: Honey Bees [Apis].

Problem Statement 2A.1:
Improving Honey Bee Health.

Problem Statement 2A.2:
Pollination of Crops.

Problem Statement 2A.3:
Developing and Using New Research Tools: Genomics, Genetics, Physiology, Germplasm Preservation, and Cell Culture.

Subcomponent 2B: Non-Apis Bees.

Problem Statement 2B.1:
Management for Crop Pollination.

Problem Statement 2B.2:
Bee Biodiversity and Contribution to Land Conservation.

Component 1: Integrated Sustainable Crop Production

Subcomponent 1A: Annual Cropping Systems

The production of annual crop species for food, feed, fiber, flowers, and fuel in the United States is a complex process. Its success depends on the integration of new knowledge with multiple technologies and strategies to promote economically and environmentally sustainable production systems capable of serving a diverse and growing population.

However, the sustainability of current annual crop production systems is challenged by a diverse range of problems. These challenges include the need to enhance crop quality and maintain or improve economic sustainability and marketplace competitiveness, while better protecting soil resources, improving water management, and reducing fertilizer usage. Other major challenges to the viability of annual crop enterprises include exotic and invasive pests and pathogens, high energy costs and environmental stresses linked to weather extremes and climate change.

To address these problems and ensure a stable and affordable food supply, there is a need for high efficiency agricultural systems that conserve energy and natural resources while mitigating adverse effects on the environment. Specific requirements include improvements in soil and water management, development of better pest management systems, design and development of superior machines and implements, and enhanced cropping system efficiency. Additionally, economic stability in U.S. annual crop production will be enhanced with improvements in cover crops, bio-energy crops, crop rotations, tillage systems, pest control systems, mechanization, conservation buffers/borders, and production systems for organic and migrating crops (*i.e.*, shifts in production crops/areas due to changes in economic, social, climatic, or political circumstances).

Problem Statement 1A.1: Develop Integrated Strategies for Soil, Water, and Nutrient Management for Optimal Yield and Economic Returns in Annual Cropping Systems.

New knowledge and technologies developed to address specific issues need to be integrated into technically feasible, economical, and environmentally acceptable management strategies. Research is often conducted within the scope of a specific discipline or to solve a specific problem. Commercial crop production problems do not occur in isolation, but rather as part of the overall production system. Specific research outcomes need to be evaluated, adapted, supplemented, and integrated into systems for soil, water, and nutrient management within the context of a crop production system.

Soil sampling practices studied for fertilizer application. A representative soil sample is a critical component of soil testing for fertilizer and lime application recommendations. Research was needed to determine optimal sampling depths for collecting soil samples to inform recommendations for conservation tillage systems. ARS scientists at Florence, South Carolina, determined that for phosphorous (P) and potassium (K), either a shallow (0 - 3 in) or deep (0 -6 in) sample was acceptable within this tillage system. However, a shallow sampling depth was a better sampling depth in the years following a lime application. With rapidly rising costs for these amendments, this information is important to growers who need to maximize economic returns from crop production inputs.

Phosphorous recovered from swine wastewater shown to be valuable as fertilizer. In addition to negative environmental impact of phosphorus (P) from animal waste, world phosphorus reserves are finite resources

and alternative sources of P nutrition for plants would be very beneficial. ARS scientists at Florence, South Carolina, previously developed a method of recovering phosphorous from animal manure to reduce the environmental impacts of this nutrient in regions with large animal feeding operations. Recently, these researchers made a striking discovery that, in addition to the environmental value, the recovered P can also be further used as a fertilizer material for plant production. They discovered that, when applied in small particles (0.5-1.0mm), the material was readily available for plant uptake. However, the material was not readily available when applied to soil as large particles (2.0 - 4.0 mm), which suggests it may make an effective slow release fertilizer. These results may enhance economic returns for growers who use animal manure treatments on their farm.

Oilseed cuphea identified as low nitrogen input crop. All crops need some nitrogen, a very expensive and energy-intensive nutrient. Therefore, it is important to provide crops with only as much nitrogen as they need and to identify and grow crop species that need very little nitrogen. In both North Dakota and Minnesota, a joint ARS and North Dakota State University team determined that the new oilseed crop, cuphea, requires very little nitrogen compared to corn to achieve close to maximum seed yields. In fact, residual soil nitrogen after corn or soybean production is sufficient for cuphea the following year. These results are now used in the growers' guide supplied by the main specialty seed company, Technology Crops International, which contracts with farmers in the northern United States, Canada, and northern Europe for cuphea seed production.

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.

Many segments of production agriculture in the United States rely heavily on human labor. Shortages of skilled workers to produce and harvest crops threaten the economic viability of annual-crop systems. Although some mechanical systems for planting, spraying, harvesting, and processing agricultural crops are available to address these issues, the availability of new technologies, rising labor costs, a shrinking workforce, and increased concern for worker and environmental protection are driving the need for advances in agricultural automation and mechanization. Optimized pest control application technology is important to ensuring the efficacy of integrated pest management strategies needed for sustainable crop production, including biological and biorational, cultural, physical, and chemical control technologies. The accurate delivery of agrichemicals and bioproducts to targets can greatly increase the efficiency of crop production by creating desirable biological effects, minimizing negative environmental impact and improving worker safety. Additionally, improved technologies are needed to better manage spray drift from both ground and aerial applications to avoid off-target drift resulting in potentially serious environmental problem in agricultural systems, especially under conditions favorable for temperature inversions.

Spray application strategies developed for bell pepper pest management. Vegetable producers lack comprehensive spray application strategies in their production programs. ARS scientists at Wooster, Ohio, found that an air-assist sprayer produced higher spray deposits on fruit than conventional treatments. The sprayer also produced significantly higher spray coverage deeper in the canopy and on underside leaf surfaces, with no significant differences identified between treatments applied at varying speeds. This work demonstrated the feasibility of air-assisted applications and low drift nozzle technology to meet lower spray coverage requirements.

Canopy opener developed to maximize spray application efficiency. Conventional boom sprayers cannot adequately deliver pesticides to the inner foliage when plants have dense canopies. Based on mathematical models developed by ARS scientists in Wooster, Ohio, an experimental mechanical canopy opener for boom sprayers was developed that is able to push apart the top of canopies to allow effective delivery of pesticides into lower parts of canopies. This research also demonstrated the use of mathematical models to design

inexpensive devices that could be used on conventional boom sprayers to greatly improve spray penetration and application efficiency.

Improved variable-rate aerial application technologies and protocols developed. Variable-rate technologies offer the capability to apply crop protectants only where needed and in the amounts needed to adequately protect crops. In order for variable-rate applications to be made, vast amounts of remotely sensed data, such as multispectral images obtained from aircraft or satellites, must be collected, analyzed, and then translated into data that applicators can use. ARS scientists at College Station, Texas, employed both ground- and aerial-based remote sensing techniques to enhance the collection and processing of data needed to make variable-rate applications. Ground and aerial applicators will use the methodologies, technologies, and protocols developed in this accomplishment to create accurate and user-friendly variable-rate, field-based prescription maps. The end result will be effective variable-rate application procedures, utilized widely by aerial applicators that will significantly reduce chemical input costs, application time, aircraft fuel expenditures, and potentially negative environmental impacts.

Collection efficiency of airborne spray flux samplers studied. Determination of the movement and ultimate fate of agricultural sprays within and off target areas is a critical concern for applicators, landowners, and researchers. There are numerous methods for the quantitative assessment of the volume of suspended spray material; however, if the fraction of the total spray volume actually sampled by the collector is not known, comparisons between collectors, comparisons with modeled data, and mass balance calculations are not possible. ARS scientists at College Station, Texas, developed protocols and established collection efficiencies of several commonly used spray flux collectors. This work allows a total accounting of applied materials and an increased understanding of how agricultural sprays are transported and deposited in the environment.

Adjuvant utilization found to reduce spray drift from aerial applications. Spray drift from the aerial application of pesticides has been recognized as a concern for the environment. The physical properties of spray additives, or adjuvants, are among the most important factors that affect atomization of a spray. ARS scientists at College Station, Texas, defined the physical properties of certain spray adjuvants and also correlated adjuvant physical properties to spray droplet spectra. Aerial applicators will use this information to appropriately select spray adjuvants that will reduce spray drift, thus increasing on-target deposition and minimizing drift, which can have adverse environmental consequences.

Effects of wind speed and bioassay cage design assessed. To protect the public from mosquitoes that can carry West Nile Virus, Eastern Equine Encephalitis, or other insect-transmitted diseases, public health officials and researchers must rely on the use of bioassay cages to measure the efficacy of insecticides and application methodologies. It is therefore critical that the bioassay cages accurately reflect spray efficacy on natural populations of mosquitoes. ARS scientists at College Station, Texas, accurately determined the effects of wind speed and screening material on spray droplet penetration into bioassay cages and on spray efficacy assessments. This accomplishment will provide critical guidance on the impact of wind speed and cage design/construction on spray droplet movement into bioassay cages and will lead to much more accurate data for public health officials to use in protecting the public against serious insect-transmitted diseases.

Problem Statement 1A.3: Decision Support Systems to Optimize Pest Management.

Producers managing annual crop ecosystems must consider a multitude of factors when making pest management decisions. Among these considerations are rising input costs and increasing world-market competition which require cost/benefit analyses for management inputs to ensure economic viability. To make such assessments, improved computer-based support systems are needed to provide the tools for making informed decisions.

Extent and timing of groundsel seedling emergence shown to be predictable. Common groundsel is a serious problem in many horticultural crops, such as strawberry, and is one of the few weeds in northern

crops that can produce two generations within a single growing season. In association with researchers from the University of California-Riverside, the University of Minnesota, and the Catholic Pontificial University (Chile), ARS scientists at Morris, Minnesota, developed a user-friendly model that allows growers and consultants to predict the timing and extent of groundsel emergence in a site-specific manner. Growers now can better plan when to apply either preemergence herbicides to prolong residual activity or postemergence herbicides to maximize efficacy on common groundsel.

Timing of early- and late-emerging giant ragweed populations predicted. Giant ragweed is an increasing problem in the Corn Belt, not only because of its competitiveness and resistance to glyphosate and ALS inhibitor herbicides, but also because early- and late-emerging populations have developed, sometimes within the same field. Postemergence control of giant ragweed depends greatly on appropriate timing of herbicide application. To facilitate control by growers, ARS scientists at Morris, Minnesota, in conjunction with Ohio State University, developed a model that predicts the timing and extent of emergence of both early- and late-emerging phenotypes. That model is Web-based and allows growers in Ohio and adjacent regions to increase the probability of successful postemergence control of giant ragweed.

New method developed to predict giant foxtail emergence. Seedling emergence of important weeds such as giant foxtail can be predicted using sophisticated computer programs, but some growers are reluctant to use such software and alternative prediction methods are needed. Consequently, ARS scientists at Morris, Minnesota, examined whether the development of various traits (bud burst, flowering, etc.) of several species of horticultural plants common to most farms of the Midwest was associated with giant foxtail emergence. Many such traits were associated with foxtail emergence; for instance, the first flowering of chokecherry occurred at the same time as 25 percent cumulative foxtail emergence. These results assist farmers and crop advisors with making timely weed management decisions.

Problem Statement 1A.4: Develop Crop Production Systems that are Productive, Profitable, and Environmentally Acceptable.

Increasing agricultural input costs, global climate change, and growing public concerns for the environment require the development of improved crop production systems that are economically viable, socially acceptable, and environmentally sustainable. Market forces are acting to increase pressure on U.S. producers to provide agricultural products of greater quality. Domestic and foreign consumers want food products with enhanced flavor, nutrition, and improved shelf-life; thus, processors require agricultural products with greater end-use utility. New information and technologies must be integrated into productive, profitable, and sustainable production systems to help U.S. growers remain competitive in the global marketplace.

Fall flowering increased in short-day type strawberry cultivars. In the mid-Atlantic coast region, short-day type strawberry plants do not produce fruit in the year of establishment. ARS scientists at Kearneysville, West Virginia, found that when 'Strawberry Festival' transplants were prepared in July and held in small containers until field planting in early September, more than 86 percent flowered by mid-October. Additional research into the processes regulating flower development showed that flowering could be reduced by illuminating strawberry crowns with red wavelength light, demonstrating that lack of red light penetration to the crowns in August plays a significant role in the induction of flowers in midsummer. As a result of this research, it is now possible to produce transplants with high fall fruiting potential without the need to expose transplants to artificial short days and chilling temperatures. Transplants developed through this research will be useful for fall production of strawberries in the mid-Atlantic coast region.

Strawberry production systems developed. Most strawberry production systems are currently designed for main season, matted row production. ARS scientists at Beltsville, Maryland, and Kearneysville, West Virginia, developed novel production systems and strawberry genotypes for summer-fruiting strawberries and for fall-fruiting strawberries. This research will aid in the development of new strawberry production systems to expand markets and marketing windows, especially for mid-Atlantic growers.

Resveratrol presence studied in strawberry. Resveratrol is a plant compound that has been shown to have anti-cancer, anti-inflammatory, blood-sugar-lowering, and other beneficial cardiovascular effects. Strawberries contain two forms of resveratrol. ARS scientists at Beltsville, Maryland, determined that genotype variation, degree of ripeness, compost, mulch, atmospheric carbon dioxide concentration, growth temperature, and growth regulator treatment all affect resveratrol content. This research suggests that both genetic background and cultural practices have potential to influence antioxidant capacity in crops.

Seed coatings shown to delay emergence of corn and soybean. Even when soil conditions are sufficiently dry, growers avoid sowing corn and soybean in the early spring to guard against early-season cold damage to seedlings. Over three seasons, ARS scientists at Morris, Minnesota, tested the theory that polymer-based seed coatings can prevent germination until soils warm sufficiently to promote safe emergence. The results verified that polymer coatings delayed seedling emergence by about 10 days, an ample period of time to protect most seedlings from cold damage. These results assist growers, crop advisors, and seed industry personnel in making wise planting decisions in spring.

Drip irrigation spacing evaluated for corn and cotton. ARS scientists at Dawson, Georgia, evaluated the economics of cotton and corn planted on 3-ft row spacing with drip tube laterals at 3-ft and 6-ft spacing. Results indicate that 6-ft lateral spacing had higher returns for both corn and cotton and that 3-ft spacing may not be cost effective for either crop.

Common waterhemp seed production found to respond differently to corn and soybean canopies. Waterhemp recently rose to prominence as a major weed in the Corn Belt, with high but unknown levels of seed production. With researchers from the University of Minnesota and South Dakota State University, ARS scientists at Morris, Minnesota, determined that the timing of waterhemp seed production in a given location was impacted by the crop species (corn or soybean) in question. This work shows that to inhibit population explosions of waterhemp, growers must emphasize early-season control in corn and late-season residual control in soybean.

Both swathing and direct combining shown to be effective for harvesting oilseed cuphea. ARS scientists at Morris, Minnesota, performed experiments in conjunction with North Dakota State University in both States to compare direct combining, chemical desiccation, and swathing for yield and ease of harvesting. Chemical desiccation was not fruitful, but the direct combining and swathing methods were of equally high value. Although direct combining is cheaper than swathing, this technique involves additional seed drying costs, causing swathing to be an attractive alternative. This finding has been included in the growers' guide supplied by the main specialty seed company, Technology Crops International, which contracts with farmers in the northern United States, Canada, and northern Europe for cuphea seed production.

Subcomponent 1B: Perennial Crops

Profitable production is especially challenging in an increasingly competitive and complex world marketplace environment. Profit limiting factors, such as foodstuff importation, input and labor costs, environmental stresses, inadequate pollination, urbanization, and greater need for environmental protection increasingly challenge the economic viability of domestic perennial crop production. Production efficiency and the sustainability of both consumer and commercial-scale production are also threatened by the fact that most perennial fruit, nut, berry, ornamental, and sugar crops possess horticultural deficiencies related to key traits that substantially limit horticultural and economic fitness. Therefore, economically viable production depends on both the development of new or improved strategies and technologies that compensate for deficiencies in key horticultural traits and on the successful integration of these products into 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.

All perennial crop cultivars/varieties/rootstocks possess limitations in key horticultural traits and/or characteristics that make them susceptible to damage from a wide variety of stressors. Consequently, cultural and pest management-associated inputs are needed to address deficiencies linked to environmental adaptation, disease, arthropods, weeds, canopy health and photoassimilation efficiency, flowering and crop-set, fruit quality, pollination, hardiness, light environment, and harvest ability. Furthermore, the productivity of perennial crop production systems is limited by the availability and quality of soil, water, light, and nutrient resources, which varies greatly among U.S. agroecosystems. These limitations include reduced soil organic matter, excessive soil salinity, reduced quality and availability of irrigation waters, degraded air and water quality from soil management systems, poor light environments, and degraded soil health and quality. New knowledge, strategies, and technologies that mitigate inherent crop-associated deficiencies and biotic and abiotic stresses are needed to improve production efficiency, crop quality, and environmental sustainability. These must be effectively integrated into new or modified perennial cropping systems.

Factors leading to nickel deficiency in plants explored. The expression of plant nickel deficiency is a mystery when nickel stores in plants and soils appear to be sufficient to satisfy crop needs. ARS scientists at Byron, Georgia, found that expression of nickel deficiency depends largely upon the zinc: nickel or copper: nickel ratio in crop tissues and organs and thus the biological availability of nickel for plant processes. Findings suggest that nickel deficiency may be more common in agricultural crops than generally thought and that excessive agricultural usage of zinc or copper fertilizers can potentially trigger nickel deficiency. These findings will provide information for improved crop production and fertilizer management strategies.

Nitrogen management for pecan trees elucidated. Nitrogen management is a major, and increasing, cost for pecan farmers. ARS scientists at Byron, Georgia, found that trees with adequate nitrogen nutrition rely on nitrogen stored from the previous season for their annual growth. This explains why trees require at least 2 years to respond to changes in nitrogen management. The results emphasize the importance of maintaining an annual nitrogen fertility program for current and future production.

Improved boron and nickel management shown to reduce crop loss to water-stage fruit-split. Crop loss to water-stage fruit-split is a major cause of crop loss in certain pecan cultivars. ARS scientists at Byron, Georgia, determined that the incidence of this form of loss is reduced, and orchard yield increased, by the timely improvement of tree nutritional status for boron and nickel.

Nitrogen fertilizer levels reduced with yields maintained. Louisiana sugarcane producers face challenges as they attempt to maximize profits and increase production efficiency in the face of significant cost increases for nitrogen (N), phosphorus (P), and potassium (K) fertilizers. ARS scientists in Houma, Louisiana, in cooperation with scientists from the Louisiana State University Agriculture Center, conducted N fertilizer research in plant-cane and first-ratoon fields, demonstrating that N rates could be decreased in both plant and first-ratoon crops without a decrease in cane or sugar yields. Research recommends that slightly more N is necessary for first-ratoon crops than plant-cane crops, and that additional N fertilizer is needed for second year and older ratoon crops. Data from these studies was used to revise N recommendations for sugarcane in Louisiana, now calling for a 15-20 percent reduction in N rates for all soil types and crop ages.

Best irrigation practices developed for blueberry. Sprinkler irrigation, often used in blueberry, tends to push water and nutrients below the roots and may supply insufficient water to meet evapotranspirational demands of the crop. ARS scientists at Corvallis, Oregon, developed and evaluated new irrigation methods and scheduling strategies for growing highbush blueberry that maximize yield and fruit quality. This research determined that proper drip placement reduced irrigation requirements, maintained higher soil water content, and lowered plant water stress compared to traditional methods of irrigation, and results clearly demonstrated that growth and production was often greatest when plants were irrigated by drip. This research documents the benefits of drip irrigation technology in terms of reduced inputs and improved blueberry quality and yield.

Particle film materials shown to reduce negative effects of heat and increase apple productivity. Heat is a limiting factor of plant productivity throughout the world, and investigations of kaolin-based particle films (PF) have demonstrated that the reflective nature of the resulting plant surface can increase productivity primarily by reducing temperature in fruit, leaf, and canopy, but the underlying plant responses are not clear. A 10-year study by ARS scientists at Kearneysville, West Virginia, demonstrated that the combination of PF and adequate water could maintain maximum photosynthesis rates at full sun levels during the midday period and minimize the midday depression of photosynthesis that can reduce daily carbon accumulation. Results suggest that the increased carbon accumulation occurring during the PF treatments at midday was likely diverted to the fruit, since the PF treatments increased fruit weight in 8 of 10 years. Thus, the use of PF may be an effective substitute for evaporative cooling not only to reduce fruit solar injury, but to improve apple quality through increased fruit weight in hot and dry climates.

Host status of litchi and rambutan to the West Indian fruit fly assessed. Knowledge of whether rambutan and litchi serve as hosts to the West Indian fruit fly is critical to increasing the trade of those commodities. An extensive survey by ARS scientists at Mayaguez, Puerto Rico, of mature fruit collected from the field yielded no fly larvae or pupae. Moreover, when exposed to 12 day old female flies, ripe litchi and rambutan fruit did not result in viable tephritid larvae. This research strongly 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.

Problem Statement 1B.2: Develop Mechanization and Automation Practices that Increase Production Efficiency.

Production efficiency and economic viability of perennial crops is tightly linked to the efficacious use of agricultural inputs such as pesticides, plant growth regulators, fertilizers, and other beneficial agents deposited on crops. These, in turn, are tightly linked to mechanization technologies for the application of agricultural inputs. For U.S. agriculture to take full advantage of safer pest control agents and chemical or biological approaches to overcoming horticultural, crop nutrition, or pest management constraints, appropriate and efficacious application technologies need to be developed, integrated, and optimized in crop production schemes. Barriers to the adoption of mechanization and automation technologies for crop spraying must be identified and overcome.

Adjuvant utilization found to reduce spray drift from aerial applications. Spray drift from the aerial application of pesticides has been recognized as a concern for the environment. The physical properties of spray additives, or adjuvants, are among the most important factors that affect atomization of a spray. ARS scientists at College Station, Texas, defined the physical properties of certain spray adjuvants and also correlated adjuvant physical properties to spray droplet spectra. Aerial applicators will use this information to appropriately select spray adjuvants that will reduce spray drift, thus increasing on-target deposition and minimizing drift, which can have adverse environmental consequences.

Low-drift nozzle tested for orchard drift management. Tree fruit crops are particularly difficult crops to protect with pesticides because they are typically taller than most conventional application equipment. ARS scientists at Wooster, Ohio, demonstrated that air induction nozzles may be effective drift mitigation technologies for orchard applications, providing producers with another option for mitigating drift; however, care must be taken to ensure that coverage requirements for maximum pesticide efficacy are met.

New approach discovered for increasing fruit quality. Fruit trees produce excess bloom that can result in over-cropping and small, poor-quality fruit. Initial tests of a rod-drum shaker mechanism on upright, narrow canopy peach trees by ARS scientists at Kearneysville, West Virginia, reduced crop load an average of 58 percent and follow-up hand thinning time by 50 percent, and increased fruit size by 9 percent at harvest compared to conventional hand thinned or non-thinned control trees. Large scale commercial orchard tests conducted in Pennsylvania showed similar results. Mechanical thinning thus appears to be a promising technique for supplementing hand thinning in peach trees.

Trellis tension monitor (TTM) developed for monitoring crop growth. The trellis tension monitor (TTM) was developed to meet the industry's need for real-time information about vine and fruit growth and to provide dynamic estimates of grape yields, information that previously was available only statically in one or two "snapshots" per growing season. ARS scientists at Corvallis, Oregon, demonstrated the utility of the TTM as an automated tool for estimating stages of crop growth during the season. Growers can apply the technology as a decision aid for fruit thinning, shoot thinning, confirmation of desired levels of thinning, initiation of deficit irrigation, and timing of supplemental hand sampling for traditional yield estimation.

Problem Statement 1B.3: Develop Perennial Crop Production Systems that are Productive, Profitable, and Environmentally Acceptable.

Perennial crop management decisions are not made in isolation, but in the context of the crop production system over the multi-year life span of a perennial crop. Individual management strategies and technologies need to be integrated into the system. Applied crop physiology, the role of new crops or varieties, and optimization of all management activities within the unique circumstances of perennial crops must be considered. New knowledge, technologies, and crop cultivars must be effectively integrated into new or modified perennial cropping systems.

Viticulture performance of red and white-skinned wine grape cultivars studied. Wine grapes are becoming an attractive option for growers in marginal production regions, due to their high economic return and the associated agribusiness and tourism. ARS scientists at Parma, Idaho, collected viticulture performance data from red and white-skinned wine grape cultivars over 4 years. This data will be used by the wine grape industry to select vineyard sites in the Western Snake River Plain of Idaho as well as in other high elevation, semi-arid production regions.

Wine quality implications studied in wine grapes. Winemaking conditions influence the final structure of a wine. Tannins (a class of phenolics found in grape skins and seeds) are important indicators of red wine quality. ARS scientists at Parma, Idaho, in cooperation with a commercial winery, examined the differences in tannin composition between seed-removed wine (involving early removal of seeds during Merlot fermentation) and traditionally made wine (control wine). Only small differences in tannin composition were observed, but were sufficient to cause the winemakers to continue with their traditional winemaking method. This study contributed to the understanding of different winemaking strategies.

Early-harvest and water-logged soils shown to reduce ratoon yields in Louisiana. As the number of sugarcane processing plants continues to decline, harvesting must begin early to avoid complete crop destruction during late-season freezes. However, early harvesting prevents sugarcane plants from sufficiently storing carbohydrates in underground crowns to establish the next season’s shoots, with some varieties experiencing up to 40 percent yield reductions. The Louisiana sugarcane industry is also becoming increasingly challenged by waterlogged soil conditions due to soil subsidence, increasingly poor drainage, and hurricanes. Scientists at Houma, Louisiana, in cooperation with the Natural Resources Conservation Service (NRCS) and the American Sugar Cane League (ASCL), screened different sugarcane varieties for yield reductions during early harvesting and tolerance to flooded conditions. Results identified several varieties with low and moderate tolerance to early harvesting, as well as several with high and low tolerance to flooded conditions. Data from both of these experiments have been integrated into Louisiana State University’s Sugarcane Production Recommendations.

Subcomponent 1C: Greenhouse, High Tunnel, and Nursery Production Systems.

Greenhouse, high tunnel, and nursery production systems offer greater control over the growth environment during production, and as a result, can achieve greater yields, enhanced quality, and/or earlier production than their field-grown counterparts. However, the increased control in nursery

production and protected horticulture comes at a cost of higher labor and fuel costs, increased reliance on substrates and inert materials from overseas markets, and an environment that enhances selection of pests that withstand traditional chemical control measures. Within protected horticulture, there are opportunities to improve water, nutrient, and substrate utilization; increase the use of mechanization; and significantly reduce the negative impact on the environment, while simultaneously preserving productivity and product quality.

High priority research needs include reducing the industry's reliance on non-renewable materials, recycling water and nutrients, developing environmentally friendly delivery systems and bio-based pest control methods, improving the use of mechanization to reduce labor costs, improving monitoring capabilities through new or improved sensors, maintaining or improving consistent product quality, and improving greenhouse fuel efficiency through enhanced resource use or structure design. New or improved products, techniques, models, and decision support aids, will enhance profitability in this globally competitive industry.

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.

Pests – in the form of insects, mites, plant pathogens, and weeds – often prevent crops from reaching their full yield and quality potential and cause post-harvest losses. Comprehensive integration of cultural and sanitation practices, that minimize pathogen population levels, dispersal of pathogens, and conditions conducive for disease development, require further development if greenhouse and nursery production systems are to remain profitable in an increasingly competitive market. Another challenge in traditional and hydroponic-based production systems within greenhouses and nurseries involves the recycling of water. Greater understanding of the significance and treatment of plant pathogens dispersed in water run-off, captured in surface ponds, and subsequently reaching ornamental crops during irrigation is critical to healthy crop production. To ensure optimal water and nutrient recycling, an improved understanding of nutrient dynamics in the plant-substrate system, water movement within the production system, and pathogen suppression in the recycled water is needed. System-specific cultural management, including the integration of new genetic material or plant varieties, can also help reduce crop susceptibility to pests during and after production. All strategies must be compatible with complex ornamental nursery and greenhouse production systems.

Relationship between nitrogen and fertilizer studied. Application of nitrogen (N) fertilizer late in the growing season can decrease cold hardiness and increase the potential for cold injury to buds and stems; however, the specific relationships between plant N status and fertilizer formulations have not been well investigated. ARS scientists at Corvallis, Oregon, in cooperation with researchers at Mississippi State University, Oregon State University, and Washington State University, determined the influence of N rate and N form on autumn and winter cold tolerance of buds and stems of green ash (*Fraxinus pennsylvanica*). Both N rate and form influenced cold tolerance, especially hardiness levels during mid-winter and the de-acclimation period in February. Results indicated that stems and buds of plants fertilized with urea formaldehyde-based fertilizer were more cold tolerant than stems and buds of trees fertilized with ammonium nitrate-based fertilizer, suggesting that trees at a similar N status can withstand different levels of cold depending on the type or form of fertilizer used during production; consequently, fertilizer component selection may be more important than application rate for production of container-grown nursery crops in climates prone to winter injury. This new knowledge will be used by growers, fertilizer manufacturers, and extension personnel to develop

fertilizer management strategies that improve plant quality for nursery stock prone to winter injury, thus increasing profitability.

Physiological changes with urea sprays. Spraying leaves of container-grown nursery plants in the autumn with urea alters uptake and use of other mineral nutrients, but little information is available on the physiological changes induced by urea sprays on nursery crops, and there is no information on whether this practice alters uptake of other nutrients. ARS scientists at Corvallis, Oregon, determined that spraying container-grown Rhododendron nursery plants with urea in the autumn alters uptake and allocation of nutrients other than Nitrogen (N), demonstrating that urea sprays increased uptake and storage of some specific nutrients in some cultivars and also caused losses of other nutrients (*e.g.,* potassium). Thus, the influence of urea sprays in the autumn on uptake of nutrients has potentially positive benefits for growth the following spring; however, when using urea sprays in the autumn as a N management technique, plant demand for other nutrients in the spring may also be higher, and spring fertilizer practices may need adjustment to ensure optimal growth. Knowledge from this accomplishment will be used by growers and by extension personnel to develop fertilizer management strategies that improve plant quality, minimize production costs, and encourage use of environmentally sustainable practices.

Silicon use shown to enhance floriculture crop production. Some field crops and a few greenhouse vegetables are known to benefit from silicon (Si) fertilization through increased stress resistance, but the response of most floriculture crops to silicon is unknown. Utilizing a multi-faceted approach, ARS scientists at Toledo, Ohio, determined the role of Si in some crops (*e.g.*, increased resistance to copper toxicity, delay in the onset and development of powdery mildew, and slight suppression of aphid population growth rates), and evaluated effective delivery of silicon to the target plants. Results indicate that inclusion of silicon in production systems of some floricultural crops can improve a plant's inherent ability to withstand stress from a variety of sources (both biotic and abiotic), which should reduce the need for applying some chemicals and improve the efficacy of others (*e.g.*, copper-containing pesticides).

Fate of pesticide droplets on targets evaluated. Extensive research has been conducted to achieve accurate delivery of chemical droplets; however, the fate of chemical droplets after deposition on leaf surfaces has not been studied. ARS scientists at Wooster, Ohio, investigated evaporation time and the area wetted by a single pesticide droplet on waxy or non-waxy surfaces and smooth crabapple leaves under controlled conditions and for droplet size, relative humidity, and chemical formulation. Studies showed that evaporation time and the wetted area of droplets affected the distribution of pesticides on targets with different surface characteristics. Results indicate that to obtain the optimal biological effect and reduce pesticide use, pesticide dosage and spray techniques should be used differently for different leaf surfaces.

Gene expression during lifespan studied in cut flower species. ARS scientists at Davis, California, isolated several genes that are up-regulated during floral senescence (growth and aging) from seven different flower species (Alstroemeria, Antirrhinum, Gerbera, Iris, Lilium, Lisianthus, and Petunia). Expression of one gene increased greatly during the final stages of flower development and aging in all the species tested, suggesting that it plays an important role in the regulation of floral senescence in a wide range of species and may have potential use as a universal marker to predict flower freshness.

VIGS analysis of regulatory genes associated with petal senescence in petunia. ARS scientists at Davis, California, used virus-induced gene silencing (VIGS) to evaluate the possible regulatory role of a number of transcription factors in pollination-induced petal senescence (wilting) in petunia. They found that pollination-induced petal wilting could be delayed by silencing a series of genes (a petunia homolog of a MYB gene, two AP2/EREBP genes, five genes in the HB family, and one gene in the bZIP family). In addition, silencing of NAC type of genes accelerated flower senescence; this research suggests that, as in leaf senescence, floral senescence is the result of a regulatory network. This research will benefit the industry in the longer term by providing more effective means of increasing flower vase life, especially of short-lived flowers such as Iris.

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 (drying out). However, ARS scientists at Davis, California, determined that dry-handled flowers showed less transportation damage (largely petal bruising) presumably because of reduced turgor (pressure within the

cell wall) and total volume. Despite substantial loss of water during transport, dry-handled flowers rehydrated fully, and performed at least as well in the vase as flowers handled according to the standard protocol. These data suggest that the value of immediate hydration of harvested flowers should be carefully examined.

Alternative postharvest control methods developed for *Botrytis cinerea* infection of rose varieties. *Botrytis cinerea* infection greatly reduces the vase life of cut flowers, specifically roses. Current postharvest strategies to reduce its impact are insufficient, especially with the expansion of international transport methods and increased transit time. ARS scientists at Davis, California, demonstrated that application of Switch as a postharvest dip dramatically reduced *Botrytis* infections in rose, but that treatment efficacy depends on application time after harvest along with postharvest environmental conditions. Therefore, it is necessary to optimize application protocols for treatment of rose varieties.

Problem Statement 1C.2: Develop Sensors and Automation Technologies for Greenhouses, High Tunnel, and Nursery Production Systems.

In light of current labor shortages, the need for mechanization and automation systems to reduce human labor requirements remains high. Moreover, plants grown in nurseries and greenhouses require efficient, specialized technologies and equipment systems for production, handling, and harvesting. Mechanical systems for harvesting fruit, flowers, nursery plants, and fresh-market vegetables are often inadequate or inefficient, and many protected horticulture-cropping systems are not well adapted to mechanization and automation. Chemical applications in greenhouses and high tunnels present potential risks to workers involved in plant production and facility operations and make biological control measures preferable. There is a need for precise delivery of agrichemicals and bio-products to ensure the desired biological effect and to minimize adverse impacts on the environment. This will require better measurement techniques for plant stress and agrichemical detection to ensure adequate application and minimal runoff or drift. Furthermore, to facilitate the application and delivery of emerging biologically based materials, there is a need for newly designed systems, significant modifications to existing systems, or reliance on biological delivery, perhaps during insect pollination. In addition, sensors that monitor pest impact on crops, as well as spray deposition and efficacy, are needed for efficient pest management. Strategies must be compatible with complex ornamental nursery and greenhouse production systems.

Half-rate spray technology implemented for nursery production. Use of traditional settings in air blast sprayers in nursery applications results in excessive spray deposition inside tree canopies and loss of spray mixtures to the ground and air. ARS scientists in Wooster, Ohio, developed new recommendations for reduced (half-rate) pesticide application, which have been adopted by nursery growers, resulting in half the usage of pesticides for pest and disease controls in nursery shade tree plants. By using the half-rate technology, growers reduced pesticide applications and reported savings of over $200-$500 per acre.

Optimal spray techniques identified for nursery applications. Unusual planting configurations can cause inefficient pesticide use during pest control for many container-grown ornamental crops. ARS scientists in Wooster, Ohio, determined the parameters (maximum spray range, uniformity of spray deposition, coverage, and air velocity) of a wide-swath air jet sprayer for container-grown crops. Nursery growers can use this information to identify optimal spray techniques to effectively control pest insects or diseases without excessive pesticide use.

Hand-held pressure gauge tester developed. Accurate pressure gauges are required to ensure proper delivery rates of pesticides or irrigation water, but they become inaccurate over time. ARS scientists in Wooster, Ohio, modified a commercially available hand-held pressure gauge tester, providing an inexpensive and user-friendly tester for pesticide applicators and irrigation managers. The device also provides

extension educators with a way to teach farmers how to set up sprayers and irrigation systems. The tester will save farmers money, conserve water, and reduce pesticide contamination of the environment.

Moisture availability in soilless substrates evaluated. 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 scientists at Wooster, Ohio, developed a new method for measuring water content in soilless substrates at low tensions. This new technique can be used to better characterize the water buffering potential of soilless substrates and to create a chart known as the Moisture Characteristic Curve (MCC), from which information can be used to more accurately program irrigation controllers. This achievement should improve irrigation precision and reduce water waste.

Problem Statement 1C.3: Develop Decision Support Systems Optimized for Greenhouse, Nursery, and High Tunnel Production Systems.

Due to growing consumer demand for produce outside of the traditional field-crop production season, controlled-environment crop production represents a significant and increasing portion of total agricultural sales. The efficiency and productivity of a greenhouse system are greatly influenced by its design, which in turn is greatly influenced by location and weather conditions. In addition, heating and cooling represent major production costs in protected-agriculture production and differ for producers in different locations. New knowledge and technologies are needed to assist producers in optimizing production within controlled-environment structures.

Enhanced greenhouse energy models developed. Equations and models exist that can separately determine plant growth and development as influenced by temperature and light, as well as the energy balance and needs of greenhouses in certain environments. However, no single model combines these calculations so that a user can easily determine how a greenhouse environment might be managed for optimal energy use, cost, and crop development. ARS scientists at Toledo, Ohio, combined their previously released Virtual Grower software, which was developed to calculate energy use for different greenhouse styles in 230 U.S. locations, with 12 plant growth and development equations, so that the influence of one cost (of heating a greenhouse) could be seen on another (that of crop production). This work has enabled growers to optimize crop production based on factors unique to their facility and location, improve production cost estimates, and increase their awareness of how one optimization strategy can influence another. The improved model has been downloaded and distributed over 500 times at no charge all over the world since its release in January 2008.

Problem Statement 1C.4: Develop Improved Crop Production Systems for High Quality Greenhouse, High Tunnel, and Nursery Crops.

Among the many factors affecting production efficiency, profitability, and environmental impact of greenhouse, high tunnel, and nursery production systems are soil and soil-less substrate constraints. The harvesting of woody ornamentals often removes large amounts of soil, thus requiring replacement or upgrading for subsequent plantings. Non-renewable, peat-based substrates and inert materials such as rockwool, on which greenhouse production depends, face limitations regarding disposal, transportation cost, and vulnerability to export market constraints. To reduce the environmental impact of controlled environment cropping systems, an improved understanding of specialty crop-cropping systems, particularly regarding interactions between the environment, soil-nutrient-water management, and pest control is needed. In addition, researchers must determine how to optimize non-renewable and on-farm resources and to integrate, where appropriate, natural biological cycles and controls to improve the sustainability and economic viability of farm operations.

Production methods and technologies are needed to achieve consistently high quality in controlled environment agricultural systems and to preserve quality during post-production. Increased product quality is expected by brokers and consumers of controlled environment products, and is a key distinguishing feature that enables producers to establish and maintain a market niche. While the definition of quality can entail many crop-specific characteristics, overall, the costs of inputs, or adoption of improved technologies, to achieve a higher standard of quality must remain below the value of production to enable economically viable crop production. Collaboration between scientists and economists during the various phases of developing agro-technologies and systems approaches is critical to assess the economic feasibility and impact of new production systems, management tools, sensors, and technologies.

Nutrient availability studied in Douglas fir bark in response to substrate pH. Little is known about nutrient availability in soilless substrates. ARS scientists at Wooster, Ohio, documented nutrient availability in Douglas fir bark (a common nursery substrate) across a broad range of substrate pH values, in both fertilized and non-fertilized substrates, as well as substrates amended with peat moss and pumice (common amendments used by nursery growers). The data showed that nutrient availability in low pH substrates is better than in highpH substrates. ARS data also show that the common practice of amending substrates with lime has a negative impact on the availability of most nutrients. Most notable about this research was the higher levels of nitrogen (N) and phosphorus (P) in low pH substrates, suggesting that more N and P might be available at low pH substrates and that less of each nutrient might be lost to leaching.

Guidelines developed for the container production of numerous ornamental crops in WholeTree substrates. ARS scientists in Poplarville, Mississippi, developed guidelines for irrigation and nutrient management in the container production of ornamental crops, which included the use of WholeTree substrates (sustainable alternatives made of pine trees). Using these guidelines, a large greenhouse operation in the Southeastern United States has implemented the use of substrates composed of 30 percent WholeTree for the production of numerous annual and perennial crops. As research on irrigation and nutrient inputs for WholeTree substrates continues, results should lead to increased commercial demand.

Component 2: Bees and Pollination.

Subcomponent 2A: Honey Bees [Apis]

Honey bees and their colonies are threatened by a myriad of pests (including Africanized honey bees, invasive parasitic mites, and insects), pathogens, pesticides, and poor nutrition that adversely affect the health of the worker bees and their queens. These factors threaten the long-term viability of the bee industry, and the agriculture of crops dependant on bee pollination.

Colony collapse disorder (CCD) is a devastating new problem. A **CCD Action Plan** was developed in 2007 by the Federal CCD Steering Committee (co-chaired by ARS and the Cooperative State Research, Education, and Extension Service) and is available online at www.ars.usda.gov/is/br/ccd/ccd_actionplan.pdf. A Progress Report on CCD-related research is due to be released in 2009. The following is a summary of ARS accomplishments on CCD to date:

The honey bee genome sequencing effort was led by ARS, in partnership with universities and industry (*Science*, 2007). It was the first insect to be sequenced since the *Drosophila* fruit fly, and its sequence has provided clues to bee mortality, including that by CCD. For instance, the bee genome was found to be lacking many of the detoxification and immunity genes found in

Drosophila, perhaps explaining the honey bee's increased susceptibility to pesticides and pathogens, respectively. This is explained ecologically in the habitat and food of the honey bee (which feeds, naturally, on toxin-free nectar rather than plant tissues, which can be rich in toxins), as well as its sociality, on which it depends to rid the colony of diseased bees. Immunity may be key, since viruses have been implicated by ARS as highly suspect as one causal factor in CCD (*Science*, 2008).

ARS has initiated an Areawide Program on Bee Health with the purpose of demonstrating that good bee management can maintain healthy bees despite the pressures of CCD. This program uses ARS technologies, such as bees developed with resistance to the varroa mite, the major bee pest (which also vectors bee viruses); special protein-rich diets developed to strengthen colonies for early spring build up; biorational miticides based on bee pheromones; and other treatments to mitigate disease and reduce stress on the colonies used in migratory beekeeping.

A more detailed description of ARS 2008 accomplishments on CCD follows:

Honey bee viruses studied. ARS scientists in Beltsville investigated the ranges and genetic traits of six honey bee viruses found in the United States. Significantly, scientists determined the past and present distributions of the Israeli acute paralysis virus (IAPV), a virus implicated in CCD. Other accomplishments include improving economical viral storage methods prior to diagnosis and adopting this protocol in analyzing field samples from the United States and abroad. Along with carrying out genetic analyses of frequencies of the major bee viruses, work continues to determine co-infection rates and implications for disease and, more fundamentally, to improve bee resistance to viruses. Research on the viral causes of bee disease is aimed at decreasing the costs of beekeeping and assuring adequate pollination.

Bee samples collected and preserved for diagnostic assays. Using field, microscopic, and genetic tests, Beltsville scientists have processed hundreds of bee samples (and hundreds of thousands of bees) in the past year, quantifying mites, bacteria, parasitic gut diseases, and viruses. In doing this, the unit has become a leader in developing efficient methods for collecting, preserving, and processing honey bees and hive materials for diagnostic assays. Information is shared freely with beekeepers, governmental regulators, and other researchers in an attempt to resolve the causes of CCD and prevent further losses for the beekeeping industry.

Problem Statement 2A.1: Improving Honey Bee Health.

Countering the effects of biological and environmental factors on the health and well-being of the honey bee hive requires a sustained, comprehensive, multi-disciplinary effort, especially given the broad scope of these factors. Parasites (especially varroa and tracheal mites), depredators that spoil hive stores (small hive beetle and wax moth), pathogens, exposure to crop pesticides and hive miticides, inclement weather, and poor nutrition all can be harmful to the hive, and in any combination, they can be devastating. In most cases, growers and beekeepers must contend with several factors in trying to keep their hives healthy and productive. In addition, because of the recent CCD outbreaks, migratory beekeeping has been unable to meet needs of almond pollination in California with domestic colonies. Bees are often moved multiple times across the country and, not uncommonly, 10 percent of colonies may be lost during each move to a new crop.

Of special concern to beekeepers is the health and robustness of the queen, which is closely linked to the health of the colony. Re-queening, an important tool of apiculture, is necessary where bee stock has become genetically weak or for making colony splits. Many beekeepers are concerned that the quality of their honey bees, especially queens and worker bees, is not as high as it should be.

New delivery system developed for essential oils to control Varroa mites. The varroa mite (*Varroa destructor*) is a worldwide threat to honey bees, and options to control them are limited. Plant essential oils show promise as acaricides against the mite, but the delivery of these compounds remains a challenge due to their low water solubility and high volatility. A technique to microencapsulate essential oils in beta cyclodextrin complexes was developed by ARS scientists at Tucson, leading to the detection of high levels of the essential oils in bee tissues without any imposed toxicity to the bees. The encapsulation technique can be used as a delivery system for many different compounds that might deter feeding and reproduction of varroa.

Products developed to control pests, parasites, and diseases in honey bee colonies. ARS scientists at Weslaco tested six products, some in a dose series, against moderate to heavy *Nosema* infections in honey bees. All were less effective than the standard dose of Fumagilin-B, the only antibiotic currently registered for its control. Fumagilin-B, while significantly lowering spore levels, did not reduce *Nosema* disease below the economic threshold. Only one product, Honey Bee Healthy, was comparable to the efficacy level of Fumagilin-B.

Comparatively fewer small hive beetle found among Russian honey bee colonies than Italian colonies. Small hive beetles (*Aethina tumida*) (SHB) began appearing in U.S. hives during the past 15 to 20 years and now infest bee colonies throughout the East. The comparative resistance of Russian colonies to the SHB was unknown. Studies done by ARS scientists in Baton Rouge showed that Russian colonies carried fewer SHB adults in their colonies, especially if entrance reducers were used in hives. This study provides a specific management tool for beekeepers to help control SHB.

Genetic diversity of Italian bees in the United States found to be similar to the diversity of Italian bees in Italy. There was a concern that importation and breeding bottlenecks had endangered U.S. bee stocks through inbreeding, but a full survey conducted by ARS scientists at Baton Rouge showed that the diversity of Italian honey bees in the United States is quite high. This provides evidence that there is no need to attempt to enrich the genetic diversity of Italian stocks by importations from Italy.

Full complement of Russian bee breeder lines released to the beekeeping industry. The need exists to provide a final transfer of all Russian bee breeder lines to industry. Working with the CRADA holder and a newly formed Russian Bee Breeders Association, ARS provided members systematically with breeder queens for queen lines and for drone sources so that each member could produce two of the eighteen lines. In the future, members will share stock to develop new drone source colonies and maintain their ability to develop all of the lines. This will permit the continued breeding and selection of Russian bees and provide mite-resistant Russian honey bee stock to the entire beekeeping industry for the foreseeable future.

Successfully requeening Italian colonies with Russian honey bees. Worries have been expressed that it is difficult to introduce Russian queens to Italian colonies. ARS scientists at Baton Rouge found that Russian and Italian colonies accepted both mated Russian queens and Russian queen cells equally well, and that higher but not economically damaging levels of varroa infestation reduce the rate of requeening success. This finding provides beekeepers with information to produce colonies with desired queen stock and increase their rate of success in managing commercial apiaries. These tools are being employed by many beekeepers throughout the country.

The suppressed mite reproduction (SMR) trait found to be caused by removal of mite-infested brood cells by adult bees. Understanding the behavior of bees that resist varroa mites will help breeders to test and select for resistance. Field testing by ARS scientists in Baton Rouge showed that bees with the suppressed mite reproduction (SMR) trait apparently removed mites from capped cells; thus, the trait was renamed varroa-sensitive hygiene (VSH). Of the mites that remained, VSH colonies had a much higher rate of nonreproductive mites (80 percent) than non-VSH colonies had (29 percent), suggesting that VSH bees removed reproductive mites more often than they removed nonreproductive mites. By knowing the mechanism behind the VSH trait, scientists and bee breeders will be better able to select for this trait and also separate this trait from other mite-resistance traits.

Extensive recapping of worker brood cells by VSH bees identified as screening mechanism. Improving understanding of the biology of VSH may help breeders in testing and selecting for varroa resistance. Researchers found that differences between VSH and susceptible bees in the frequency of recapping of brood cells tend to be greater than differences in other measures related to mite resistance. In addition, recapping is easier to identify than other measures of mite resistance (*e.g.*, the reproductive status of varroa). Recapping frequency thus has been identified as a simple screening tool that correlates to the expression of VSH by a colony.

Italian X varroa sensitive hygiene (VSH) germplasm developed. ARS scientists in Baton Rouge sought to combine bee lines having high varroa sensitive hygiene (VSH) with lines of commercial Italian stock, yielding some lines with good beekeeping characteristics and that also had low varroa population growth. The best performing colonies are being propagated to develop a semi-closed population of VSH germplasm for future release to industry. When completed, this germplasm production should improve adoption of mite resistant bees by commercial beekeepers involved in crop pollination.

Russian honey bee resistance to tracheal mites found to result from autogrooming. The mechanism of honey bee resistance to tracheal mites was uncertain, but work by ARS scientists at Baton Rouge has confirmed that the primary mechanism of resistance is autogrooming by very young adult bees. This advance makes it possible to directly phenotype breeding stock and potentially develop marker-assisted breeding.

Varroa resistance and general beekeeping utility of VSH honey bees demonstrated. Field studies are needed to document the utility of mite-resistant bee stocks. VSH and Russian bees developed by ARS scientists at Baton Rouge were tested in cooperation with beekeepers in Alabama. Through three seasons of measurement, resistant stocks required less treatment against parasitic mites than the Italian-based control stock did, and the overall average honey yield from Russian (59 lb) and VSH (52 lb) colonies was comparable to that of control colonies (46 lb). Beekeepers did not report any significant behavioral problems with resistant stocks.

Problem Statement 2A.2: Pollination of Crops.

Honey bees are essential for the seed and fruit set of crops comprising one-third of U.S. agriculture. Colonies often pollinate several different crops during the same year, beginning in early spring and ending in late summer. Pollinating some crops (e.g., melons, cucumbers, and blueberries) is extremely stressful to honey bees because there is relatively little pollen and the crops lack nutritional value for the bees. Colonies are weakened and often cannot be introduced for pollination of other crops. The colonies need to be intensely managed or combined with others to achieve large enough populations to survive the winter. Weakened colonies also are more susceptible to disease and impacted more by parasitic mites. Nutritional stress on colonies might be alleviated with supplemental feeding of protein while colonies are in the field for pollination.

Honey bees found to collect large amounts of upland cotton pollen in Louisiana. In dry areas, honey bees do not collect upland pollen, but such pollen collection had not been studied in more humid areas. ARS scientists at Baton Rouge discovered that honey bees do in fact collect upland pollen, creating the possibility of fostering the selection of hybrid cotton using honey bees as pollinators.

Worker flight activity of Russian and Italian honey bees shown to be equal during both blueberry and almond pollination. Scientists believed that there were potential differences between the ability of Russian and Italian stocks to pollinate during cooler weather. However, ARS scientists at Baton Rouge found that both Russian and Italian stocks were equally useful for commercial pollination in the same weather conditions. This finding is instrumental for promoting the adaptation of Russian honey bees for commercial pollination.

Impact of synthetic brood pheromone (SBP) on almond pollen collection studied. ARS scientists at Tucson conducted field trials near Bakersfield, California, to investigate bee colony size and composition as factors in almond pollen collection. They found that Superboost (synthetic brood pheromone, or SBP) increased pollen collection only on small 4-frame colonies that were used for trapping pollen but not in other colony types, and that this failure of other colony types to collect more pollen was caused by the bees actively managing the pollen storage area near the brood nest and the ease of replacing consumed pollen. Scientists concluded that in the area where the bees actively manage for pollen storage, adding SPB is unlikely to increase almond pollen foraging. This suggests that the use of SBP may be appropriate for treating colonies on crops with relatively low pollen levels (*e.g.*, blueberries and cucurbits), as bees are unlikely to harvest enough pollen from them to provide a pollen storage area.

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 a strategy called marker-assisted breeding that should 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. An 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.

Genetic diversity of Italian bees in the United States is similar to the diversity of Italian bees in Italy. There was a concern that importation and breeding bottlenecks had endangered the United States stocks to inbreeding. A full survey conducted by ARS scientists in Baton Rouge, Louisiana, showed that the diversity of Italian honey bees in the United States was quite high. This provided guidance that there was no need to attempt to enrich the genetic diversity of Italian stocks by importations from Italy.

New electrotransformation method developed for use with Gram-positive bacterium, *Paenibacillus larvae*. Gram-positive bacterium, *Paenibacillus larvae*, is a serious pathogen of honey bees. The identification of toxins produced by this pathogen is increasingly important, considering the recent emergence of antibiotic-resistant *P. larvae* bacterial strains. ARS scientists at Weslaco, Texas, have developed an electrotransformation method for use with the bacterium, which has been used to determine, through sequence analysis, that the natural bacteria plasmid carries a tetracycline resistance gene (TetL). Thus, the new method will be a step toward developing a genetic system for this species and will also allow the study of several previously discovered natural plasmids of *P. larvae.*

Subcomponent 2B: Non-Apis Bees.

While the European honey bee is the only *Apis* species in the United States, there are more than 3,500 identified species of bees native to North America. These non-*Apis* bees have been utilized as pollinators of crops and continue to play a critical role in maintaining native flowering plants that form the basis of our wild land ecosystems. In light of the recent onset of CCD, the contribution of non-*Apis* bees to plant and crop production takes on a special importance. To maintain the productivity and the health of these bees and expand non-*Apis* bee species use in crop production, there needs to be a greater understanding of the physiology and behaviors of select species of interest to growers and the bee industry, including 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 (whose lifestyles range from solitary to social) are to play a greater role in crop production, more information is needed on their stewardship, including their habitat requirements, husbandry, handling and over-wintering 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. Better knowledge in these areas should lead to improved management strategies.

A new bee identified to pollinate cane berry fields. Cane berry producers have sought ways to lessen their dependence on honey bees for pollination because they are often relatively small growers without access to migratory beekeepers. A manageable native bee in the genus *Osmia* has been identified by ARS scientists in Logan as a good berry pollinator. ARS has now developed methods to successfully use this bee for commercial cane berry pollination, including methods to increase its population levels, after completing 5 years of successful field testing and modification. This bee is now being used by some Oregon farms as well as in California. Populations are being increased 2- to 3-fold per year in commercial berry fields using nesting materials that are readily available to growers.

Effect of fire on native bees examined. Fires represent a major ecological force in the West, although their effects on pollinators are poorly known. ARS scientists at Logan conducted a 2-year study in two widely separated localities, Yosemite National Park and Zion National Park, and compared pollinators in adjacent plots of burned and unburned forest and shrub land. In both parks, the abundance and diversity of bee pollinators was significantly greater in the burned areas. Burns therefore appear to represent opportunities for increasing pollinator populations, and as such, may be important ecological events for maintaining wild bee diversity.

Nest recognition for a pollinating bee species studied. The use of olfactory cues for nest recognition by the solitary alfalfa leafcutting bee, *Megachile rotundata*, was studied in a greenhouse environment by ARS scientists at Logan. Findings provide evidence that the bee's Dufour gland plays a role in providing olfactory cue compounds for nest recognition; this work may lead to better bee management strategies.

Weather conditions correlated with bee losses due to pollen ball syndrome. "Pollen balls" (PB) is a condition in the alfalfa leafcutting bee where a fully-intact pollen and nectar provision (as provided by the mother bee) is left in the nest cell at the end of the season. This condition, accounting for 60 percent of reproduction losses in commercial populations, occurs if the egg or very small larva dies, or if an egg was never laid on the provision. ARS scientists at Logan collected alfalfa leafcutting bee nest cells over a 3-year period from several seed producing states and from Canada. Scientists found that in Canada, PB cells were more common in cool, wet weather, and most contained mold. In the United States, where PB was more common, most PB cells were not moldy, and were more common in fields with more hot days. Scientists also found that most cells with no larvae or dead eggs were present under cool conditions, while cells with larvae dying at a very young age were more common in very warm weather. Therefore, PB has been correlated with extreme weather conditions, indicating that growers should moderate the moisture and temperature fluctuations in their hives as much as possible.

Little similarity shown between immunity in leafcutting bees versus honey bees. The honey bee genome has been sequenced and used to identify important immune response pathways. ARS scientists at Logan have now identified and sequenced genes for the alfalfa leafcutting bee related to chalkbrood infections. In comparing these genes to honey bees, only a few genes have been found in common. These results are added evidence that honey bees have a relatively unique immune system among the insects. The improved

scientifically based understanding of immunity in bees will lead to improvements in disease control in these beneficial insects and assist scientists in developing alfalfa leafcutting bees that are more disease tolerant.

Chalkbrood disease in alfalfa leafcutting bees demonstrated to be controllable with fungicides. Alfalfa leafcutting bees are typically stored over winter as cocoons. ARS scientists at Logan determined that partial control of chalkbrood disease can be achieved by treating the cocoons with fungicide when the bees are warmed in the spring before being released into the field. To achieve disease control, nesting boards must also be disinfected and used in combination with fungicide treatments. Seed producers have not been able to control this disease in the field, and this method provides the most substantial control yet offered.

Western bumble bee species developed as greenhouse pollinators. Bumble bees are used for pollination of greenhouse crops, such as tomatoes and peppers, reducing pollination costs considerably over hand pollination. Unlike honey bees, bumble bees are well adapted to greenhouse environments, but there are no species commercially available in the Western region. ARS scientists in Logan have identified three Western bumble bee species with good production potential, and queen production has been improved from less than 10 percent in 2007 to more than 25 percent in 2008. Thus, these species show great potential to meet the need for a western bee that can be mass propagated.

Problem Statement 2B.2: Bee Biodiversity and Contribution to Land Conservation.

As with crop production, there is growing concern about the sustainability of pollination services in natural landscapes. Land managers in the western United States are in critical need of affordable native plant seed for revegetation of rangeland and wild lands, due to the destruction of native plant communities from invasive weeds, natural disasters, and human activities. Farm production methods for wildflowers could provide an affordable seed source, and in the quantities necessary for revegetation efforts, but information is lacking on what bee species (if any) are needed and how to acquire and manage these bees on a commercial scale. In addition, the 2007 NAS report documented specific examples of bee deficits, including the possible extinction of the Franklin bumble bee and the disappearance of the bumble bee *Bombus occidentalis* in parts of its native range. Inadequate systematics capacity was also mentioned. While the study team suspected declines of other wild bee species, they indicated that any such analysis was greatly limited by lack of data. 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.

Bee identification enhanced. Bees are currently undergoing rapid declines, and some species are going extinct. A rapid assessment of our native pollinators is much needed, but the inability to rapidly and accurately evaluate bee status presents a major roadblock. Currently, in the United States and the world, only a few experts in bee taxonomy are competent to provide such identifications. ARS scientists at Logan have worked in collaboration with the Patuxent Wildlife Refuge to develop Web-based identification guides to the bees of the Eastern United States and a guide to the genera of *Megachilidae*, a prominent bee family of North America. These guides allow non-specialists to accurately identify bees and expand our National capacity to conduct pollination research and preserve threatened bees.

The mason bees: a framework for identification of potential crop pollinators. Over a thousand species of mason bees serve as pollinators that exist throughout North America, Europe, Africa, and temperate Asia, all with slightly different habits. They are extremely important because of ease at which they can be managed as crop pollinators, but selecting the best pollinators is hampered by our ability to distinguish the species. Thus, a taxonomic revision of this group is needed to allow accurate identifications. Collaborative work between ARS and researchers at Zurich and Cornell University resulted in the development of a DNA-based taxonomic tree, and DNA analyses show that mason bees originated in Europe and that some species previously included in the group are not closely related. This study improves species identifications for the *Megachilidae* genus.