



AGRICULTURAL RESEARCH SERVICE
ACTION PLAN
NATIONAL PROGRAM 305—CROP PRODUCTION

GOAL: 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, production, and conversion efficiencies; 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.

The United States produces more than 325 million acres of commercial-scale grains, sugar, fruits, nuts, vegetables, and ornamental crops, with the commercial producer value exceeding \$110 billion annually. However, sustaining and/or enhancing the economic production of food, fiber, flowers, and other crops is a continuing challenge. Production inputs are increasingly expensive and are causing cost/price squeezes in essentially all plant agriculture operations.

To exacerbate the situation, land resources for profitable crop cultivation are rapidly diminishing, requiring improved management strategies for maximum sustainable production if the Nation is to maintain a basic capacity for food self-reliance, or for domestic plant agriculture to endure as a significant component of the Nation's economy. The Nation's agricultural resources also require management to promote environmental sustainability. To enhance the development of sustainable systems for crop production, ARS must consider producer profit; integrated pest control, including effects on non-pest species such as bees; effects of inputs on environmental ecosystems, including soil, air, water, and protected areas; pollination and pollinators; environmentally sound control-agent application systems; labor-saving mechanization systems; and compatibility of inputs with worker safety and food quality requirements.

These market, production, and environmental concerns require the adaptation and development of new technologies to provide economically viable and environmentally sustainable crop production systems while meeting the Nation's increasing demand for food, flowers, and fiber. In particular, all inputs of production agriculture must be assessed to ensure their safety and the absence of damaging environmental effects. Thus, to improve food, flowers, and fiber production systems, ARS must consider the potential effects of these systems on the Nation's natural resources and on environmental quality during the development process. Also, particularly in light of labor shortages and rising labor costs, ARS must develop new

mechanization technologies to promote safe work environments, efficient production systems, and optimized production and processing of higher quality products.

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.

The Crop Production National Program (NP 305) is comprised of two major components:

- Integrated Sustainable Crop Production Systems; and
- Bees and Pollination.

RELATIONSHIP OF THIS NATIONAL PROGRAM TO THE ARS STRATEGIC PLAN: Outputs of NP 305 research support the "Actionable Strategies" associated with the performance measures shown below from the ARS Strategic Plan for 2006-2011, Objective 2.2: Increase the Efficiency of Domestic Agriculture Production and Marketing Systems.

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 are developed and used by ARS customers.

Component 1: Integrated Sustainable Crop Production Systems

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.

To achieve these goals, a number of environmental concerns that influence production and profitability need to be addressed, including global climate change; water quality and availability; nutrient management; food safety and quality; energy consumption; protection of bees; and impacts from invasive species. In addition, there is a need to optimize cultural and pest management systems and integrate inputs for single and multiple crops. Furthermore,

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.

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.

Research Needs:

- Incorporate new and existing knowledge and technologies into integrated management strategies for annual crops that optimize yield, quality, and economic return while conserving or increasing soil organic matter, reducing

soil erosion, minimizing nutrient leaching and runoff, and improving soil quality.

- Improve knowledge and systems for managing conventional and organic systems with respect to plant nutrient, water, and climatic- or weather-associated stresses.

Anticipated Products:

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

Potential Benefits:

- Increased water infiltration into soils, reduced erosion, and improved nutrient management through new soil management strategies.
- Higher yield and crop quality with minimal water expenses through better understanding of crop water use and plant stress.
- Enhanced accuracy in monitoring and applying water, nutrients, and pesticides will improve efficiency of crop production and reduce the potential for environmental contamination.

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.

Research Needs:

- Integration of new and existing knowledge and technologies into refined mechanical systems for planting, harvesting, and processing row and fresh

market crops to increase efficiency, maintain crop quality, and improve worker safety.

- Improved understanding of the interactions between the timing of application, environmental conditions, pest biology, and microclimate parameters on resulting pesticide efficacy.
- Improved application technologies and delivery systems for agrichemicals.
- Development of new technologies and protocols for managing drift of agrichemicals.

Anticipated Products:

- New or improved automated and robotic systems for production, harvesting, and processing of agricultural crops.
- Protocols using remote sensing technologies to better manage crop systems for water stress, nutrient management, and pest control.
- Efficacious, reliable, and sustainable pest management systems.
- A greater understanding of relationships between application parameters and biological and environmental impacts.
- 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.
- Weather monitoring systems that facilitate deciding if, when, and how chemical agents are to be applied over a wide geographical area.
- A pilot warning system to alert pilots to aerial spraying above a preset altitude.
- Development of application technologies to deliver organic products.

Potential Benefits:

- Increased production, improved crop handling efficiency, reduced costs of handling, storing, and harvesting commodities, and enhanced worker safety.
- U.S. farmers remain competitive in the global marketplace despite reduced labor availability.
- Increased control of plant pests at reduced cost and less potential for environmental harm.
- Reduced damage to off-target plants, animals, and water resources due to spray drift from ground and aerial-applied pesticide technologies.
- New methods and technologies to help agrichemical applicators increase compliance with safety and regulatory requirements.

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.

Research Needs:

- New or enhanced computer-based pest management decision systems to manage a complex and ever increasing annual-crop knowledge base.
- Decision support tools enabling chemical applicators to avoid spraying during conditions favorable for off-target movement of sprays.
- User-friendly computer models or decision support systems for producers, regulators, and researchers.

Anticipated Products:

- An enhanced information database for improving crop management decision support systems and complex models.
- Computer-based decision support systems and models that optimize pest management strategies.
- User-friendly software products for weed phenology and optimization of herbicide application timing.
- Decision tools that can be used to avoid spraying during conditions favorable for off-target movement of sprays.
- Models for quantification of drift and associated deleterious effects during temperature inversions vs. non-inversion conditions.

Potential Benefits:

- Increased pest management efficacy and efficiency and a reduction in the potential for negative environmental impacts.

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.

Research Needs:

- Integration of multi-disciplinary scientific knowledge and technologies to develop new and improved conventional and organic annual crop production systems that integrates cropping and weather-related factors with product quality and economic factors to achieve optimal production efficiency and profitability.

Anticipated Products

- Improved region-specific cropping system practices for existing, new, and alternative crops.

- 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.
- Methods for using remote sensing and spatial application inputs for optimizing crop quality.
- Improved knowledge of how environment and production practices determine crop processing characteristics, flavor component quantities, and/or nutritional composition.
- Knowledge of genetic and production practice interactions on food and fiber quality components.

Potential Benefits:

- Information will enable plant breeders to better understand how environmental and production practices influence genetic expression of desirable traits.
- Improved food quality.
- Better production systems will help U.S. growers remain competitive in the global marketplace, and ensure consumers will have a stable, safe, and affordable source of food and fiber, while protecting the environment.

Subcomponent 1A Resources:

Seven (7) ARS projects coded to National Program 305 address the research problems identified under Subcomponent 1A:

Location:	Lead Scientist(s):
Dawson, Georgia	Sorensen, Ron
Florence, South Carolina	Bauer, Phil
Lane, Oklahoma	Russo, Vincent
Poplarville, Mississippi	Copes, Warren
Stoneville, Mississippi	Thomson, Steven
Morris, Minnesota	Gesch, Russell
College Station, Texas	Hoffmann, Wesley

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.

Research Needs:

- Investigation of the critical gaps in existing knowledge and deficiencies in horticultural and pest management technologies.
- Identification of soil, water, and nutrient factors in perennial crop production systems that limit production efficiency, and development and adaptation of technologies to mitigate these limitations.
- Identification and investigation of factors that limit efficiency, acclimation, or profit for key specialty crops.
- New knowledge and technologies to enable perennial crops to overcome limiting production barriers.
- Identification and manipulation of factors related to solar radiation that limit production efficiency, technology adaptation and integration, and profit for certain perennial crop ecosystems.
- Devise improved cultural and pest management strategies or systems compatible with healthy populations of bee pollinators.

Anticipated Products:

- 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.
- 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.
- 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.

- 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.
- Increased knowledge and understanding of how microclimate environments in perennial cropping systems limit production efficiency and crop quality.
- Microclimate management technologies and strategies that increase production efficiency and crop quality for apple, grape, and peach.
- Knowledge of impact of pest management strategies on honey bee (*Apis*) and non-*Apis* bee pollinators.

Potential Benefits:

- Improved efficiency of water and nutrient use, sustainability of soil quality, and health of perennial crop production systems.
- More effective pest control strategies, reduced unit costs, and increased viability of production systems.
- Improved productivity and quality of light-sensitive apple, grape, and pecan production systems.
- Reduced negative impact of pest management strategies on *Apis* and non-*Apis* bee pollination capacity for crops.

Problem Statement 1B2: 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.

Research Needs:

- Development of site-specific management techniques to overcome spatial variability of soil nutrient levels and crop yield components that complicate the application of fertilizers and pest and disease control agents.
- Integration of production, harvesting, and pest management strategies with automation technologies to provide decision aids and mechanization systems to improve application of materials to targets, control of key plant canopy characteristics, and handling of plant products.
- Computer vision systems to aid in harvest, precision farming, and cultural practices.
- Development or adaptation of sensors and techniques enabling fruit and crop identification, location tracking, determination of maturity, and quality assessment.

- Improved understanding of how changes in formulation chemistry affect droplet size, evaporation, drift potential, and plant uptake of pest control agents and growth regulators, and better knowledge of how to deliver materials in the most efficacious manner while minimizing impact on workers and off-target areas.

Anticipated Products:

- New technologies and strategies that provide economically attractive and environmentally sound alternatives to current practices for perennial crops.
- 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.
- Technologies and strategies that minimize off-target spray movement during application to perennial crops and reduce worker exposure.
- Technologies and strategies for assessing factors influencing improvements in automation, control, and efficiency, thus improving delivery and deposition of pesticides and growth regulators.

Potential Benefits:

- Optimized application of crop production materials, safer and healthier environment for workers, and reduced potential for environmental damage.
- Reduced labor costs and requirements for production systems.
- Better plant health and greater economic yield and quality.

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.

Research Needs:

- Multi-disciplinary and integrated research to fill gaps in existing knowledge and deficient technologies to increase production efficiency and crop quality.
- Integration of improved technologies that enhance profit and sustainability of production systems.
- Identification and manipulation of factors related to solar radiation that limit production efficiency, technology adaptation and integration, and profit for certain perennial crop ecosystems.
- Integration of new crops or cultivars into new or existing perennial crop production systems.

Anticipated Products:

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

Potential Benefits:

- Reduced cost per unit of production, improved pest control at lower cost while safeguarding bee pollinators, less potential for environmental contamination, and continued economic viability of perennial crop production systems.
- Availability of production systems including new varieties, cultivars, and/or rootstocks available for niche sites or niche markets.

Subcomponent 1B Resources:

Eleven (11) ARS projects coded to National Program 305 address the research problems identified under Subcomponent 1B:

Location:

Byron, Georgia
College Station, Texas
Corvallis, Oregon
Kearneysville, West Virginia
Mayaguez, Puerto Rico
New Orleans/Houma, Louisiana
Poplarville, Mississippi
Stoneville, Mississippi
Wooster, Ohio

Lead Scientist(s):

Wood, Bruce
Hoffmann, Wesley
Tarara, Julie
Glenn, Michael; Takeda, Fumiomi
Goenaga, Ricardo
Johnson, Richard
Copes, Warren
Thomson, Steven
Derksen, Richard; Zhu, Heping

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.

Research Needs:

- Evaluation of existing natural and synthetic products to control pests.
- Exploration of the interaction between plant nutrition, genetic composition, and pest susceptibility.
- Development of new strategies for controlling pathogens in irrigation water.
- Development of integrated cultural and chemical control strategies that address pathogen survival and dispersal at multiple plant production stages and/or in multiple plant species of ornamental plant production systems.

Anticipated Products:

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

Potential Benefits:

- Improved disease control will help produce higher quality products.
- Reduced overall costs of inputs/chemicals to assist growers in maintaining profitability.
- Targeted use of disinfestants in irrigation systems.

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.

Research Needs:

- Enhanced efficiency in production protocols to reduce handling and hand-labor intensive procedures.
- Improved automation of routine operations through use of existing technologies coupled with the use of new or improved technologies, such as sensors and tagging techniques to track pest movement and plant needs.
- Improved application procedures for pest and crop management materials to meet the needs of greenhouse, high tunnel, and nursery plant production.
- Increased understanding of highly complex interactions between pesticide application, irrigation, and plant nutrition to produce healthy nursery and greenhouse container-grown crops, enhance the environment, and conserve water resources.

Anticipated Products:

- New sensors for rapidly and economically monitoring plant growth and stress in greenhouses, high-tunnels, and nurseries with minimal labor.
- Optimal production practices that reduce wastewater and nutrient use and lower production cost in greenhouses, high-tunnels, and nurseries.
- New automatic irrigation control systems for optimal nursery and greenhouse irrigation practices.
- Insect tracking technology in protected environments and nurseries.
- Improved understanding of insect dispersal and behavioral patterns to aid the development of efficacious management strategies and improve production efficiency.
- 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.

- New sensors or new applications for existing sensor technology to assess coverage of sprays.
- New or adapted agrochemical application equipment for use in the greenhouse, high-tunnel, or nursery environment.
- Improved pest management strategies arising from existing and new spray techniques.
- 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.

Potential Benefits:

- New technologies will help reduce labor costs, while adding production capacity, to help improve profitability.
- Reduced exposure to pest control agents and pesticides will mean healthier and more marketable plants and improved working conditions for employees.

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.

Research Needs:

- Development of greenhouse and nursery-based models to predict fuel needs, crop growth optimization, labor needs, and costs of production.
- Production protocols matched with structure/weather/location.
- Integration of economic information with new or existing crop production models.
- Optimization of structure design relative to geographic location (use of predictive modeling could be employed).

Anticipated Products:

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

Potential Benefits:

- Decision support aids would help producers use fuel more efficiently and reduce production costs, thereby increasing profitability.

- Better production protocols would allow for more efficient use of protected structures.

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.

Research Needs:

- Development of alternative components for existing non-renewable or non-recyclable materials, such as substrates and other growth media.
- Evaluation of alternative inputs (*i.e.*, CO₂ enhancement to compensate for temperature reduction, or on-site recycled components as replacements for non-renewable growing medium) to determine if savings can be achieved.
- Determination of the cost/benefit relationship for various inputs in cropping cycles.
- Development of technologies to track water, fertilizer, substrate components, growth regulators, pesticides, and other agrichemicals within greenhouses and nursery production systems to enable the assessment of potential economic savings, pollution abatement, and opportunities for greater production efficiency.
- Development of molecular understanding of flower senescence.
- Integration of combustion products (CO₂, H₂O) from heat generation into crop production systems.

- Integration of product quality into controlled environment production systems research including development of protocols and technologies to achieve a consistent level of quality in controlled environment agriculture in a cost-effective manner.
- Development of sustainable production systems that enhance productivity while reducing losses due to post-harvest disease, longevity, and quality issues.

Anticipated Products:

- New or modified substrate components for floriculture and ornamental production and materials for potted production.
- Improved production systems for greenhouse, nursery, and high-tunnel production.
- 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.
- Guidance to improve vase-life of flower species.
- Production systems for evaluation of new and improved crop varieties for suitability in the greenhouse, high-tunnel, and nursery industries.

Potential Benefits:

- Efficient and economical production of high-quality nursery, high tunnel, and greenhouse crops with improved environmental stewardship.
- Greater availability of high-quality products and increased consumer satisfaction.
- Greater consumer acceptance of perishable commodities.
- Increased consumption of commodities.
- New opportunities for growers to develop/expand markets (locations) and/or convert seasonal production to extended-season production.
- Recognition of greenhouse and nursery systems as a carbon source or sink.

Subcomponent 1C Resources:

Seven (7) ARS projects coded to National Program 305 address the research problems identified under Subcomponent 1C:

Location	Lead Scientist(s)
Davis, California	Jiang, Cai-Zhong
Poplarville, Mississippi	Copes, Warren
Stoneville, Mississippi	Thomson, Stephen
Toledo, Ohio	Locke, James
Wooster, Ohio	Derksen, Richard; Zhu, Heping
Kearneysville, West Virginia	Takeda, Fumioni

Component 2: Bees and Pollination.

In the United States, managed bees are vital to the production of more than 90 crops, including almond, alfalfa and sunflower, apple, cherry, melon, and berries. Only a few species of bees have been adapted for commercial pollination, and their health and management are critical to agricultural production. The honey bee (*Apis mellifera*) is a versatile pollinator (and honey producer) that, alone, pollinates crops with an added value in the billions of dollars. However, since the 1980s, two parasitic mites, *Varroa destructor* and *Acarapis woodi*, have devastated beekeeping operations, driving production costs sharply higher, and reducing the availability of honey bees for pollination. Feral honey bees have virtually disappeared because of these mites. Managed honey bees rarely survive unless mite infestations are treated with acaricides; however, the mites have become resistant to most miticides. Other persistent and often severe problems are caused by the bacterium responsible for American foulbrood disease and a newly introduced beetle pest, the small hive beetle, which attacks honey bee colonies and destroys bee products. In 2006, the situation worsened, as up to 80 to 90 percent of the bees in some beekeeping operations disappeared due a syndrome of unknown cause, now called colony collapse disorder (CCD). CCD poses the greatest threat yet to beekeeping and to growers dependent on those bees for pollination. A separate CCD Action Plan was developed in 2007 by the Federal CCD Steering Committee (co-chaired by the Agricultural Research Service) and is available online at www.ars.usda.gov/is/br/ccd/ccd_actionplan.pdf.

There is also a growing niche for non-*Apis* bees that specialize in specific crops or that can be used in greenhouses. They are also critical components of our ecosystems, and some are needed for land restoration. As detailed in the 2007 National Academy of Sciences (NAS) report “*Status of Pollinators in North America*,” these species are threatened by shrinking habitat and lack of information about their biological requirements, including their parasites and diseases. A variety of native and non-native species could be better used to enhance pollination efforts if they could be produced or managed effectively. There is great need to better understand pollination requirements, processes, and mechanisms, as well as bee pest and disease management strategies.

The Action Plan addresses these and other problems. Additional problems will be addressed as they arise or are anticipated, or as new technologies permit. For example, Africanized honey bees continue to expand their distribution in the southern United States. If genomics techniques allow, they will be used to develop means for identifying these invaders.

An Areawide project demonstrating methods for managing healthy bees will also be conducted during the life of this Action Plan. Methods used will include acaricides tested for mite control, development of diets for improved nutrition, resistant lines of bees, and disease control methods.

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.

Honey bee losses have reached an unprecedented level in 2006 and 2007, in part due to CCD, which is characterized by the sudden unexplained loss of worker populations in previously healthy colonies, leaving only a queen and a few workers in the colony, is perhaps related to “disappearing disease” reported in the 1970s and earlier. This syndrome, with reported losses in apiaries in 35 States and Puerto Rico, has appeared as demand for colonies for pollination of almonds has increased, and is coincident with an increase in migratory beekeeping to meet that demand.

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.

Research Needs:

- Development of integrated pest management (IPM) systems for parasitic mite management, including developing resistant bees, traps with lures or exclusion devices, and environmentally “soft” miticides that are non-toxic to workers and queens.
- Determination of the role of varroa mites in suppressing bee immunity and in vectoring bee viruses, especially the appearance of virus disease long after varroa is eliminated by miticides.
- Development of additional methods (*e.g.*, lure traps) to protect hives and hive stores from small hive beetles in “honey houses,” which will also help in monitoring the beetles in the field.
- Determination of the level of honey bee stock resistance to parasites and pathogens, identification of bee genes, traits, and markers associated with resistance, and breeding of bees with improved resistance.
- Improvement in molecular tools for assessing the effects of diet, management, and other stressors on the abilities of bees to resist disease.
- Establishment of bee cell lines.
- Improvement in the sensitivity, ease of use, and cost of disease diagnosis.

- Determination of improved management to produce larger colonies for early pollination.
- Determination of the effects of miticides on bees and the impact of pesticides on foragers, both through lethal (acute) and sub-lethal (chronic) exposure.
- Development of miticide-resistance management programs, and procedures for reducing bee exposure to pesticides.
- Determine the effects of nosema on colony growth.
- Determination of best management practices for pollination migratory beekeeping, including the acceptable number of transports and proper treatment of bees during and after transport.
- Identification of nutritional factors that stimulate colonies to rear brood, and determination of the effects of nutrition from pollen, artificial diets, and nectar substitutes (*i.e.*, protein and sugar) on bee health, pollination rates, and honey production.
- Identification of signals (particularly chemical cues) provided by larvae to nurse bees that stimulate feeding to become queens.
- Development of feeding regimes for colonies so that nutritional needs are met for rearing queens and drones.
- Characterization of the microbial associates of healthy honey bees.

Anticipated Products:

- Traps, lures, soft pesticides, and other IPM tools for management of bee pests and protection of hive products.
- Bee cell cultures for bee virus isolation, diagnosis, and study.
- Supplements that can be added to larvae grafted into cells to be reared into queens that will enhance feeding by nurse bees.
- Dietary supplements for queen-rearing and drone production colonies.
- Resistance management programs, especially for varroa.
- Methodologies for minimizing bee exposure to insecticides.
- Increased knowledge about the role of chronic pesticide exposure and other environmental stresses on bee health, and role of stress in promoting CCD.
- Better pollen and nectar substitute diets for improved strength of colonies for early season crops, such as almond.
- New control strategies and products for management of nosema.
- Nutritional supplements to reduce the occurrence and impact of pathogens and mites.
- Tailored nutrition management systems based on monitoring the quality of forage, *e.g.*, as affected by weather conditions.
- Information for plant breeders on the nutritional characteristics desired for healthy bees.
- Better understanding of the roles of non-pathogenic bacteria in maintaining bee health.

Potential Benefits:

- Ability to recognize and respond to emerging bee pest and pathogen threats.

- Increased health of managed honey bees for pollination and honey production, including early initiation of brood rearing for crop pollination.
- Longer availability through reduced mite resistance to miticides and lower cost of miticides due to development of resistance management strategies.
- Management responses tailored to the condition of the hive, the crop or forage, and its environs.
- Healthy fecund queens that are adequately mated and survive for a year or more in colonies.

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.

Research Needs:

- Development of methods for providing protein supplements to colonies when pollinating crops that are nutritionally inadequate.
- Determine the effects of supplemental feeding on foraging and pollination rates.

Anticipated Products:

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

Potential Benefits:

- Colonies that maintain vigor and population growth during pollination.
- Improved overwintering survival of colonies.

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.

Research Needs:

- Development of molecular tools for identifying bee strains, subspecies, and stocks (lines) of interest.
- Knowledge of the honey bee genome (genes, alleles, and markers) that enable researchers to make progress toward selecting for desirable traits, and development of protocols to screen germplasm for desirable or undesirable traits.
- Development of techniques for non-invasive assessment of colony stress (*i.e.*, via development of a “bee health chip” microarray).
- Development of molecular tools, including bee cell culture, for studying pathogen invasion and bee defense against common bee diseases, including American foulbrood and chalkbrood.
- Better understanding of genes and proteins controlling queen-worker developmental differentiation.
- Reliable long-term storage methods for sperm and embryos.
- Determination of factors involved in poor mating and survival of queens.

Anticipated Products:

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

Potential Benefits:

- Certification tools that allow verification for end users of Russian stock or other breeding products.
- Bee stock selected for greater viability.
- New genomic tools that will enable a much better understanding of the responses honey bees have toward a variety of stresses, ranging from parasites and pathogens to nutrition and beekeeping management.
- Increased availability of tools for breeders to integrate and maintain disease resistance traits in their bee stock.
- Improved ability to recognize and respond to emerging disease threats.
- Commercial or public repositories for honey bee germplasm from diverse lineages to help maintain stock diversity and allow complex breeding strategies.

- Easy-to-use tools for breeders to help lessen the risks of inbreeding in their breeding lines.
- Improved sperm survival times that allow breeders to assess stock potential prior to large-scale breeding efforts.
- Understanding of the genetic and physiological factors involved with early queen supercedure.

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.

Research Needs:

- Determination of the effect of cell handling (*e.g.*, rough physical treatment during wintering, incubation, and release) on establishment of alfalfa leafcutting bee and blue orchard bee nests.
- Determination of stocking densities for the alfalfa leafcutting bee and alkali bee, both in terms of providing optimal pollination as well as maximum bee build-up.
- Evaluation of nesting establishment and orientation cues (including chemical attractants) that mediate dispersal and nesting behavior of alfalfa leafcutting bees and blue orchard bees.
- Determination of the role of chemical cues in parasite attraction to nests to assure that attractants used artificially do not increase parasites.
- Investigation as to the cause and management of a condition called “pollen balls” in alfalfa leafcutting bees.
- Development of a better understanding of the diversity of the *Ascospaera* fungi (which causes chalkbrood disease) using molecular systematics.
- Determination of the modes of disease transmission of alfalfa leafcutting bee to *Ascospaera*, including multiple infections, disease reservoirs, and determination of the genetics of chalkbrood resistance.

- Development of molecular tools for studying *Ascosphaera* infection and immune response of the alfalfa leafcutting bee during development of chalkbrood disease.
- Identification of methods for controlling chalkbrood, including fungicides and disinfection strategies for nesting material and shelters. Methods should be robust, such that they can be applied to other solitary bees.
- Development of management systems for mass production of blue orchard bee for California almond pollination, and their relatives for other crop applications.
- Identification of bumble bee species native to the western United States amenable to artificial propagation, and that might be used to augment open field pollination.
- Development of production systems for managing bumble bees in portable nesting boxes for crops produced in enclosed systems.
- Evaluation of diseases and parasites in bumble bees.

Anticipated Products:

- 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.
- An evaluation of the host range of the *Ascosphaera* in bees.
- Identification of genetic markers for chalkbrood resistance in bees.
- 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.
- 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.
- A western bumble bee species that can be used for commercial pollination of enclosed crops in the West.
- Identification of prevalence and occurrence of bumble bee diseases and parasites.
- Determination of the feasibility of managing bumble bees for pollination of field crops.

Potential Benefits:

- Increased ability of U.S. growers to produce alfalfa leafcutting bees and blue orchard bees, with reduced dependence on importing bees and minimized grower risks and increased sustainability.
- Determination of the feasibility of breeding chalkbrood-resistant bees, potentially reducing the need for chemical control treatments.
- Preventing the introduction and spread of new chalkbrood diseases, useful for regulatory purposes.
- Provide affordable choices to almond growers for practical and effective pollinators at a time when CCD is decimating honey bee colonies.
- Provide effective, manageable, and affordable pollinators at a scale tailored for the small farms that typically produce native seed crops or cane fruits.
- More cost-effective, easy-to-use methods for pollination of greenhouse crops.

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.

Research Needs:

- Broad, base-line surveys of bee diversity in public rangelands and national parks, and the characterization of bee pollinator guilds in wild lands where bees will be critical to sustaining restoration efforts.
- Determination of the status of native bumble bee populations and evaluation of factors that threaten the health of wild populations and the identification and evaluation of other sensitive bee species in wild lands.
- Revision of key taxa in the bee family Megachilidae.
- Development of new techniques to assist in easier identifications of bees for non-experts (*e.g.*, using imaging systems and interactive keys).
- Maintenance and expansion of the U.S. National Pollinating Insects Collection, including the associated Web-based database.
- Identification of native forbs with potential for commercial seed farming that can be used to restore wild lands, discovery of their best pollinators, and development of bee management strategies for pollinating these forbs.

Anticipated Products:

- 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.
- Assessment of the status of *Bombus occidentalis* populations and other native bumble bees.
- Generic/subgenera revision of Anthidiini trap-nesting bees.
- Revision and Web-based identification tool for Nearctic *Osmia* (which includes the blue orchard bee).
- Full digitization of the U.S. National Pollinating Insects Collection.
- Processes for obtaining key pollinators for crop use.

Potential Benefits:

- Contribution to the conservation of America's wealth of bee pollinators, particularly bumble bees.
- Contribution to the understanding of bumble bee population dynamics and factors influencing population cycles of important pollinator species.
- Ability to identify key groups of bee pollinators (the Megachilidae) for use in ecological surveys and the identification of future pollinators.
- Access for land managers and researchers in pollination, ecology, and biology to the wealth of biological and ecological data in one of the world's largest bee collections and access to identification tools.
- Restored ecosystems with native plant guilds that include flowering plants.

Component 2 Resources:

Seven (7) ARS projects that are coded to National Program 305 address the research problems identified under Component 2:

Location	Lead Scientist(s)
Tucson, Arizona	Degrandi-Hoffman, Gloria
Baton Rouge, Louisiana	Danka, Robert; Rinderer, Thomas
Beltsville, Maryland	Vacant; Evans, Jay
Weslaco, Texas	Adamczyk, John
Logan, Utah	James, Rosalind