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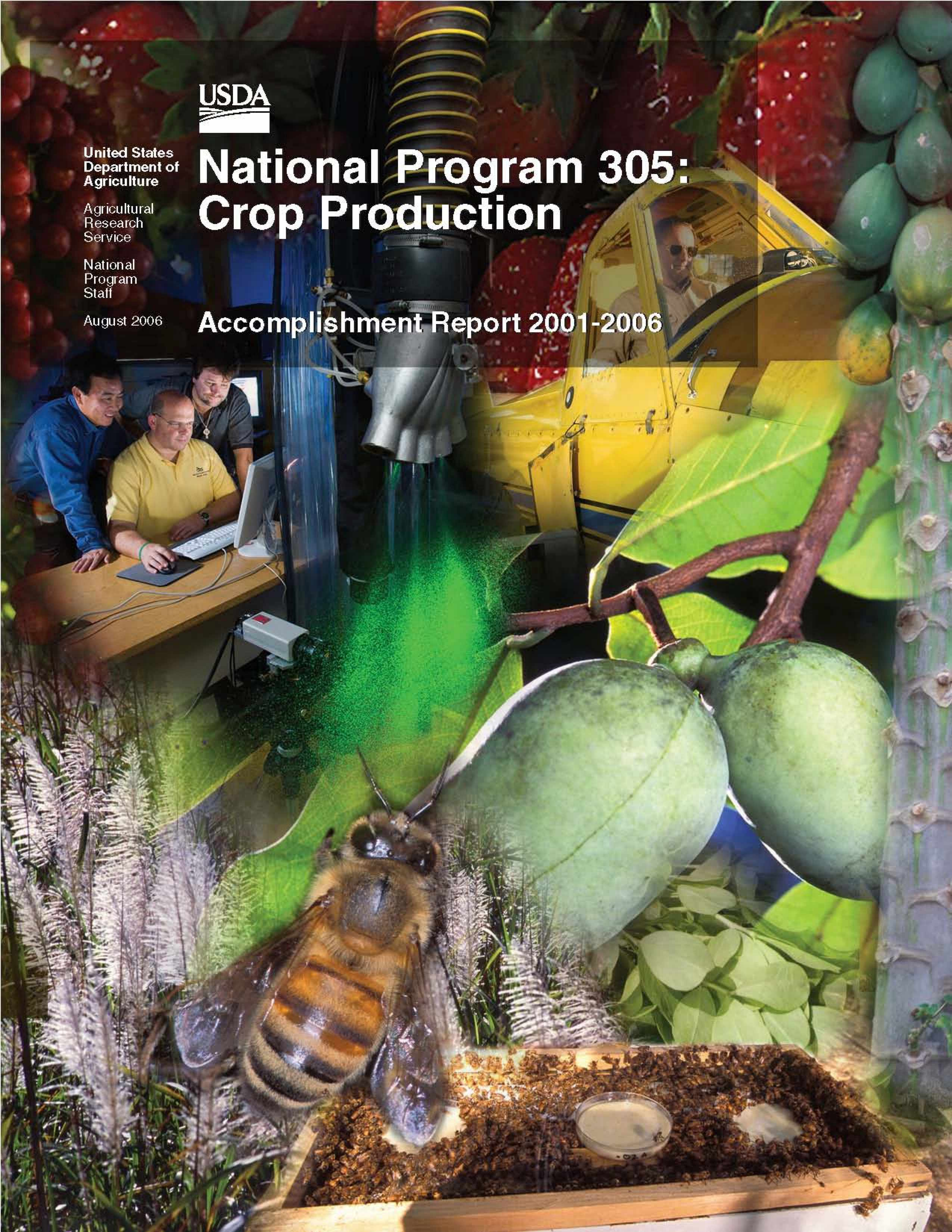
National Program 305: Crop Production

Accomplishment Report 2001-2006



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Background and General Information

Agricultural research has made the American food and agricultural system the most productive the world has ever known. Crop yields in the United States have increased approximately one percent per year over the last 50 years, which over time has had remarkable impact. In 1890 it took 35 to 40 labor hours to produce 100 bushels of corn, while today that can be accomplished in only 2 hours. This has contributed to the fact that the United States is the world's leading agricultural exporter, and agriculture is the only sector of our economy that provides a positive trade balance to our nation.

In an increasingly competitive global environment, however, maintaining U.S. competitiveness is a continuing challenge. Production inputs, including land preparation, planting, fertilizing, and irrigation, as well as pest, pathogen, and weed control, are expensive relative to profits. Crop acreage must be managed for maximum production for each commodity segment to remain viable. Prudent management also dictates that agricultural practices do not negatively impact the environment. Management practices must be economical for the producer, while safeguarding surrounding ecosystems. These concerns will govern the ongoing development of new technology to provide economically-viable and environmentally-sound sustainable crop production systems, while meeting the increased United States and world demand for food, fiber, flower, feed, and fuel. New mechanization technology must promote a safe work environment, a more efficient system of production, and the production and processing of a higher quality product.

The Agricultural Research Service (ARS) is the intramural research agency for the U.S. Department of Agriculture (USDA), and is one of four agencies that make up USDA's Research, Education, and Economics mission area. The 2006 ARS budget of $1.15 billion is allocated to 22 National Programs, which manage research conducted in 108 ARS laboratories throughout the United States and overseas. There are around 2,200 full-time scientists in ARS, which has a total workforce of 8,000 employees. The National Program addressing Crop Production is NP 305. NP 305 involves research conducted at 23 U.S. locations by 62 full-time scientists and has an annual appropriated budget of approximately $23 million.

The USDA/ARS National Program 305 Crop Production mission is to develop and transfer sound, research-derived knowledge that will result in the economical production of food and fiber crops and products that are safe for consumption and use, while preserving environmental quality.

This National Program's mission follows from the USDA Strategic Plan (see http://www.ars.usda.gov/aboutus/docs.htm?docid=1766) which is directed towards achieving goals mandated by the USDA Research, Education, and Extension Mission Area Strategic Plan and the USDA Strategic Plan for 2002-2007 (see http://www.usda.gov/ocfo/usdasp/usdasp.htm). The products of NP 305 research contribute toward broader goals (termed "Actionable Strategies") associated with two specific Performance Measures from the ARS Strategic Plan for 2003-2007. *Goal 1*: Enhance Economic Opportunities for Agricultural Producers.

- Performance Measure 1.2.5**:** Provide producers with scientific information and technology that increase production, efficiency, safeguard the environment, and reduce production risks and product losses.
- Performance Measure 1.2.6: Improve the understanding of the biological mechanisms that influence plant growth, product quality, and marketability to enhance the competitive advantage of agricultural commodities.

To accomplish its mission, the Crop Production National Program has three major program components, each with more specifically-focused problem areas.

- The <u>Integrated Production Systems</u> Component addresses researchable problems in the areas of *Models and Decision Aids, Integrated Pest Management, Sustainable Cropping Systems,* and *Economic Evaluation.*
- The <u>Agroengineering, Agrochemical, and Related Technologies</u> Component addresses researchable problems in the areas of *Automation and Mechanization to Improve Labor Productivity, Application Technology, Agrochemical and Bioproducts, Sensors and Sensing Technology, Controlled-Environment Production Systems,* and *Worker Safety and Ergonomics.*
- The <u>Bees and Pollination</u> Component addresses researchable problems in the areas of *Pest Management* and *Bee Management and Pollination*.

This report focuses on the research accomplishments associated with NP 305 – Crop Production.

Planning and Coordination for NP 305

USDA/ARS National Programs follow a five-year program cycle, initiated by a Customer/Stakeholder Workshop. The first NP 305 National Program Cycle began with two Workshops that were held to solicit customer input pertaining to needs for ARS research in the crop production area. The first workshop was held on November 19-20, 1999, in Beltsville, Maryland, to obtain input on research issues for the Bees and Pollination Component of the Crop Production National Program. Customers and stakeholders from national, regional, and state beekeeping organizations, state departments of agriculture, pesticide companies, university scientists and extension personnel, individual beekeepers, including producers and users of pollinators other than the honey bee, and others involved in agribusiness met to provide input concerning their needs and concerns. Those unable to attend the workshop had the opportunity to submit written comments that were included in a briefing book provided to all attendees. The priority needs identified by customers were incorporated into the two Problem Areas within the Bees and Pollination Component of the NP 305 Action Plan.

The second workshop was held on October 30-November 2, 2000, in San Diego, California, to obtain customer input on other aspects of crop production. During the first session, attending customers were broken out into eight commodity groups: citrus, tropical/subtropical fruit and sugar crops; small fruits; tree fruit and tree nuts; ornamentals and turf; vegetables (two commodity breakout groups); grain and forage; and fiber, oilseed, and oil crops. A second session focused on specific issues, including: sustainable agriculture; the economics of production; greenhouse crops; organic farming; integrated pest management; small farms; and regulatory mandates and environmental issues. Approximately 200 attendees from commodity groups, individual producers, university departments, state departments of agriculture, Federal research and regulatory agencies, and grower coalitions attended the meeting and provided input concerning their needs relating to problems of crop production.

Based on these in-depth discussions, three major Research Components were identified prior to developing the NP 305 Action Plan.

The NP 305 Action Plan was drafted by writing teams composed of ARS scientists and members of the USDA/ARS National Program Staff (NPS). The writing teams combined input from the Workshops, their own knowledge of the subject matter area, and input from other ARS scientists and cooperators to identify the key, priority needs that could be addressed by ARS research. These needs were aggregated into Problem Areas for each Research Component. After a public comment period, the draft Action Plan was revised and completed.

Once the Action Plan was completed, specific five-year research Project Plans were written by individual scientists or teams of scientists. Project Plans included statements of the anticipated products or information to be generated by the Project, how they were expected to contribute to solving the larger National Program Problem Areas, and time lines and milestones for measuring progress toward achieving the Project goals. All Projects Plans associated with NP 305 were then evaluated for scientific quality by external peer panels. The project peer reviews were administered by the ARS Office of Scientific Quality Review (OSQR). Project Plans were revised in response to review panel recommendations, and then approved for implementation. Progress achieved in attaining the Action Plan goals is now being assessed by an external Assessment Panel. This assessment is in preparation for the beginning of the next five-year National Program Cycle.

Coordination of the Crop Production National Program is the task of National Program Leaders who comprise the NP 305 Leadership Team. NP 305 is also coordinated with other ARS National Programs and with activities of other agencies, such as APHIS, CSREES, FDA, EPA, etc.

How This Accomplishment Report Was Constructed and What It Reflects

In this Report, information about National Program 305 achievements and their impact, and/or potential anticipated benefits, is organized according to the three National Program Research Components and their constituent Problem Areas, described in the National Program 305 Action Plan. The report first outlines the three NP 305 Research

Components and the outcomes, goals and commitments for Problem Areas within each Component from the current Action Plan. These are followed by selected accomplishments achieved during the last five years, the impact and/or potential anticipated benefits of those achievements on solving problems and meeting high priority needs identified by customer/stakeholders, and selected publications in the NP 305 Action Plan. For the most part, the content of this report is derived from responses to a recent survey of the scientists assigned or contributing to NP 305, who were asked to summarize their project's major accomplishments during the last five years, the impact of each, and to provide key references documenting those accomplishments. Consequently, this report does not include all accomplishments achieved by each NP 305 research project but, rather, only those selected by the ARS scientists polled, and the ARS scientists and National Program Leaders who authored this report. Nevertheless, the scope of this report encompasses a subset of the total spectrum of NP 305 accomplishments, chosen to illustrate the total progress and achievements at the National Program level.

Many ARS projects are associated with more than one National Program because their objectives are broad enough to encompass more than one area, and because National Programs overlap in order to best address the problems of U.S. agriculture. NP 305 encompasses 24 research projects. In addition, 16 research projects associated with other National Programs also contribute to NP 305. The titles of the individual projects are listed in **Appendix I – Research Projects**, which is organized according to the relevant NP 305 Research Component and geographical location of the research unit. Note that the individual research projects have not been associated with specific Problem Areas because, in general, the projects address the challenges and problems of multiple Problem Areas.

Component I: Integrated Production Systems

Integrated Production Systems. Modern cropping systems are complex and consist of highly integrated management components pertaining to crop protection, resource management, and mechanization. Environmental priorities such as mitigating global climate change, ensuring ground water and air quality, managing nutrients in the ecosystem, while providing for food safety and quality, and reducing impacts from invasive species, greatly influence production and profitability. Pest control systems, cover crops, rotations, tillage systems, buffers and borders, and integration and coordination of inputs for single or multiple crops must be optimized for each production system. In addition, these elements must be combined in new ways to address the needs of small, intermediate, and large-scale farms; conventional, low input, and organic production; and, production in protected environments (*e.g.,* greenhouses). New and/or upgraded technology that enhances a sustainable and profitable environment for production agriculture is needed. This new technology should address the need for lower-cost, higher-efficiency inputs, to conserve energy and natural resources, while enhancing the environment impacted by agricultural enterprises. New production systems are needed that focus on not only traditional crops, but also new crops; the availability and implementation of improved models and decision aids; cropping systems that sustain productivity with lower-cost inputs; production methods that foster conservation of natural resources; efficient and integrated control strategies for multiple pests; and, improved methods, principles, and systems for irrigation. These are high priority areas for ARS and its customers and are a major focus for the Agency.

Research in this component primarily concentrates on models and decision aids; integrated pest management (multi-pest as opposed to a key target pest); sustainable cropping systems that make the most efficient use of nonrenewable resources and on-farm resources and that integrates, where appropriate, natural biological cycles and controls; and economic evaluation.

The following summaries, organized into three subcomponents or Problem Areas, identify the Goals and anticipated Outcomes for research in the Integrated Production Systems area. Selected Accomplishments and their Impact are described.

Problem Area Ia - Models and Decision Aids

<u>Problem Statement</u>: The production of crops involves making decisions on a continuing basis regarding the commitment of expensive inputs. Decisions regarding inputs for producing a commodity are based on a body of knowledge about components that are not always well integrated into a system of production. Information is not always available or current for comparing optional inputs to determine the most productive and cost-effective methods or for predicting output from individually or collectively applied inputs. Application of any input or set of inputs or commitment of resources to a production system has ramifications that may not be fully known or understood. To make the most intelligent choices, producers need models and decision aids that will accurately predict future results of inputs.

Goals:

- Develop/update user-friendly crop production models and decision aids that can be used to predict crop performance in defined environments, facilitating crop management decisions;
- Develop models/decision aids that will consolidate new information and technology into a form that is usable by producers to determine cost-effective inputs for a crop enterprise or whole-farm operation; and,
- Develop models/decision aids that will predict long-term benefits or negative results from the application of inputs to a given enterprise or operation.

Expected Outcomes:

- More timely assessment and/or determination of the biological, economic, and environmental soundness of alternative input for crop production and management; and,
- Increased efficiency of labor, processing, and energy use.

Selected Accomplishments and Impact:

Models for weed management. Models and decision aids were developed and integrated into management-oriented software for weeds important in temperate, Mediterranean, and tropical climates. All models are related to predictions of the timing and extent of weed seedling emergence and growth, and the associated decision aids permit more science-based weed management decisions. User-friendly software applications include freely available packages named SeedChaser, SolarCalc, WeedCast, WeedEm, WeedTurf, and WheatScout, which are simple and user friendly. Furthermore, all models employ user-supplied weather, soil, and/or machinery information, thus making the simulations site-specific and maximizing local relevancy for users. **Impact:** Thousands of copies of the initial software application, WeedCast, have been downloaded from the World Wide Web or distributed, by request, on compact disks. Primary users are Agrochemical industry representatives, organic farmers, and crop consultants. WeedCast and the other decision aids are being used by several universities around the globe for classroom instruction and hands-on laboratory exercises. WeedCast has been the basis for similar software development initiatives in Africa, Argentina, Australia (“WeedEm”), and Europe (*e.g.*, “WeedTurf”). SolarCalc, a recently released sub-model intended to improve predictions of surface soil temperatures, is being employed by the energy sector for improved placement of solar panels, odor detection, and measuring atmospheric dispersion parameters, and by other ecological and agricultural research groups and the United States Navy for undisclosed uses.

Improved technologies for soil-less greenhouse plant production. On January 19, 2006, ARS scientists released the initial version of “Virtual Grower” computer software which aids in the design of cost-effective greenhouse structures. This software allows growers to quickly design a greenhouse on a computer with different greenhouse styles and materials for 233 U.S. cities for which weather data is readily accessible. After designing the greenhouse, the user case select fuel type, heater efficiency, and heating schedules to calculate heating costs for that greenhouse. The system is user-friendly, allowing users to easily alter construction or management parameters to investigate cost-saving energy strategies. As the software is expanded in future editions, it will allow the grower to factor in other economic considerations in greenhouse design. **Impact:** Currently over 600 copies of the software have been printed and distributed or downloaded directly to sites, primarily in the United States, but extending as far as France, Slovenia, Japan, and Canada.

Problem Area Ib - Integrated Pest Management (IPM)

Problem Statement: Economic losses of food and fiber caused by pests and pathogens cost U.S. producers and consumers billions of dollars annually. Insects and mites, weeds, plant pathogens, and nematodes often prevent crops from reaching their full yield and quality potential. Controlling these pests involves a significant financial investment in external inputs. However, control methods such as host plant resistance, cultural and physical practices control, pesticide application, and biological control, often have been developed on an individual pest/host crop basis and typically need better integration. Pest management strategies that were developed in isolation are often implemented without adequate regard for pest population densities, action thresholds, or natural enemies; and, have not been integrated with control strategies for unrelated pests. For example, little is known about the effects of weed control on insect pest populations. The results of their uncoordinated management strategies that affect overall production goals.

Goals:

- Develop and implement sustainable, integrated approaches for the management of arthropod, weed, and disease pests through an integrated holistic system of biological physical, cultural, and chemical methodologies;
- Reduce pest populations to economically acceptable levels while minimizing impacts on human health and the environment;
- Develop alternative pest control measures and holistic management systems to help minimize crop damage while maximizing human safety, environmental compatibility, and economic returns;
- Integrate new and commonly used pest management technology and knowledge into agricultural production systems;
- Improve the effectiveness and predicted effect of different integrated control methods; and,
- Demonstrate and transfer to customers multipest IPM systems.

Expected Outcomes:

- IPM strategies, integrating new technologies and refined current tools, for more effective, economical, and environmentally-sound multi-pest control procedures; and,
- Adoption of holistic IPM system approaches by end-users.

Selected Accomplishments and Impact:

Below the reader will find selected research accomplishments that contribute to this and other national programs. In addition, some projects are administratively housed in other national programs but contribute to the goals in NP 305. For example, the pheromone work, some of which is reported below, also is being conducted in numerous ARS laboratories that participate in other ARS national programs.

Cultural control of *Armillaria* root disease. In an effort to control losses due to *Armillaria* root disease in California vineyards, ARS scientists have: 1) identified specific California forest types as sources of *Armillaria mellea* inoculum; 2) characterized pathogen spread in vineyards; 3) examined the effects of the disease on vine performance; and, 4) evaluated control practices. The ARS scientists found that *A. mellea*, previously considered rare on the West Coast, is widely distributed in California forests, urban landscapes, orchards, and vineyards. The apparent expansion of localized disease centers in vineyards, which form where infected forest trees once stood, is not due to pathogen growth from vine-to-vine, but, instead, is due to staggered timing of infection that occurs when vines randomly contact residual tree roots (*i.e.*, inoculum) and become infected by the pathogen. A novel approach for testing disease control treatments in the field - using improvements in yield of symptomatic-treated vines as quantifiable measures of treatment efficacy - accommodated the fact that *A. mellea* does not reliably infect plants under greenhouse conditions. With this methodology, ARS evaluated two control treatments, root collar excavation (a cultural control) and a soil inoculant known as Vesta® (Biologically Integrated Organics, Inc., Sonoma, California; a biological control), and found both to significantly improve the productivity of infected vines in the field. **Impact:** This work revealed the high risk of planting vineyards on sites cleared of mixed-hardwood forest, due to the common occurrence of the pathogen on all major tree species. Both root collar excavation and the soil inoculant, Vesta® are now considered effective organic control measures for the control of *Armillaria* root disease.

Use of particle film technology for insect control. Current usage of particle film technology has impacted agriculture by reducing insecticide usage in pear and grape. Field research demonstrated that particle film technology effectively provides a safe replacement for some uses of organophosphate and carbamate insecticides in a wide range of crops, including apple, walnut, olive, mango, papaya, cacao, citrus, pear, grape, blackberry, blueberry, tomato, peach, and nectarine. Use is quickly expanding to new insect control and horticultural applications in the United States and internationally. The Mediterranean fruit fly, a major import pest world-wide, is also effectively repelled by Surround®. Human food safety and the environment have benefited from its use. There is progress in the development of new uses for particle film technology in the form of pesticide delivery systems that reduce the amount of toxic pesticides applied to crops in combination with particle films. The particle film concept was commercialized by the Engelhard Corporation through a CRADA and has already reduced the percentage of organophosphate and carbamate insecticides from food production as mandated by the Food Quality Protection Act. In organic agriculture, particle film technology represents the first broad utility material that provides effective insect control and high produce quality in organic fruits and vegetables. Its adoption by organic growers will further increase the growth of this expanding industry in the United States and globally. Surround-WP® has been certified by OMRI as an organic material that can be used by registered organic farms in the United States. In 2002, the Michigan Organic Board recommended that Surround WP® be its foundation pest control system. **Impact:** Surround WP® has become the standard practice for early season control of pear psylla, an insect that has rapidly developed resistance to insecticides used against it. Currently, Surround WP® usage on pear has been estimated at 80 percent of the national insecticide usage in pear. Surround® usage in pear directly translates to reductions in toxic insecticide usage. Particle film technology represents the first effective means of combating insect-vectored diseases. As a highly effective insect repellent, particle film technology deters insects from feeding, thus preventing transmission of disease agents. California was recently invaded by the glassy-winged sharpshooter, which vectors the deadly grape disease, Pierce's disease. In just 2 years, this pest destroyed $25 million in grape acreage and threatens $40 billion in California grape-dependent industries. Surround WP® controlled the glassy-winged sharpshooter in grape better than conventional insecticides with one-half the number of insecticide applications. Surround WP® is now recommended by the University of California Extension Service for early-season and post-harvest control of the glassy-winged sharpshooter.

Weed control with kaolin clay and mulches. The number of registered herbicides for small fruit production continues to decline. A novel weed control strategy was developed for small fruit production systems. ARS research indicated that hydrophobic and oil-based mulches were excellent alternatives to conventional herbicide treatments for suppressing weeds. NP 305 scientists identified hydrophobic kaolin clay particle as an environmentally safe new weed management technique that helps compensate for the lack of available synthetic chemicals for small fruit crops, as well as other horticultural crops, and improves the economic viability of small fruit production. **Impact:** The new products are being used for weed control and for management of other pest problems adversely impacting blackberry and raspberry growers. ARS scientists are now extending this technology to evaluate a kaolin-based product to manage three major pests: slugs, raspberry crown borer insect, and raspberry root-rot fungus, through the application of products developed from the research.

Areawide pest management program for Russian wheat aphid and greenbug. This ARS sponsored areawide project was conducted in a region including Oklahoma, Texas, Colorado, Nebraska, Kansas, and Wyoming in collaboration with university scientists, extension personnel, and commercial wheat growers. A total of 146 growers collaborated with ARS during the four year project. A computer decision aide called the Greenbug Management Decision Support Tool was developed and is available in on-line and CD formats; it is a primary source of knowledge for wheat growers and pest managers for decision-making. The tool is being expanded to include Russian wheat aphid pest management. Program information updates are published periodically and mailed to over 300 stakeholders. The focused research, education, and outreach activities resulted in dramatically increased use of integrated pest management programs emphasizing the sustainable pest management practices of host plant resistance, diversified crop rotations, and biological control. This project also facilitated the development and deployment of pest management decision-making tools in the form of computer decision aides and insect sampling schemes. **Impact:** As a result of this program, many collaborating growers now regularly scout for the greenbug and Russian wheat aphid and use the results of scouting to make control decisions. In addition, growers now take advantage of the role of natural enemies, resistant wheat cultivars, and crop rotation as key tactics in aphid pest management decisions. This was not the case prior to this program. Sociological evaluation in the project facilitated by extensive use of focus groups and grower interviews during the program, showed that growers learn the most about effective crop diversity by learning from their peers.

Pheromone-based monitoring and attract-and-kill technologies. Improvements in pheromone-based monitoring techniques for boll weevil populations were developed, and limitations were identified. Close association of pheromone traps with prominent vegetation resulted in increased trap effectiveness, and orientation of traps to down-wind sides of brush lines reduced chronic problems with trap interference from high wind speeds. Evaluation of a new "superlure" pheromone formulation documented improved pheromone retention by the new lures, compared with standard lures. Field studies indicated that the widely used insecticidal kill strip is generally ineffective at preventing escape of boll weevils from traps. Field and laboratory studies of the Boll Weevil Attract and Control Tube (BWACT) resulted in assay methodology that was more reliable than previously used techniques, while demonstrating the ineffectiveness of the BWACT devices as a control tactic. **Impact:** Association of boll weevil pheromone traps with prominent vegetation will maximize population detection while relieving problems with trap interference associated with chronic high wind speeds typical of South Texas. This information will become valuable in eradication maintenance programs where early weevil detection is critical to program success. Elimination of the kill strips from eradication trapping protocols may offer small, but significant cost savings without impacting trap effectiveness. Results from BWACT studies were instrumental in preventing the inappropriate adoption of this technology as a core control tactic in environmentally sensitive areas of eradication zones, and has reduced the use of these devices in some cotton production regions of South America. Evaluations of the superlure suggest that proposed use of this new formulation to extend lure replacement intervals by the Southeastern Boll Weevil Eradication Foundation may result in poor weevil population detection.

Boll weevil reproductive dormancy. Morphological and biochemical indicators of boll weevil reproductive dormancy were identified and correlated to host-free survival, and a previously proposed indicator of dormancy, the supercooling point, was deemed unreliable. Host cues were found responsible for dormancy induction irrespective of photoperiod, in contrast to long-standing reports of photoperiod as the critical induction cue. Improved feeding regimes were developed to yield a high proportion of dormant, long-lived weevils, which ensured the success of efforts to define the temperature dependence of host-free survival and the emergence patterns of overwintering weevils. Improved knowledge of boll weevil dormancy facilitated studies of longevity on regrowth and vegetative cotton plants, which indicated survival abilities much greater than those previously reported. **Impact:** Accurate identification of dormant boll weevils, and ability to forecast temperature-dependent survival rates, facilitates the reliable assessment of the overwintering potential of weevils in eradication programs. This information is critical to efforts to improve the effectiveness of diapause sprays in active eradication programs. Improved knowledge of boll weevil survival potential on regrowth and vegetative stage cotton was used as justification for continued post-harvest insecticide applications to growing cotton stubble in Arkansas eradication programs.

Characterization of neuropeptides. Neuropeptides of pest insects have been identified via analysis of single nerve and/or organ tissue using mass spectroscopy. A specific class of neuropeptides was discovered that regulates the release of digestive enzymes in pest lepidopteran insects. The active 3D-shape required for several insect neuropeptides to successfully interact with the active site was identified. Surfactant analogs were developed that penetrate the cuticle of moths, as well as the midgut wall and emerge in the circulatory system to reach target sites. Pseudopeptide mimetic analogs of neuropeptides that disrupt normal insect life processes were developed with enhanced resistance to degradative enzymes. Active site molecules were characterized that are required for the development of non-peptide neuropeptide mimics, which feature optimal biostability and bioavailability. **Impact:** This accomplishment provides new and important structural and location mapping data on neuropeptides that regulate aspects of diuresis, digestion, and development in pest insects. This research has advanced progress toward the development of neuropeptide technology that will effectively control pest insects without reliance on conventional insecticides.

Integration of composted mulch and interplanting in apple orchards. Composted poultry litter mulch, interplanting peach trees with extrafloral nectar glands in apple orchards, and planting companion plants in orchards, have increased the biodiversity of parasitic and predatory insects on apple and peach trees resulting in better management of insect pests. Under orchard conditions most insect pests were controlled through biological control with companion plants and interplanting as well as with chemical insecticides. **Impact:** These results provide information on how orchard management can be modified to increase biological control and reduce insecticide use. The results provide some of the first documented evidence of the benefit of these practices on pest management in fruit orchards. These management practices are being adopted by organic fruit growers.

Pollen Reference Collection. Pollen grains are distinct and identifiable to the family, genus, and often species rank and can be used as a durable, natural marker. Pollen identification can be used to determine the geographical origin of the plant which produced the pollen, feeding and migratory activities of insects, and differences among insect species in the use of habitats and food sources. The Areawide Pest Management Research Unit (APMRU) Pollen Reference Collection was created from four pollen reference collections. The collection consists of 9,500 glass slides of pollen and other vascular plants, 10,000 scanning electron micrographs, 5,000 light micrographs, and 1,000 pollen packets from vouchered specimens and 250 plant specimens. About 75 percent of the collection is archived in a data base that can be sorted by pollen characteristic, plant species or family, country where collected, collector, and date collected. Twenty-five percent of the collection's micrographs are stored in digital format at www.pollen.gov. **Impact:** Pollen from the APMRU collection has been used to determine the foraging resources of boll weevils during host-free periods, help determine migratory routes of corn earworm moths, explain fruit fly population growth, determine the botanical origins of honey, and examine non-host food sources of two species of corn rootworm. The publicly-accessible collection has been used by university, government, and private industry researchers and students world wide. Micrographs and the use of micrographs from the collection are frequently requested and have been used for national TV programs, books, popular press publications, and scientific displays. The American Geological Institute and Texas A&M University have used the micrographs in outreach programs to teach school age students about science, plants, ecology, interactions between plants and pollen, and allergies.

Problem Area Ic - Sustainable Cropping Systems

Problem Statement: U.S. agriculture is found across fundamentally different ecological and climatic zones, each requiring unique cropping systems that efficiently utilize local and regional resources to produce food, nonfood, pharmaceutical, and fiber crops.

It is uncertain which cropping systems will be sustainable without key Agrochemicals (*e.g.*, methyl bromide, organophosphates), and which food quality and safety issues will be affected with the loss of these materials. Alternative soil management systems need to be developed that maintain or increase soil productivity. The response of current cultivars in new cropping systems is often unknown, and the adaptability and economics of new conventionally-bred and genetically-engineered cultivars is unknown for new and existing cropping systems. Further, many cropping systems are not adapted to mechanization and automation. The interactions of environment, soil-nutrient-water management, pest control, and genotypes are not well understood in cropping systems. Many of the diagnostic and predictive models for cropping systems are incomplete.

There is a continuing need for an integrated system of crop production practices having a site-specific application that will over the long-term: satisfy food, fiber, flower, feed, and fuel needs; enhance environmental quality and the natural resource base upon which the economy depends; make the most efficient use of nonrenewable resources and on-farm resources, and integrate, where appropriate, natural biological cycles and controls to sustain the economic viability of farm operations, and, enhance the quality of life for farmers and society as a whole.

Goals:

- Improve understanding of the effects of management practices and their interaction on crop productivity and quality;
- Understand the effects of integrating biotic (living) and abiotic (nonliving) factors as related to crop performance and production efficiency;

- Integrate pest control, soil-water-nutrient management, and mechanization into economically and environmentally sound cropping systems;
- Identify, evaluate, and effectively utilize new germplasm, including cover crops that are adapted to sustainable cropping systems;
- Develop soil-water-nutrient management systems that make the most efficient use of natural resource and production inputs; and,
- Increase crop productivity and quality in production systems in a sustainable manner.

Expected Outcomes:

- Increased knowledge base of the effects of new technology for sustainable cropping systems to optimize production efficiency and farm profitability and minimize negative environmental impact; and,
- Better understanding of agroecosystem and integrated production management systems to improve crop productivity and quality.

Selected Accomplishments and Impact:

In this section we have organized the research accomplishments by crop type or cropping system: 1) New Crops/New Uses, 2) Small Fruits, 3) Perennial Tree and Vine Crops, 4) Vegetables, 5) Field Crops, 6) Cross Commodity Issues.

1) New Crops/New Uses

The development of new crops for use in challenging environments such as the arid Southwest can dramatically enhance grower productivity and profitability. In addition, the development of new cultivars that facilitate earlier planting dates, provide value added to an existing commodity, or make new uses possible, all contribute to grower productivity and effective stewardship of the land.

Development of new/alternative industrial crops. ARS scientists have developed production systems for two new crops, guayule and lesquerella. Besides *Hevea*, guayule is the only known plant that produces significant amounts of natural rubber/latex. Because many people are allergic to *Hevea* rubber/latex products, ARS turned to guayule latex to provide a hypoallergenic source of natural latex for products such as medical catheters, gloves, and condoms. Another benefit of guayule is that the resin has pesticidal properties. Further, the waste residue after latex extraction can be made into construction materials that have termite and wood rot resistance, and/or the resin can be extracted and impregnated into other wood products to give them termite and wood rot resistance.

The United States imports over $100 million of castor oil each year for use in lubricants, cosmetics, plasticizers, protective coatings, surfactants, and pharmaceuticals. Lesquerella oil can replace castor oil for many of these uses and can be used in other products for which castor oil is not suited.

All production systems for guayule and lesquerella have been made available to growers and cooperators involved in commercial production of these two new industrial

crops for the arid Southwest. The production systems developed include information on recommended planting methods, irrigation management, fertility practices, pest control measures, and harvesting methods.
Impact: Guayule is now being grown commercially in Arizona and California by Yulex Corporation. Information on production systems and seed provided by this research project were critical for this commercialization to occur. A pilot plant has been built by Yulex and hypoallergenic latex is being sold to latex product manufacturers. Within the next two years commercial products made from guayule latex should be available to the public.

Lesquerella is being developed commercially by Terresolve, Inc. Over 45,000 pounds of seed have been produced on growers' fields utilizing germplasm lines and production practices developed in NP 305. The seed has been used for crushing and processing into various bioproduct formulations. These studies have provided germplasm, production systems, and products from new crops that will diversify the crops being produced in the United States and enhance the rural economy.

New and unique uses for kenaf. Kenaf fibers were examined for their use as a renewable adsorbent material to replace activated carbon. Ozonation of kenaf fiber resulted in a five-fold increase in pollutant adsorption, and composting the spent kenaf resulted in complete removal of adsorbed dichlorophenol. Chromatography analysis indicated that kenaf absorbed larger molecular weight molecules more efficiently than it absorbed smaller molecular weight molecules. Kenaf also has odor absorption capacity, particularly for larger molecular weight components. These findings could increase the demand for kenaf to replace activated carbon and thus make kenaf a profitable crop for the farmer. **Impact:** ARS research has shown that kenaf can be useful in odor reduction and adsorption of a wide variety of organic compounds. The finding that whole stalk kenaf can be used to adsorb organic compounds from contaminated water can have broad socioeconomic impact on manufacturers that produce such wastes. The potential for production of these alternative crops and/or value added products could potentially provide a significant boost to the rural economy of Mississippi.

Soybean cultivars bred for new uses in sustainable, organic agriculture. ARS scientists developed the new six-foot tall soybean cultivar 'Tara' that was bred to provide increased crop residue to control soil erosion. Tara, the first of a new generation of soybean cultivars, was bred, tested, released, protected under Plant Variety Protection, and licensed to Southern States Cooperative for marketing to farmers. Tara provides 72 percent more crop residue after grain harvest than conventional cultivars.

A new generation vegetable soybean cultivar, 'Moon Cake,' was also bred and released to farmers. The fresh green seeds of the six-foot tall Moon Cake provide a healthy high protein vegetable for human consumption. After the seeds are harvested, the plants can be fed to livestock, serving a dual use that is valuable to small scale diversified farming operations**.**
Impact: Tara is now being used by farmers on several thousand acres. If used on all soybean acreage nationally, it is estimated that this additional crop residue would reduce soil erosion by 210 million tons per year and save up to $325 million dollars in water

purification costs, including reduced dredging of lakes and rivers. The exceptionally tall growth of Moon Cake, more than twice the height of most vegetable soybeans, enables it to compete against weeds. Organic farmers in Maryland, Pennsylvania, Tennessee, and Missouri are using Moon Cake.

Cuphea, an alternative oilseed crop. Research conducted by ARS scientists facilitated the commercialization of a new alternative oilseed crop, cuphea. Seeds of this new crop contain high levels of capric acid, a useful fatty acid not produced by other temperate oilseed crops. Cuphea can serve as a domestic replacement for certain high-value petroleum-based lubricants and can be used in such products as lip balm, deodorant, skin lotion, and sunscreen. A complete growers' guide was developed which provides science-based advice to farmers, seed companies, and crop consultants on how to plant, manage, and harvest the crop and process seeds to extract oil. **Impact:** Cuphea acreage increased exponentially through involvement of a specialty seed company that buys harvested seed from farmers and a specialty oil company that buys the extracted oil. First grown on-farm in 2004 only in west-central Minnesota, cuphea's regional acreage expanded in 2006 to include lands in North Dakota and South Dakota. The ARS growers' guide is used in all cuphea growing contracts issued to farmers. Oil extracted from commercially grown seed was bought by an industrial firm in Arizona to formulate and test personal care products. Requests by a large industrial partner for testing cuphea-based products indicate that 8000 acres of the crop are needed in 2007.

2) Small Fruits

Small fruit production represents a significant component of U.S. agriculture. In general, small fruits such as strawberry, blueberry, cranberry, raspberry, and blackberry are high value crops grown using intense farming practices. ARS scientists are working towards development of cost-effective approaches to enhance such important characteristics as nutritional value, yield, and the geographic range over which popular varieties can be cultivated.

Blackberry production system. Trailing blackberries from the Pacific Northwest do not produce fruit in the eastern United States because their fruiting canes are usually killed back to the ground in the winter. The combination of simple cultural practices, - a modified rotatable cross-arm (RCA) trellis system, and covering plants with insulation material in winter - overcame the lack of cold hardiness in trailing 'Siskiyou' and 'Boysenberry' blackberries established at Kearneysville, West Virginia (39º Latitude N). The cover also provided protection against the wind. 'Siskiyou' plants in covered plots produced 3 to 5 times more fruit than plants in the open. **Impact:** The trailing varieties produce high quality fruit much earlier than the eastern thornless blackberry varieties. Extending the harvest season by growing varieties that ripen early, or late in the season, meets market demand for fresh blackberries and enhances grower profitability.

Improvements in strawberry cultivation. Excessive runner production weakens plants and reduces branch crown development resulting in reduced yields. The commercially available formulation of a plant growth regulator, prohexadione-Ca, effectively reduced fall runners and enhanced branch crown formation of the June-bearing cultivar 'Chandler' in a cold climate annual hill system.

"Advanced Matted Row" (AMR) was developed to incorporate beneficial aspects of both Annual Hill and traditional Matted Row culture systems into a sustainable production system. This system includes matted row-type culture, but on raised beds with sub-surface drip irrigation and organic mulch. Five years of replicated field trials demonstrated enhanced yield and fruit quality in AMR systems.

Researchers further found that strawberry plants grown under increased atmospheric CO_2 concentrations produced fruit with increased phytonutrient content, antioxidant capacity, sugar content, and concentration of aroma compounds.

Impact: ARS research facilitated expanded registration of prohexadione-Ca for use on strawberry. The AMR system is now being used to a limited extent in the eastern United States, primarily by pick-your-own and organic growers. The CO_2 research demonstrated that protected cultivation of strawberry could improve fruit quality, nutritional value, and flavor using limited modification of existing technology.

Elevated antioxidant levels of raspberry fruit after methyl jasmonate application. Preharvest applications of methyl jasmonate (MJ) resulted in raspberry fruit with higher preferred soluble solids content (total sugars, fructose, and glucose), and lower undeliverable acid content (malic and citric) than untreated fruit. MJ treatments also significantly enhanced the content of beneficial anthocyanins, total phenolics, flavonoids, and antioxidant capacities in the fruit. Cyanidin 3-rutinoside was the most dominant anthocyanin and was the major contributor to antioxidant activity in 'Jewel' raspberries. **Impact:** The impact of this research has not yet reached its full potential, but adoption of the MJ procedure will likely increase as the demand for enhanced nutritional value berries increases. This information has been adapted for use as a selection trait in strawberry breeding programs to enhance the nutritive value of strawberry, as well.

3) Perennial Tree and Vine Crops

Perennial tree and vine crops present unique challenges. Given the long term cropping cycles and the significant inputs required for up to 4 years before first harvest, careful consideration needs to be given to such factors as: cultivar/rootstock selection, and, orchard/vineyard management, including disease and pest management strategies. Below are examples illustrating progress made in each of these areas.

Plant growth regulator to control vegetative growth of apple trees. Apple trees often produce excess vegetative growth that reduces cropping and increases disease problems such as fire blight, along with increased cultural management costs. ARS scientists demonstrated that a newly discovered plant growth regulator, prohexadione-Ca, an anti-gibberellin, was effective in significantly reducing shoot growth and the shoot blight stage of fire blight. **Impact:** Prohexadione-Ca was granted a label for use in apple production. ARS research results were used in preparing label use rates, methods of application, and warnings associated with potential negative effects when applied under certain conditions to select apple cultivars.

Particle film use in apples. Sunburn damage in apple orchards can reduce yields by 50 percent. Previously, the most common method of sunburn prevention was cooling with overhead sprinklers. ARS scientists demonstrated that a particle film could be manipulated to increase photosynthesis and plant productivity, while reducing sunburn damage. This particle film is the first material to suppress heat damage and sunburn without the use of evaporative cooling. In addition, the particle film diffused canopy light and increased apple red color development. **Impact:** The particle film material, Surround Crop Protectant®, was commercialized to reduce heat stress and sunburn damage in apples. Surround® is the primary sunburn protectant for apple in the western United States. The chronic drought situation in the western United States plus the many other issues facing agricultural water use make particle film technology an economic alternative to overhead sprinklers.

New apple cultivars. Apple growers are interested in new apple cultivars to enhance profitability, while consumers are demanding newer apple cultivars with high quality and unique and distinct flavors and textures. However, a widespread systematic evaluation of apple cultivars had not been carried out in North America for more than 50 years. New horticultural and pest susceptibility information was developed on 40 new apple cultivars in replicated plantings as part of the NE-183 Regional Project, "Multidisciplinary Evaluation of New Apple Cultivars." Among the cultivars evaluated, several proved well adapted to the eastern United States, and, particularly, the mid-Atlantic apple growing region. The scab resistant cultivar "GoldRush' exhibited good overall disease and insect resistance, excellent productivity and storage qualities, good flavor and texture following storage, and was identified as a highly promising new cultivar for both fresh and processing markets. **Impact:** Based on these evaluations, a number of the newer apple cultivars are being planted throughout the eastern United States.

New peach tree architecture. Peaches are produced on seedling-rooted trees planted, because of broad canopies, at low tree densities, which contributes to low yields per hectare. Two new peach tree forms, the pillar and the upright, were planted and managed under several training systems and at four planting densities to determine their horticultural characteristics. These novel peach tree forms have shown significant yield increases over conventional peach trees planted at low densities while producing fruit of high quality. In related work, ARS scientists have shown the endogenous plant hormone, auxin, to play a major role in determining the upright and narrow nature of fruit tree canopies. **Impact:** The new peach tree forms offer growers a method of increasing yields on smaller units of land using increased tree density. Such systems offer the potential for increased use of mechanized culture and lower production costs. The ability to regulate plant hormone levels, which, in turn, manipulate tree architecture, will facilitate increased tree density, reduce pruning requirements, and increase plant yield.

Role of nickel in plant health. The postulated role of nickel (Ni) as an essential plant nutrient was validated and officially recognized by fertilizer regulators as an essential plant nutrient element for pecan. ARS scientists also discovered its role in disease protection. As a result of this work, a commercial Ni fertilizer was developed with regulatory approvals obtained for the labeling, sale, and usage of Ni fertilizers in the

United States. Additionally, a plant nutrient deficiency (Ni) was shown for the first time to be correctable by usage of novel natural product fertilizers derived via phytomining from soils by metal hyperaccumulating plants (i.e., *Alyssum* sp.). **Impact:** This discovery solved the old and increasingly severe problems of a) the "mouse-ear" or "little-leaf" maladies exhibited by pecan and several other woody perennial species, and b) the "replant" malady found in pecan orchards; thus, providing a means of preventing major economic losses previously encountered in a variety of woody perennial crops. The research on formulation of a Ni product led to the commercialization of a Ni fertilizer and the formation of a new company (NiPan, LLC) to market Ni fertilizers. Based on its importance in conferring plant tolerance to certain phytopathogens, Ni is now used as a nutritional additive to fungicide mixes. The correction of Ni deficiency by extracts of *Alyssum* biomass offers a natural product source for correction of Ni deficiency, thus ensuring compliance with criteria for certified organic agricultural products.

Environmental causes of sunscald in grapes. ARS scientists described the environmental mechanism causing sunscald (browning) in grapes, using the red-skinned variety, *Vitis vinifera* cv. 'Merlot.' The work demonstrated for the first time under vineyard conditions how different classes of phenolic compounds (*e.g.*, flavonols, anthocyanins) in the skins of red wine grapes are affected differentially by light and temperature. Results showed that heated fruit, whether naturally heated by sunlight or artificially heated in the shade, had lower concentrations of anthocyanins than did cooled, sunlit fruit. The work was carried out in the vineyard using a simple but novel system of controlling the temperature of grape clusters and separating the effects of light and temperature *in situ.* **Impact:** The results of this research have generated much interest, particularly, in the arid western United States among wine grape growers who are adjusting some of their canopy management practices according to fruit aspect (*e.g.*, east vs. west) in areas with hot summers and high solar radiation. The largest winery in Washington state (>2.2 million cases annually) has begun hand-thinning fruit clusters preferentially on the west side of the vine canopy in vineyards that are designated for their high-value, high-margin products.

Cover crop management system enhances U.S. date production. A two-step process to enhance date production was developed. It consisted of, first, a one-time slip plowing between the tree rows to a depth of 5 ft. to break the hard pan and allow the movement of water and nutrients deeper into the soil profile and, second, a management system using a native legume cover crop, lana vetch, to cover the soil surface between October and May of each year. **Impact:** The cover crop suppressed weeds, improved soil fertility, recycled macro- and micro-nutrients, improved water percolation, shaded the soil surface, reduced evaporation, and lowered soil temperature. Within three years, tree growth per year tripled, yields significantly increased by an average of 12 to 20 percent, and fruit quality also improved. At the same time, production cost was reduced by $100/ac due to savings on cultivation, fertilizer, and water. Approximately 45 percent of the date orchards in Coachella Valley are using this cover cropping system. This technology has been extended to other crops resulting in an increase of cover cropping acreage from 500 to 25,000 acres in the Coachella Valley, including use in approximately 40 percent of the grape acreage.

4) Vegetables

Similar to small fruit production discussed above, vegetable production is conducted under intense farming practices that often rely on the use of soil fumigants.

Cover crop based production of tomato. The use of a biologically-based system for winter production of fresh-market tomatoes was evaluated. The system consisted of a cropping rotation in which nematode-resistant cover crops (cowpea, velvet bean, or sunn hemp) were followed by a nematode and fusarium/verticillium resistant tomato cultivar. Tomatoes in these cover crop based-systems produced equivalent or higher yields and net returns in selected years compared to the conventional fumigation based system. **Impact:** These results show that fumigation might not be necessary under some conditions and that a cover crop based-system can be an economically viable alternative for growers of high-value crops in the southeastern U.S under specific conditions. In addition, the alternative system reduced soil erosion, improved soil fertility, and has great potential for protecting the environmentally fragile agro-ecosystem of the Everglades.

5) Field Crops

Removal of sugarcane residue for increased yields. ARS scientists discovered that the blanket of residue deposited over the soil during green-cane harvesting of sugarcane slows the spring emergence of the ratoon crop and reduces yields 10 to 15 percent. The slowdown was exacerbated by cold soil temperatures and high rainfall during the winter months as the residue had an insulating effect, keeping the soil colder and wetter. The residue was found to possess autotoxic and allelopathic effects on the emerging crop, which, when combined with temperature and moisture effects, accounts for the yield reductions observed in the ratoon crops. To avoid these effects the residue should be removed at least from the row top as soon after harvest as possible to insure optimum yields the following year in the ratoon crop. **Impact:** If post-harvest residues generated during the harvesting of green cane are not removed either by burning or mechanical means, a $20 to $30 million-yield loss can be expected in the ratoon crops that comprise about 75 percent of the harvested acreage. These studies provided residue removal guidelines to Louisiana sugarcane producers that excluded burning, minimized yield losses, and reduced environmental impact.

Variable rate application of lime to lower sugarcane production costs. In recent years, sugarcane growers have been faced with increased economic pressure and must find ways to decrease input costs while maintaining yields and avoiding negative environmental impact. Yield data, analyzed with geostatistical methods, were found to be spatially correlated with soil-pH profiles across the field. Precision agriculture techniques were utilized to document the extent of variability present in large commercial sugarcane fields. Variable rate application of lime reduced the total amount of lime applied by up to 50 percent, and resulted in statistically equivalent or superior cane and sugar yields in plant and ratoon crops. **Impact:** Using a precision agricultural approach, the variable rate application of lime reduced grower costs and enhanced profitability by applying lime on as-needed bases throughout the field, which also minimized adverse environmental effects.

Cotton management with conservation tillage in the southeast United States. Growing cotton with conservation tillage is becoming more common for cotton production in the Southeast. ARS scientists have shown that conservation tillage, which reduces water deficit stress, can result in better cotton fiber physical properties than cotton grown with conventional tillage. Thrips populations were lower in cotton grown with conservation tillage than in cotton grown with conventional tillage, especially when a rye cover crop was used. This will lead to improved integrated pest management recommendations for this cropping system. **Impact:** This research has contributed to a significant increase in acres where conservation tillage is being used in the Southeast. Growers, consultants, extension agents, and Natural Resources Conservation Service personnel are the primary beneficiaries of this research.

Planting schemes for peanuts. Research showed that a lower seeding rate for peanut with twin- or diamond-row planting patterns had the same yield as the recommended single-row pattern. Twin-row planting patterns resulted in the highest yields at 4812 lbs/ac compared with other planting patterns. Market grade was higher for twin- and multi-row patterns compared with single-row plantings. Twin- and multi-row plant patterns have lower stem rot disease compared with single-row plantings. Studies were also conducted to determine the interaction of row pattern and disease control in peanuts. Research indicates that there is no interaction between planting pattern and disease control. Peanut planted in twin rows had better yield in five of six trials. Diamond-row planting patterns produced better yields than single-rows in four of six trials, but were not superior to twin-row planted peanuts. **Impact:** Using a twin- or diamond-row pattern has the potential to save producers millions of dollars in seed costs without affecting pod yield. Twin-row planting patterns tended to have the best yield and grade, and lower disease incidence compared with the single-row planting pattern. This presents the possibility of applying less fungicide without reducing yield.

Subsurface drip irrigation (SDI) in cotton. From 2000 to 2005, corn, cotton, and peanut yields were documented with respect to surface and subsurface drip irrigation (SDI) systems. The yields of corn, cotton, and peanut were similar when irrigated using surface, subsurface, or overhead irrigation. **Impact:** The use of subsurface drip to supply irrigation needs, combined with new recommendations on nitrogen rate to cotton, has the potential to save producers millions of dollars in water and fertilizer costs without reducing yield or grade of cotton. Subsurface drip irrigation can be an alternative solution for growers to irrigate leased or small irregular shaped acreage without large irrigation system input costs. Long term studies are needed to determine economic impacts, however, if yields are consistently high for corn, cotton, and peanut, subsurface drip can be an economically feasible irrigation practice for irregular shaped areas or small land owners.

Early planting system for cotton. ARS scientists documented that Mid-South cotton yields are limited by the amount of sunlight the crop receives during the growing season.

Due to sunlight limitation, an early-planting production system was developed that shifted the period of reproductive growth closer to the summer solstice. On average, the yields from early planted cotton were 10 percent greater than cotton planted in the traditional time frame, with no impact on fiber quality. Early planting results in the avoidance of late season stresses such as water deficits, high temperatures, and greater insect infestation. Early planted cotton requires no alteration in plant growth regulator or nitrogen fertilization programs. Slightly higher seeding rate is needed to insure optimal plant densities compared to cotton planted in the traditional time frame. ARS scientists also documented how drought stress, potassium fertilization, plant growth regulators, and heat stress alter cotton growth, development, yield production, and fiber quality for different cotton cultivars. **Impact:** Responding to a cotton yield plateau that occurred in the late 1990's in the Mid-South, this early planting production system offers producers a chance to achieve higher yields, while minimizing the need for some late-season inputs such as an extra irrigation or insecticide application. On average, 8 percent of Mississippi's total cotton acreage had been planted by April 23-24 between 1996 and 2000. Record cotton yields for the state were produced in 2003 and 2004 when 22 and 21 percent, respectively, of the cotton acreage was planted by April 25. Thirty-six percent of the cotton acreage was planted by April 24 in 2006.

Early soybean production system (ESPS). Fungicides increased yield and soybean seed quality for maturity group IV and V varieties when planted in early April (planting window for ESPS) and early May. Planting soybean in early April aided in avoiding late-season disease pressure while reducing the need for fungicides to improve soybean yield. The efficacy of strobilurin and triazole fungicides applied alone and in combination reduced disease pressure and improved soybean seed yield and quality when applied to reproductive growth stages of soybean grown in the ESPS. **Impact:** Soybean yields were increased 6 to 12 bushels/ac and economic net returns were increased $20 to $50/ac when foliar fungicides were applied to soybean grown in the ESPS. Fungicide use and economic inputs can be reduced in the Mid South by growing early maturing varieties in the ESPS. This will significantly improve the profitability of soybeans. Fungicides known to have efficacy on the Asian soybean rust pathogen were utilized in this research so that recommendations can be made to stakeholders as to what fungicide(s) can be utilized and at which crop stage they should be applied to manage the pathogen if it becomes established and impacts soybean grown in the United States.

6) Cross Commodity Issues

This section describes progress being made towards the development of technologies that will impact the production of a number of crops. This includes such important issues as wastewater management and the use of particle films to reduce freeze damage.

Management of on-farm use of wastewater. One management option available to wastewater producers is the reuse of wastewater for crop irrigation. ARS scientists examined the response of ten forages to irrigation with saline-sodic waters that simulate typical drainage effluents from irrigated agricultural operations in the San Joaquin Valley, and which contained low concentrations of the potentially toxic trace elements selenium (Se) and molybdenum (Mo). Tall wheatgrass, bermudagrass, and paspalum were the best candidates for the reuse systems examined. Importantly, it was noted that wastewaters and drainage effluent may cause mineral ion imbalances in forages which may cause deficiencies and toxicities in ruminants. **Impact:** Use of recycled saline effluents in a sustainable agricultural system will conserve fresh water supplies, reduce the volume of drainage water requiring disposal, reduce the area affected by shallow water tables, and optimize land productivity. Production of high quality forages is the most promising strategy for economical utilization of these waters. The research provides guidelines for the reuse of captured runoff or wastewaters to decision makers in other industries. ARS is providing commercial operators with requested details and consultation about saline effluents and their use in irrigated forages.

Wastewater use in rice production. ARS scientists have examined the physiological parameters contributing to salt tolerance in grain crops (rice, wheat). More than 50 genotypes of rice were evaluated for salt tolerance. Physiological and biochemical parameters (ion selectivity, stomatal conductance, photosynthetic capacity, leaf area, carbon ion discrimination, biosynthesis of osmoprotectants) were quantified. Experiments were conducted to identify and quantify the effect of salt stress on specific stages of growth in rice such as panicle, spikelet and tiller initiation, and seed filling. Water management practices and crop production functions, developed under greenhouse conditions which minimize rice yield losses, were confirmed by long-term field trials. Plant injury and yield reductions due to salinity were correlated with irrigation scheduling and long water holding periods in rice fields. The response of wheat to stress application or relief at three growth stages (leaf initiation, spikelet initiation, and terminal spikelet differentiation) demonstrated that salt tolerance is a stage-specific phenomenon and that tolerance at one stage of growth may not be correlated with tolerance at other developmental stages. **Impact:** The research demonstrated that modern cultivars of rice are more salt sensitive than the obsolete cultivars on which the standards were based. Current salinity guidelines for California-grown rice have been modified and older guidelines have been adjusted based on this work. This research provided tools, guidelines, and management strategies which will minimize yield of agronomic crops irrigated with low-quality waters.

Molecular mechanisms for cover crop influences on agroecosystems. Process level research was conducted to understand the interactions of cover crops within agroecosystems. A network of plant physiologists, plant biochemists, molecular biologists, chemists, plant pathologists, rhizosphere ecologists, nematologists, and entomologists has been developed to determine the chemical signals/toxins and downstream signaling pathways responsible for cover crop influences on plants, the fate of the specific signals/toxins in the soil environment, and the potential role of plant endophytes and soil organisms. Molecular approaches demonstrated that expression of select genes and proteins is enhanced during delayed crop senescence and increased disease tolerance in hairy vetch grown tomato plants. Release of compounds from cover crop residue that can either stimulate or inhibit important weed and pest species was shown to be influenced by the age and management of the tissue. **Impact:** This multidisciplinary team will extend the understanding of mechanisms by which cover crops influence agroecosystems and could lead to more precise management practices for enhancing cover crop use.

Use of particle film to reduce freeze damage. Spring frosts limit the productivity and geographical range of the fruit and vegetable industry. Previously, wind machines and over-head irrigation were the only mitigating practices available to producers to reduce freeze damage. ARS scientists demonstrated that a hydrophobic particle film could separate moisture and dew from the plant surface and prevent ice nucleation on plants and reduce freeze damage. Laboratory and field studies confirmed freeze injury reduction. **Impact:** A patent has been issued and development of applicable technology is progressing under a cooperative research agreement between ARS and the Engelhard Corp. This technology will provide growers another tool to ensure early and consistent crops with reduced reliance on fossil fuels and irrigation resources.

Probem Area Id – Economic Evaluation

Problem Statement: A viable U.S. agricultural sector depends on consistent profitability for the producer. Financially feasible inputs applied at the correct time and in the optimal amount can lead to profitable production if prices and yield are sufficient to cover input costs. Costs of producing crops can be controlled based on an expected yield level, but producers have little direct control over commodity prices. Similarly, producers have no control over weather and can alleviate some weather-related problems such as drought only by adding expensive inputs.

Inputs for production of crop commodities are associated with discrete annual variable and fixed costs. The cumulative value of these costs results in the total cost for a year's production. Profit results when the value of the produced commodity exceeds the value of the cumulative costs for production. To maintain the economic viability of crop production, costs of inputs or adoption of technology must remain below the value of production. Scientists will need to work more closely with economists during the various phases of developing agrotechnologies and systems approaches.

Goals:
- Improve profits and financial stability for individual producers of crops;
- Develop economical integrated crop production practices;
- Develop new and economical integrated crop production systems; and,
- Improve use efficiency of crop production inputs.

Expected Outcomes:
- Reduced inputs associated with high economic risk;
- A continued supply of high quality, safe commodities is economical to produce and market with increased global competitiveness; and,
- Improved financial stability and subsequent sustainability of whole-farm and commodity sectors.

Selected Accomplishments and Impact:

ARS makes every effort to include economic analyses, where appropriate, as described in the accomplishments for Problem Areas Ia – Ic. Additional economic expertise is housed within National Program 207 – Integrated Agricultural Systems – and we anticipate increased collaboration between NP 305 and NP 207 in the future.

Selected Publications – Component I

Integrated Production Systems Publications

Ia - Models and Decision Aids

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Ib - Integrated Pest Management

Armillaria

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1) New Crops/New Uses

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6) Cross Commodity Issues

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Patents

Title	USPTO #	Issue date	Expiration date
Method for Protecting Surfaces from Arthropod Infestation	6027740	22-Feb-00	5-Mar-17
Treated Horticultural Substrates	6464995	15-Oct-02	5-Mar-17
Pesticide Delivery System	6514512	4-Feb-03	2-Oct-20

Component II: Agroengineering, Agrochemical, and Related Technologies

Agricultural enterprises need new and improved technologies that will improve productivity and protect the environment and worker safety and health. To counter rising labor costs and a shrinking workforce, crop production enterprises need new knowledge, techniques, and mechanized equipment in order to remain competitive in a global marketplace. Many crops, especially those produced for the fresh market, still rely almost totally on hand harvest. Increasing world food needs, environmental concerns, and health risks dictate that Agrochemicals and bioproducts be precisely applied by the most efficient and effective methods. Most current chemical application techniques involve movement of the material through the air between a machine and the target site, therefore leading to deposition in unwanted areas. The variety of target locations and weather conditions means that no single application technology is suitable for all situations. Worker safety is always a concern, either from exposure during application or to material residues after application. Regulatory action designed to limit adverse impact of Agrochemicals and bioproducts places restrictions on application that requires either limited use, which could lower yields, or development of new, more effective, and safer application technologies.

Another need in all phases of crop production is agriculture-specific sensors to provide information on which to base management decisions such as the application of inputs, determining the optimum time for harvest, product storage, and processing. Sensors are needed to measure and provide required information to control automated operations and to allow managers to make correct decisions.

The quality and yield of many high-value crops is increased when the crops are grown under controlled environments, and a significant portion of agricultural income now comes from sales of crops grown in these conditions. There is need for information on the design, retrofit, and use of controlled-environment facilities for efficient production.

Agriculture ranks high among occupations in exposure to work-related injury and illness. Concerns for worker well-being, along with regulatory restrictions, place an increased emphasis on worker protection, safety, and welfare.

Problem Area IIa – Automation and Mechanization to Improve Labor Productivity

<u>Problem Statement</u>: The segments of production agriculture that rely on human labor are facing shortages of skilled workers to produce and harvest crops. Rising labor costs and a shrinking workforce place these U.S. industries at a competitive disadvantage in the marketplace compared to producers outside the United States, who have adequate labor at substantially lower cost. Agricultural enterprises facing serious labor shortages and rising costs are fruit and vegetable production and floral nursery and greenhouse operations. Mechanical systems for harvesting some fruit and vegetable crops used for processing have been developed and commercialized, but are still unavailable for many other U.S. crops. New knowledge and techniques are needed to increase labor productivity in producing and harvesting fruit and vegetable crops. Mechanical systems for harvesting fruit and vegetables for the fresh market are nearly nonexistent. For both fruits and vegetables, new cultivars, cultural practices, growth regulators, and Agrochemicals are needed that are compatible with more efficient and effective mechanization practices for production and harvest. Efficient technologies and equipment systems are needed to produce, handle, and harvest most plants grown in nurseries and greenhouses, labor intensive operations for which alternatives have not been found.

Goals:

- Develop ergonomically correct and safe aids that significantly increase labor productivity and decrease task drudgery in producing and harvesting crops, especially for, but not limited to, fruit, vegetable, greenhouse, and nursery crops;
- Develop mechanical harvesting systems to greatly increase labor productivity, reduce costs, and maintain quality, especially for, but not limited to fruit, vegetable, greenhouse, and nursery crops; and,
- Develop automated and robotic systems to improve labor productivity, reduce costs, and maintain quality in producing and harvesting crops, especially for, but not limited to, fruit, vegetable, greenhouse, and floral and ornamental crops.

Expected Outcomes:

- Increased productivity;
- Decreased costs for producing and harvesting crops;
- Increased worker safety; and,
- Optimized harvesting systems.

Selected Accomplishments and Impact:

Trellis tension monitor. A "trellis tension monitor" was developed and patented for automated yield estimation in trellised crops, particularly vineyards. This novel technique involves measurement at 10-second intervals of the tension in the main horizontal support wire of a trellis, so that a continuous record is available to the grower at any moment during the growing season. Change in the tension of a trellis wire reflects change in the mass supported by the trellis, and thus indicates vine growth, fruit growth, and potential yield. This automated method of assessing vineyard status and potential yield is a major departure from longstanding industry standard methods of gathering such information, all of which are either labor intensive and/or provide only an infrequent "snapshot" of the crop. The trellis tension monitor is applicable to any trellised crop. **Impact:** Real-time, continuous measurements of tension in the trellis wire provide growers, wineries, and juice processors with information on the dynamics of crop development. This method, for the first time, makes such measurements economically feasible. With timely information, growers can make equally timely adjustments to their management practices, such as initiating a deficit irrigation regimen to slow vegetative growth. Alternatively, growers can immediately identify any unexpected patterns in fruit development.

Apple conveyer system for fruit orientation. NP 305 scientists developed an apple conveyor system that properly orients fruit regardless of its shape. This technology is a key step in development of an automated apple sorting and grading system. It will increase the cost effectiveness of re-sorting apples for specific markets without damaging the product. Another step toward an automated apple sorting and grading system includes the development of an apple bin filling device that reduces or eliminates bruising. **Impact:** The system for properly orientating apples facilitates the development of an automated grader capable of sensing and eliminating apples with surface defects. This technology has been made available to the apple industry. Commercial packing of apples often involves multiple resorting and movement of apples, with the potential for damage. A novel bin filling device reduces damage to 1-4 percent. This technology is now being used in commercial apple packing businesses.

Mechanical harvesting of cherries. ARS scientists developed and patented a mechanical harvesting system for fresh market stemless cherries. The harvester uses several rapid displacement actuators to release fruit from the trees. To minimize bruising, three inclined scaffolds are used for each cherry tree, to catch the fruit and guide it to collection points. **Impact:** The mechanical harvesting system collected stemless cherries with minimal bruising, equivalent to hand harvesting. This technology will reduce harvesting costs by at least 50 percent and increase worker productivity by 15-fold. Since there is a growing customer demand for stemless cherries, the harvester's impact on the fresh cherry market will increase even more in the near future.

Cotton harvesting and yield monitors. Yield monitors for stripper harvesters were found to be unreliable due to high levels of foreign matter that are normal with stripper harvested cotton. Modification of bur extractors and stripper units on cotton strippers used to minimize foreign matter in stripper harvested cotton provided an improved harvesting system that would minimize foreign matter while maximizing income for producers and ginners. Additionally, defoliation and desiccation techniques were found that significantly reduce chemical cost while maintaining fiber quality and improving economical returns to producers, reducing the cost of ginning for stripper harvester cotton. **Impact:** The cotton industry is adapting to the changing demands of the textile industry, which is now focused primarily overseas. Modified harvesters have shown that fiber quality can profitably be maintained from field to textile mill. Chemicals and defoliants that prepare cotton plants for stripper harvesting reduce input costs while allowing modern high capacity gins to produce a uniform product desired by the world textile industry.

Effects of harvesting time on both cotton quality and boll weevil infestations. ARS scientists found that weather effects, primarily the quantity and length of time that the crop receives moisture, were directly related to delayed harvest dates, affecting yield, fiber and seed quality, and producers' income. Additional research demonstrated the inability of the boll weevil to survive the harvesting, storing, and ginning processes. **Impact:** Cotton producers can now better estimate their losses due to delayed harvest, providing an added incentive to initiating harvest as early as boll maturity allows. The discovery that boll weevils in cotton bales and gin trash are unable to survive the harvesting, storage and ginning process has reduced the cost of shipping cotton to foreign countries by eliminating the need to fumigate cotton bales and thereby opening markets not previously available to U.S. cotton.

Problem Area IIb – Application Technology for Agrochemicals and Bioproducts

Problem Statement: Modern crop production depends on precise delivery of Agrochemicals and bioproducts to ensure the desired biological effect while minimizing adverse impacts on the environment, particularly in adjacent land areas, and on worker health. Crop yields would decrease significantly without use of these products and materials. Increasing world population, environmental concerns, and health risks dictate that these materials be delivered by the most efficient and effective methods. Food Quality Protection Act (FQPA) regulations are placing stringent restrictions on the availability and use of many Agrochemicals and bioproducts. Future regulatory action, such as changes in chemical labeling, may limit delivery options and require new technologies. More recently developed agrochemicals and bioproducts, as well as those in development place greater demand on application processes for optimum effectiveness when compared to older materials.

Applications that occur in controlled environments, such as greenhouses, present increased risks to operators and others involved in plant production in confined environments. Differences in product formulations and handling requirements often require specialized equipment. Application of new biological materials will likely require delivery through newly designed systems or significant modifications to established systems.

When soil conditions and crop foliage prohibit the use of ground machines, aerial application is the only feasible application method. Aerial application permits large areas to be treated rapidly, thus ensuring timely application. Canopy penetration is extremely difficult in some crops and resulting higher pressure or higher volume applications can reduce application efficiency. Air-assisted delivery has shown potential for improving canopy penetration and spray distribution, but is often more expensive than traditional applications. To minimize the need for land being taken out of production because of the need for no-spray buffer zones, applications are being made with coarser sprays to reduce drift.

Goals:

- Define agrochemical handling and delivery factors that enhance viability of biological pest management and the effectiveness of crop production chemicals;
- Relate application parameters to biological impact;
- Develop practical means for assessing and controlling spray drift;
- Develop means to provide site-specific application; and,
- Develop technologies and information to help applicators comply with safety and regulatory requirements.

Expected Outcomes:

- Improved application technologies that increase chemical deposition on target areas and reduce off-target movement;
- Elucidated relationships between spray fate and biological effects;
- Improved canopy penetration and coverage;
- Improved efficiency and effectiveness of applications by determining target surface microstructure and morphology;
- Viable delivery of conventional and biological materials for both above- and below-ground pests, while conserving biological control agents; and,
- Enhanced delivery and effectiveness of crop production and protection materials through incorporation of current and new sensor technology into application systems.

Selected Accomplishments and Impact:

Aerial spray nozzle models. Twenty-two spray nozzle models have been developed and tested in wind tunnel studies conducted by ARS engineers. The model outputs were developed in accordance with a droplet size classification standard produced by the American Society of Agricultural and Biological Engineers. The effective transfer of nozzle atomization models to aerial applicators that use both helicopters and fixed wing aircraft (calibrated in both English and Metric units) through the USDA's website, meetings with customers, and publication of an aerial applicator user manual have greatly benefited the aerial application industry. A PowerPoint training module detailing the state of the art in spray drift mitigation was developed in cooperation with EPA and state extension specialists and was presented to over 1800 agricultural aviation industry participants from October 2002 to May 2005 through multi-state programs of the National Agricultural Aviation Research and Education Foundation's Professional Aerial Applicator Support System (PAASS). **Impact:** These spray models are now being extensively used by aerial applicators in the United States and other countries. The computer models and the published handbook facilitated aerial applicator compliance with EPA regulations for spray drift mitigation and other state regulations already in force. For example, these models are required by the Arkansas Plant Board before any nozzle can be used during an aerial application in Arkansas.

Spray applications of nematodes. To preserve viability of insect-pathogenic nematodes (biocontrol agents) that are applied by spray, NP 305 scientists completed trials and computer simulations to evaluate flow conditions through common types of agricultural nozzles. Four different insecticidal nematode species were identified and tested and empirical models were calibrated for each of the insecticidal nematode species. The models were shown to be able to predict damage to insecticidal nematodes within 5 percent of actual observations. **Impact:** Spray equipment manufacturers and producers of biological agents can use information on sprayer components to optimize equipment choices to achieve the greatest possible viability of the biocontrol agents and enhance the success of pest management programs.

Variable-rate application systems. The use of variable-rate technology for aerial application has seen a major increase during recent years, especially for cotton. Since aircraft typically travel at 150 mph when applying chemicals, it is critical that these systems respond quickly so crop inputs can be applied to the correct field sections according to pre-defined application maps. NP 305 scientists have worked with commercial interests to address two critical areas necessary for evaluation of variable-rate aerial application systems: 1) determination of positioning accuracy represented by the airplane guidance GPS that assists with variable rate aerial application of chemical; and, 2) performance evaluation of a variable-rate flow controller (AutoCal™), which is coupled with the GPS receiver. ARS scientists have overcome the difficult task of determining the dynamic accuracy of the GPS receiver in fast moving aircraft by developing a special ground-based event triggering device that allows determination of dynamic positioning to 0.01 s precision. **Impact:** Results from position testing along with field tests of the flow controller have led to continual improvements of the flow control system software and hardware and have provided data on GPS receiver accuracy. The Autocal™ flow controller is being used by several aerial applicators in the United States and abroad. Aerial flow control technology improvements brought about by this research have been transferred to aerial applicators through Houma Avionics, the controller's manufacturer.

Spray adjuvant effects on spray deposition and drift. Over the past five years, numerous spray drift adjuvants have been introduced into the market reducing off-target spray drift deposition. ARS scientists assessed the ability of those adjuvants to increase spray droplet size and reduce the fine droplet or driftable component of the spray spectrum. Most adjuvants increased droplet size and reduced driftable fine droplets, while three had no effect and five had only minimal effect and were unable to change the spray category from fine to medium. **Impact:** Results from the spray drift adjuvant studies facilitated aerial applicator selection of spray drift retardant adjuvants to mitigate off-target spray drift.

Development of an attracticide bait. NP 305 scientists developed and field tested an attracticide bait (feeding attractant, feeding stimulant, and insecticide combined) for *Helicoverpa* and other destructive noctuid moths in corn and cotton. This bait reduces toxicant use by up to 90 percent over conventional pesticide application. The research projects also optimized ground and aerial application equipment and operational parameters for efficacy. **Impact:** ARS scientists, in cooperation with BioGlobal technical personnel, have tested and defined appropriate ground and aerial application methodologies, formulations, and techniques for optimized use of a reduced-toxicant product. This work helped facilitate the EPA registration process by providing field efficacy data.

Problem Area IIc – Sensor and Sensing Technology

<u>Problem Statement</u>: There is an increasing demand for information technology in all phases of the crop production process. Information is needed about soil, field, crop, and pest conditions, such that management and inputs can be applied in the right place, in the right amount, and at the right time, in order to optimize profit and protect the environment. Information is needed about crop quality parameters for selective harvest, and to monitor quality during storage and processing. Information also is needed to improve the efficiency of crop production operations, to protect the United States food supply from invasive foreign pests, and to facilitate agricultural research and production. Such information can be acquired in a timely and efficient manner using sensors and sensor technology. Sensors are not commercially available for most biological, agricultural, and natural resource needs.

Sensors of importance to crop production include general-use sensors and those tailored to a specific agronomic need. Significant trends and technologies exist to support the adoption of sensors in crop production. Cutting-edge computer technology is available in field-ready configurations and is generally not a limiting factor. GPS data and GIS technology allows accurate geo-referencing of sensor output. Most new agricultural equipment is electronically controlled, facilitating the use of sensed data. Finally, the introduction of precision agriculture systems, and especially combine-yield monitors, has familiarized many producers with electronically-derived information and made them more willing to adopt such information as a basis for management decisions.

Goals:

- Develop and test sensor technology (hardware and software) to be used in pesticide application to ensure appropriate application and delivery to target;
- Develop and test sensor technology for measuring soil and site factors that control water infiltration and movement (*e.g.*, topography, soil physical properties, compaction) to improve water utilization, to manage water drainage and runoff, and to reduce nonpoint source pollution from soil, fertilizers, and pesticides;
- Develop and test sensor technology for determining levels of nutrients in soil and plants;
- Develop and test remote and nontraditional sensor technology (*e.g.*, acoustics) for pest detection and quantification;
- Develop and test sensors for selective harvesting, particularly for fruit and horticultural crops; and,
- Develop and test technology for detection and segregation of GMOs in soil and products, if deemed feasible.

Expected Outcomes:

- New sensors and technologies that increase productivity and decrease costs of crop production;
- Improved ability to detect crop pests at entry points, within fields, or on an areawide basis through the application of sensor technology;
- New sensors and systems that reduce the environmental impact of crop production by facilitating site-specific control of inputs such as nutrients, water, and chemical pesticides;
- Improved harvesting, segregation, and storage systems through the application of sensors for monitoring and control of operations; and,

- Improved ability to monitor regulatory compliance and verify product quality and/or composition through the application of new sensor technology.

Selected Accomplishments and Impact:

Monitoring water and fertilizer use in nurseries. A water and fertilizer monitoring system was developed to study irrigation and fertilizer options for nurseries with pot-in-pot container productions. Various plant species and container medium composts were tested under varied rainfall and climate conditions. Research showed that large amounts of water and fertilizer were lost through drainage with current irrigation and fertilizer practices because of over applying water and nutrients to container-grown plants during a short period of time. Findings from the experimental monitoring system can reduce water use by 40 percent for pot-in-pot nursery production. **Impact:** Four leading nursery companies have used this technology to change their irrigation practices to reduce water use and production costs and to reduce pesticide use by half. The technology also reduces labor costs and minimizes adverse environmental pollutions due to pesticide applications.

Remote sensing with agricultural aircraft. Remote sensing is an established tool for the detection of field characteristics to support crop management decisions. Images representing these characteristics are processed and used for site-specific application of field inputs such as insecticides, herbicides, fertilizers, cotton defoliant, and cotton growth regulators. Remote sensing systems for agricultural aircraft are easy to schedule because the aircraft are already used in agriculture for spraying operations. ARS researchers used an Air Tractor 402B agricultural aircraft fitted with several remote sensing systems to acquire images for use in variable rate applications. Each of these sensing systems can be moved into position using a convenient FAA-approved modular slide rail system and used with GPS receivers for triggering multispectral cameras and for image georeferencing. These stand-alone GPS receivers have been evaluated for positioning accuracy using video mapping and a ground-based event trigger for the airplane. **Impact:** Success has been demonstrated with digital video for the detection of weeds and wild host plants for tarnished plant bug. Digital video has also been used for detection of deleterious constituents in water bodies and detection of the spectral characteristics of catfish ponds to support analysis of cormorant depredation. A radiometric thermal imaging camera is being used to detect the onset of crop water stress along with readings from ground-based infrared temperature sensors (IRTs) and for detection of fire ant mounds.

Problem Area IId – Controlled Environment Production Systems

Problem Statement: Controlled-environment crop production represents a significant portion of agricultural sales, particularly for floral and nursery crops. Growing consumer demand for produce outside of the traditional field crop production season is also increasing demand for greenhouse-grown food crops. While field crop production systems can be relatively easily changed to meet production needs, it is difficult to adapt existing controlled-environment structures to new production needs. The efficiency and productivity of a greenhouse are greatly influenced by its design, which is in turn greatly influenced by location and weather conditions.

Production issues that are common for all structures include air movement for plant health, material handling issues, and sensors and control systems for site-specific production. Additional research is necessary to help producers understand how to optimize production within controlled-environment structures. Taller structures, for example, will trap heat higher above a crop than traditionally shorter structures, and present other air circulation issues that will affect crop health and pest management. Open roof designs that provide plants with more natural growing environments can improve plant production, but further research is needed on the effects of open and/or retractable roofs to improve the efficiency of these designs. It also is imperative that these designs be flexible to accommodate changes in crops and production systems to meet changes in market demands.

Goals:

- Evaluate system components that will enhance ornamental and food crop production within controlled-environments and provide flexibility to meet changing market demands; and,
- Develop techniques that will enhance facility management and handling of crops within new and existing controlled-environment structures.

Expected Outcomes:

- Improved efficiency and effectiveness of production, air movement, energy management, water and nutrient management, and material handling factors within controlled environment production systems.

Selected Accomplishments and Impact:

New strawberry propagation system. NP 305 scientists developed a novel technique to program strawberry plants to flower within four weeks after field establishment. The new transplant propagation technique, using plugs in a controlled environment greenhouse, enables strawberry plants to flower in the fall (early October) without being exposed to artificial short daylength or chilling temperatures. **Impact:** Several growers in the mid-Atlantic coast region are using this propagation technique to produce strawberry transplants that will flower from October to December and again in spring. The cultivars that flower in the fall are being used by a strawberry breeder for generating seedlings which will be evaluated for improved fall flowering and other horticultural attributes. Production of strawberry transplants that flower in the fall and again in spring offers growers in the mid-Atlantic coast region a means to grow strawberries for the holiday season when the price is several times higher than during the traditional spring fruiting season. Short-term cropping systems improve opportunities for farm diversification and help growers to produce a variety of fruit crops for niche markets.

Problem Area IIe – Worker Safety and Ergonomics

Problem Statement: Agriculture ranks high among occupations in terms of the probability of suffering a work-related injury or illness. Regulatory restrictions and concern for worker well-being are placing an increased emphasis on worker protection, safety, and welfare. Regulations dictate that efforts to limit exposure of crop production workers to hazardous agricultural inputs and to physically unsafe procedures must become a priority. Production of many high value crops, including fruits, vegetables, and ornamental plants, often expose workers to repetitive manual operations (*e.g.*, picking fruit and pruning), to physical stresses (*e.g.*, standing on ladders with round rungs while carrying heavy containers), and to pesticide exposure, either during or after application. Fruit and vegetable production is labor intensive, with hand harvesting accounting for half of the total production cost. Little research is being conducted to develop technology that will reduce agricultural worker exposure to risk of injury and illness.

Goals:

- Develop technology for production and processing for crops, especially, but not limited to, fruit, vegetable, and ornamental crops that decrease worker exposure to hazards;
- Develop and test automated technologies for pesticide application that reduce worker exposure to pesticide; and,
- Develop and test methods, equipment, and sensors that best quantify exposure of agricultural workers to safety risks.

Expected Outcomes:

- Pruning, harvesting, and produce delivery systems that decrease worker exposure to injurious repetitive motion hazards and other ergonomic risk factors;
- Equipment and procedures that enhance worker safety and reduce repetitive motion in produce packing and processing operations;
- Automated application technologies that reduce worker exposure to pesticides while maintaining efficacy; and,
- Protective clothing and equipment that will reduce occupational exposure to agricultural applications.

Selected Accomplishments and Impact:

While ARS recognizes that this is an important area of research, Congress has committed no funds to it; and, due to competing research needs and lack of engineering expertise, personnel were not redirected toward this specific Problem Area in the last five years. However, many of the projects discussed in Problem Area IIa-IId inherently reduced producer and worker exposure to pesticides through more precise application of pesticides and the development of biological alternatives to conventional pest control materials. Also, the development of automated sorting and grading equipment will reduce worker exposure to manually intensive operations that are usually done in close proximity to moving machinery. A new ARS initiative in the next five years on mechanization, if funded, will expand our effort in this area.

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Component III: Bees and Pollination

Managed bees are vital to U.S. agriculture. The commercial production of more than 90 crops, including almond, apple, citrus, cherry, blueberry and squash, as well as numerous seed crops are accomplished through bee pollination. The honey bee, *Apis mellifera,* is our most important agricultural pollinator. In addition to the $300 million of honey, beeswax, and other hive products produced annually, crop growers rent more than two million honey bee colonies every year to assist in the pollination of a wide variety of crops with an added market value exceeding $15 billion. Honey bees, however, are threatened by a myriad of pests, parasites, and pathogens, including viruses, bacteria, fungi, protozoa, the small live beetle, and two species of parasitic mites. Alone, the parasitic mite *Varroa destructor* has devastated beekeeping operations nationwide, driving production costs sharply higher and reducing the availability of honey bees for pollination. The bacterium responsible for American foulbrood disease of honey bees puts all colonies in the United States at risk, and a newly introduced beetle pest that attacks honey bee colonies and bee products causes other persistent and often severe problems. The movement and transport of managed bees for commercial pollination purposes pose additional problems and risks to colonies. Lack of suitable nutrition, particularly during times of transport, results in weakened colonies that are more susceptible to parasites and diseases and less effective pollinators. Migratory honey bee colonies in the southwestern United States and California face an additional challenge from feral populations of Africanized bees which can invade hives and replace managed colonies of European bees.

Honey bees are not the only bee species, and there is a growing niche for the use of some of the other species for pollination, such as, bumble bees, alfalfa leafcutting bees, and orchard bees (collectively referred to here as non-*Apis* bees). Some species may be used to pollinate specific crops or can be used in greenhouses. Some bee species are threatened by a shrinking native habitat and lack of information about their biology and bionomics. The ultimate goal is to integrate fundamental and applied research efforts to improve the health and sustainability of native and non-native pollinators, thereby contributing to the vitality of the U.S. agricultural sector that depends on bee pollination.

Problem Area IIIa – Pest Management

Problem Statement: The *Varroa* mite is a large external parasite that develops primarily on immature brood. *Varroa* has become such a serious problem that it is virtually impossible to maintain honey bee colonies without chemical treatments to control infestations. The close association between mite and honey bee makes chemical control difficult, a problem exacerbated by the potential for pesticide-contaminated honey and beeswax and the development of mite resistance to any chemical control. In addition, *Varroa* mites are suspected of being involved in the transmission of honey bee viruses. The tracheal mite *Acarapis woodi* is a microscopic parasitic mite that inhabits the respiratory tubes of adult bees. Infestations are seasonal in nature and difficult to detect, since detection requires dissection and microscopic examination of bee tissue. American foulbrood disease is a devastating disease of honey bee larvae, caused by the bacterium *Paenibacillus larvae*. Bacterial resistance to terramycin (oxytetracycline), the only antibiotic approved for foulbrood prevention and control, is widespread across the United States, contributing to the urgent need for alternative controls. The small hive beetle (*Aethina tumida*), an invasive species that is a pest of both honey bees and their hive products, has been found in 13 states, and its spread is imminent due to movement of beetle-infested colonies by migratory beekeepers and the shipment of bees used to establish new colonies. Several species of fungi, collectively causing "chalkbrood" diseases, affect both *Apis* and non-*Apis* bees. Non-*Apis* bees have a number of pest problems, some that may be mitigated by better housing and management systems.

Goals:

- Develop new integrated pest management (IPM) control strategies for *Varroa* mites;
- Identify and develop effective chemical and non-chemical controls for the bacterium that causes American foulbrood disease;
- Develop effective chemical and non-chemical treatments for the small hive beetle;
- Determine the economic impact of honey bee viruses and develop diagnostic tools for their identification;
- Develop effective controls for tracheal mites; and,
- Develop effective methods for controlling chalkbrood in bees, especially for the alfalfa leafcutting bee.

Expected Outcomes:

- A combination of biological, molecular, genetic, chemical, and non-chemical approaches to control parasites, pests, and pathogenic organisms of honey bees and non-*Apis* bees that will reduce our reliance on synthetic pesticides; and,
- Diagnostic techniques to monitor colony health, thereby affording appropriate and timely treatment decisions.

Selected Accomplishments and Impact:

Chemical control of *Varroa*. With resistance to fluvalinate and coumaphos (respective active ingredients in the miticides Apistan® and Checkmite+®) well-documented across the United States, there is an urgent need to develop new *Varroa* controls in the short term, until non-chemical methods prove effective and gain widespread acceptance. ARS scientists evaluated Apiguard®, a patented, commercial miticide consisting of a slow-release formulation of thymol. While the product requires two successive treatments and is most effective within a specified temperature range, field evaluations showed efficacy of > 95 percent, equal to the control offered by Checkmite+®. **Impact:** This thymol-based product could substitute for other miticides that have become less effective or ineffective, and the use of Apiguard® will contribute to the viability of U.S. beekeeping.

Heptanone to control *Varroa* mites. ARS scientists found that a compound (2-heptanone) made by bees in the hive during comb building is a very potent miticide. The compound also stops honey bee robbing behavior and prevents wax moths from destroying stored comb. A U.S. patent was awarded for the use of 2-heptanone to control mites and other honey bee colony pests. ARS scientists have been conducting experiments with a new delivery system composed of a thin strip, designed by ARS, that releases 2-heptanone in colonies for 42 days to control *Varroa* mites. The strip is composed of microencapsulated 2-heptanone coated with a mixture of sugar and wax. The bees tear the tablet apart and thus release the compound. In pilot tests, certain formulations caused mite mortality rates that were comparable to commercially available miticides used on non-miticide resistant populations. **Impact**: Commercial production of 2-heptanone will provide a new method to control *Varroa* that is both biodegradable and leaves no residues in the wax or colony equipment. The compound also can provide new methods to prevent robbing behavior in colonies and prevent comb destruction from wax moths.

Formic acid to control parasitic mites. ARS scientists developed a gel formulation of formic acid to control *Varroa* and tracheal mites, and devised a delivery system for the gel that was easily integrated into existing bee management practices. The gel formulation was safer to handle than liquid formic acid and the slower release rate required fewer applications than its liquid counterpart. A U.S. patent was awarded and the product was licensed and marketed, although problems with manufacturing and packaging led to the withdrawal of the commercial product from the market. **Impact:** While the ARS-designed gel product was withdrawn from the market by the licensee, the concept put forth by ARS scientists of using a gel formulation coupled with a slow-release delivery system has been exploited by other companies. Currently, NOD Apiary Products, Ltd. offers a slow-release formulation of formic acid (Mite-Away II™) to beekeepers for parasitic mite control.

Bee breeding and stock improvement for parasitic mite control – ARS Russian honey bees. Russian honey bees that exhibited resistance to *Varroa* were imported by ARS scientists through quarantine into the United States, and after extensive evaluation, were found to have variable but useful resistance to *Varroa*, excellent resistance to tracheal mites, and excellent ability to overwinter in even the extremes of northern locations. Scientists evaluated over 170 queen lines in single colony or multi-colony tests in several states for possible inclusion in a breeding program. Eighteen premier queen lines were selected and retained for a breeding program designed to improve the overall economic value of the stock. In conjunction with this breeding program, ARS Russian honey bee research has shown that: 1) Russian honey bee resistance to *Varroa* results from several mechanisms that act in concert; 2) Russian honey bee resistance to *Varroa* is enhanced in apiaries having only Russian colonies; 3) *Varroa* populations develop more quickly in shaded apiaries, while honey production is greater in sunny apiaries; 4) hybrid colonies have commercially-useful levels of *Varroa* resistance; and, 5) the excellent overwintering abilities of Russian honey bee colonies is in part due to their excellent tracheal mite resistance. The best ARS Russian honey bee stocks have been transferred to the beekeeping industry through a Cooperative Research and Development Agreement (CRADA) in which the cooperator produces breeder queens and distributes them to queen breeders and honey producers that in turn produce production queens for sale or for their own use. **Impact:** The ARS Russian honey bee program has afforded to U.S. beekeepers a stock of honey bees that requires little or no management to control *Varroa* mites, no management to control tracheal mites, and that survives winters very well. The

ARS effort directly impacts the availability of bees for U.S. crop pollination, since the availability of Russian colonies for pollination is stable regardless of the development of mites resistant to miticides.

Bee breeding and improvement for parasitic mite control – SMR/VSH trait. Complementing the ARS "Russian bee" breeding program is research designed to make other commercially favored honey bees resistant to *Varroa* mites by increasing the frequency of mite-resistant genes. By carefully monitoring the mite's life cycle, ARS scientists were able to select colonies that maintained low levels of reproductive *Varroa*. They originally termed this heritable trait "SMR" (for suppression of mite reproduction), because they believed that immature bees, upon which the mites developed, were somehow increasing the infertility of female mites and thereby interfering with the mite's ability to produce offspring. However, recent investigations revealed that the adult bees from these colonies were hygienic – able to detect and remove *Varroa*-infested pupae from capped brood cells, and that bees with this trait preferentially remove brood infested with mites that are reproductive. The trait has been subsequently named "VSH" (for *Varroa*-sensitive hygiene) and it has been demonstrated to confer strong resistance to *Varroa*. The VSH trait has been released to the United States beekeeping community through a CRADA with commercial bee breeders and to scientists in the United States and Canada for further evaluation. **Impact:** The VSH trait is highly desirable since a significant level of resistance is retained when commercially-reared VSH queens are free-mated with unselected drones (males). Therefore, strict mating control of VSH queens is not needed and the trait can be added to any desired stock of honey bees. This accomplishment, along with the ARS Russian bee accomplishment, reduces reliance on synthetic pesticides and impacts the availability of honey bees for pollination purposes.

Other non-chemical methods to reduce *Varroa* populations – Screened bottom boards. *Varroa* mites that become dislodged from adult bees often fall to the hive bottom ("bottom board") and can reattach to other adult bees that are entering and leaving the colony. ARS scientists discovered that a small physical separation (1.5 in.) between mites and honey bees could prevent mite reattachment. Scientists designed and constructed a "screened bottom board" through which dislodged mites fell into a "dead space" devoid of bees, thereby preventing reattachment. Laboratory and subsequent field-testing indicated mite populations could be reduced anywhere from 15 percent to 40 percent using the screened bottom board. **Impact:** This "low-tech" approach to mite control using relatively inexpensive materials was transferred to the bee industry in a series of articles appearing in honey bee trade journals. The ARS screened bottom-board, or variations thereof, is currently being sold by many major distributors of beekeeping supplies, and it offers a method of reducing *Varroa* populations without the use of chemicals.

New antibiotic to control American foulbrood disease. To mitigate the threat of oxytetracycline-resistant *Paenibacillus larvae,* causal agent of foulbrood disease of honey bees, ARS scientists undertook an ambitious effort that resulted in FDA approval of tylosin tartrate and the availability of a commercial product, Tylan®. The effort included *in vitro* laboratory screenings of numerous alternative antibiotics, meeting with U.S. Food

& Drug Administration (FDA) regulatory officials to understand requirements for approval of new products, designing protocols, and conducting field research focusing on target animal safety, efficacy, and residues in honey, and submitting all research data and analyses to FDA for scientific review. ARS scientists also worked with the Regulatory Affairs division of Elanco Animal Health, and played a crucial role in Elanco's New Animal Drug Application (NADA) submission by supplying wording for the product label, which included Mixing Directions, Directions for Use, and Residue Warnings. On October 20, 2005 the FDA approved Tylan® (tylosin tartrate) Soluble for the control of American foulbrood disease of honey bees. **Impact:** Information submitted to the FDA by ARS scientists was subsequently requested by personnel of Agriculture and Agri-Food Canada to support official Canadian registration of this antibiotic. By supplying a new antibiotic to control this devastating disease of honey bees, ARS scientists have made available a means to protect the nearly four million bee colonies at risk in North America.

Non-chemical approaches to control American foulbrood disease. While U.S. beekeepers and the bee industry tend to rely upon chemical solutions in the near term, the use of antibiotics is costly and can foster bacterial resistance. To reduce reliance on antibiotics, ARS scientists have utilized molecular approaches to examine the underpinnings of bee disease and bee immunity, focusing on the causative agent of American foulbrood disease. Scientists have developed a laboratory assay for immune responsiveness and survival of honey bee larvae exposed to the American foulbrood bacterium, have identified numerous candidate genes and a novel receptor, and developed a large-scale breeding program to determine the extent to which resistance to foulbrood disease is heritable. They have also identified non-pathogenic bacteria that can induce an immune response in honey bees that is effective against challenge with the foulbrood bacterium. **Impact:** The bioassay and genetic screen for immune responses is now being used to test U.S. honey bee stock for exploitable variations in this trait. The potential role of using non-pathogenic bacteria as a management tool was featured in the honey bee trade journal *Bee Culture* and is generating interest among beekeepers as a future treatment strategy. Identification of receptors involved in the immune response will contribute to the development of novel methods to increase honey bee resistance to microbial pathogens.

Epidemiology and transmission of honey bee viruses. While numerous honey bee viruses are known to exist, their epidemiology and pathogenesis are poorly understood. Using cutting-edge molecular approaches, ARS scientists have developed rapid, accurate, and sensitive methods capable of detecting and identifying as many as six honey bee viruses in a single bee or parasitic mite. These molecular techniques have proven to be powerful tools resulting in: 1) unequivocal evidence that the parasitic *Varroa* mite is a capable and efficient vector of bee viruses and that uninfected mites are able to acquire virus from association with infected mites; 2) the first report of deformed wing virus (DWV) in the United States, quantification of this virus in different life stages of the bee, and the conclusion that overt symptoms (*i.e.,* deformed wings) are a function of virus levels and not merely the presence or absence of virus; and, 3), the finding of an alternate route of transmission, namely that viruses can be transmitted vertically from the queen bee to her offspring. **Impact:** The strong correlation between *Varroa* mite infestation levels in bee colonies and the risk of virus infection has emphasized to the beekeeping community, at large, the crucial need for effective mite controls. ARS research on honey bee viruses has been incorporated by the USDA Animal & Plant Health Inspection Service (APHIS) into documents regarding the importation of honey bees, and a technical protocol, "Detecting Honey Bee Viruses," has been drafted by ARS scientists and added to APHIS risk assessment reports.

Non-chemical control for small hive beetle in the field. ARS scientists have developed trapping systems for monitoring and control of the small hive beetle in the field. The systems are based on ARS identification of a yeast (carried by the small hive beetle) that releases potent attractants for the beetle when it ferments pollen collected by honey bees. **Impact:** Using the "in-hive" trapping system, as many as 25,000 adult and larval beetles were captured from 4-frame hives in as little as two weeks. In early trials, the decline of bee populations in severely infested hives, at the point of collapse, has been reversed and the hives have become functional again in as little as three weeks. The system is currently being tested by commercial and hobby beekeepers in Florida and a patent has been applied for by USDA.

Non-chemical control for small hive beetle in the 'honey house.' In addition to attacking bee colonies, the small hive beetle can have a negative economic impact by infesting honey comb before honey extraction, rendering it unusable. While investigating basic beetle biology in the laboratory, ARS scientists examined the temperature/humidity requirements for beetle life stages and demonstrated that low humidity (<50 percent) inhibits the hatchability of small hive beetle eggs. This observation was field-tested in 'honey houses' – indoor facilities where honey is stored prior to extraction – operated by commercial beekeepers in Florida. By simply circulating air through stacks of stored honey and thereby reducing the humidity, hive beetle damage was eliminated. **Impact:** This cultural control method of lowering the humidity in stored honey provides commercial beekeepers with an inexpensive, non-chemical control measure to limit the economic impact of this invasive beetle pest.

Epidemiology and control of chalkbrood disease in alfalfa leafcutting bees. "Chalkbrood" is a disease caused by fungi in the genus *Ascosphaera* that attack honey bees and non-*Apis* bees, particularly the latter. Although less of a problem in honey bees than the pests mentioned above, chalkbrood is a serious disease of non-*Apis* bees. Alfalfa seed is an important crop in western North America and the alfalfa leafcutting bee, *Megachile rotundata,* is specifically managed for alfalfa pollination. Chalkbrood disease is such a problem for these bees that U.S. alfalfa seed producers and growers must purchase and import about 50 percent of their leafcutting bees annually from Canada, where the disease is thought to be less prevalent. ARS scientists partnered with alfalfa seed producers and commercial pollination providers from different growing regions in an effort to understand the epidemiology of chalkbrood disease. Results indicated that mortality of immature managed bees was disproportionately higher than laboratory-reared bees, which led to a review of existing management practices. ARS scientists compared the different on-farm methods for disinfecting bee nesting boards and other equipment used to rear bees and concluded that these management practices were inadequate to control chalkbrood. Scientists subsequently screened a series of fungicides for efficacy in controlling chalkbrood and found Rovral® (iprodione) to be both effective and of low toxicity to the bee larvae. **Impact:** A better understanding of the epidemiology of chalkbrood disease has led to improved bee management techniques and increased production of alfalfa leafcutting bees. Since pollination currently accounts for 20 percent of alfalfa seed production costs, any reductions can significantly improve the overall economics of production.

Problem Area IIIb – Bee Management and Pollination

Problem Statement: The management of domestic bee colonies for honey production and/or pollination is labor intensive and time-consuming. Assessing overall colony health, applying various treatments to combat disease or parasites or to supplement nutrition, and manipulating the hive for maximum productivity, involves opening and examining each and every individual colony. Modern migratory beekeeping, where hundreds to thousands of colonies are placed on pallets and moved by flatbed trucks over huge areas of the United States causes additional stresses on bees. Lack of suitable nutrition, particularly during times of transport, results in weakened colonies that are less effective pollinators. The Africanization of European honey bee colonies has become problematic in major pollinating areas of the United States from Texas to California and is essentially a management problem. The reproductive capability of every honey bee colony relies on the queen, and her health directly impacts colony survival. Beekeepers across the United States are concerned that the quality of queens – and the subsequent bees she produces – is not as high as it once was. Many honey bee queens die during shipping, are not being as readily accepted by colonies at installation, and are being superseded (replaced) at an unacceptable rate. The inability to effectively store honey bee germplasm in the form of eggs and semen makes it difficult to keep viable stocks available for long periods and to select genetic stocks that are resistant to mites and diseases.

The management of non-*Apis* pollinators poses a separate set of problems. Nesting materials, shelters, and rearing techniques have been well developed for the alfalfa leafcutting bee, and are commercially available, but methods for producing other important pollinators, such as the blue orchard bee and bumble bees are not so well developed. Furthermore, these bees have their own set of disease and parasite problems that needs to be addressed. The huge diversity of native bees has essentially been unexplored, particularly with regard to the plants and crops they visit and pollinate. The systematics, or classification, of many important pollinator groups is inadequate. Many species are still undescribed, and the relationship between species and between groups of species, remains unresolved.

Goals:

- Identify nutritional deficiencies that contribute to honey bee colony decline during pollination and develop improved nutritional supplements;
- Determine factors that contribute to European bee colony takeover by Africanized bees;

- Determine factors that contribute to decreased survival of queens and worker bees, and mitigate these factors;
- Develop and optimize germplasm storage technology for honey bee semen and eggs;
- Identify factors such as nesting materials, rearing and cultural techniques, and crop management practices that contribute to the improved sustainability of non-*Apis* bees;
- Develop and demonstrate new pollination techniques and pollinator management systems that will improve farm profitability and contribute to the management and sustainability of native plants in our western rangelands; and,
- Develop modern phylogenies and taxonomic revisions of bee species in order to document bee pollinators in the United States and their biological traits, select and accurately identify candidate crop pollinators, and create user-friendly tools for identifying bees.

Expected Outcomes:

- New practices for bee management that will improve overall bee health and sustainability, and supply improved pollination systems for our nation's farmers, including supplemental feeding to prevent colony decline;
- Improved methods of honey bee queen production, shipping, and introduction, and the development of indicators of queen quality and survivorship;
- New bee species that will facilitate development of new pollinators for specialized situations such as greenhouses, wildland seed crops, and the protection of threatened and endangered native plants;
- Availability of pollinators for crops that currently are not able to obtain adequate numbers of pollinators, such as California almonds;
- Reduced threats caused by Africanized bees; and,
- New technologies for preservation of honey bee germplasm, namely eggs and semen.

Selected Accomplishments and Impact:

Development of an artificial diet for honey bees. Commercial honey bee colonies that are transported over large distances for contract pollination often suffer from lack of pollen and nectar resources. An artificial diet that can be fed to colonies during these periods or when flowering plants are generally unavailable is essential for supplying growers with strong colonies for pollination. ARS scientists and their CRADA partners have addressed the needs for a dietary supplement and have developed and formulated a liquid protein diet for honey bees. Scientists have shown that bees will consume this diet and rear brood using it as the sole food source and developed a powder formulation of this diet to reduce production and shipping costs and have showed that the powder can be reconstituted with tap water at room temperature, is highly palatable to honey bees, and is as effective in building colony populations as the original liquid diet. Fed the liquid diet, honey bees maintained hemolymph protein levels that were significantly higher than bees fed other commercial diets currently available, allowing the bees to live as long as those fed pollen. A patent has been filed for the diet formulation, and commercial production will hopefully begin within a year. **Impact:** Supplying beekeepers with an inexpensive and easy to use artificial diet can help ensure that strong, populous colonies are available for pollination. All facets of the United States beekeeping industry will benefit from this accomplishment, since the diet will enable colonies to rear brood during pollen and nectar dearth, thereby building bee populations earlier in the spring and thus creating healthy, robust bees for pollination.

Mitigation of takeover (usurpation) of European bee colonies by Africanized honey bees. A major problem facing commercial beekeepers, particularly when transporting colonies throughout the southwestern United States, is the Africanization of their European honey bees. European honey bee queens that mate with Africanized drones produce offspring with defensive behavior comparable to pure African honey bees. Africanized bees can invade European colonies and replace the European queen with an Africanized queen, which results in an immediate change in the colony's behavior. Furthermore, once a European colony becomes Africanized, it is difficult to introduce European queens successfully using traditional requeening techniques. ARS scientists and their collaborators have identified several factors that contribute to the loss of European colonies in areas where Africanized bees have immigrated. These factors include: 1) use by European queens of Africanized rather than European drone sperm resulting in the production of a majority of Africanized workers; 2) a shorter developmental period for Africanized queens compared to European queens, with workers preferring the Africanized queens; 3) "intermorphs" (female bees with characteristics of both workers and queens) in Africanized colonies that may play a role in usurpation; and, 4), European colonies that go queenless, have confined queens (unreleased queens during management requeening), or that when recently requeened, are overtaken by Africanized bees in the fall of the year. Scientists have also identified a queen-specific volatile compound that may play a role in queen acceptance. **Impact:** Recommendations on fall requeening of European colonies in Africanized areas that include methods to detect and prevent colony invasions have been made to the U.S. beekeeping community. We anticipate other research results will foster additional protocols and recommendations to prevent usurpation of European colonies.

Impact of miticides on honey bee queen development. There is a growing concern among honey bee queen breeders, and beekeepers in general, about queen health and productivity. This concern appears to coincide with the growing use of synthetic pesticides to control infestations of parasitic mites, since these pesticides are persistent and accumulate in beeswax, and, queens, because they are long-lived, may face considerable exposure. ARS scientists investigated the impact of coumaphos, a widely-used pesticide used to control *Varroa*, on queen development by rearing immature female bee larvae destined to be queens in "queen cups" (wax cells used to rear queens) containing known amounts of this pesticide. Monitoring acceptance, emergence, weight and other parameters indicative of bee "health," scientists found that coumaphos residues in beeswax adversely affected queen development. Queens exposed to coumaphos at 1000 ppm did not develop, and less than 50 percent of the grafted queens emerged at 100 ppm, the tolerance established by the U.S. Environmental Protection Agency (EPA) in beeswax. **Impact:** The deleterious effect of coumaphos on queen development demonstrates that careful monitoring of residue levels in beeswax is necessary to produce viable queens. This information has been transferred to the bee industry through trade publications and numerous presentations at bee meetings.

Germplasm preservation. Genetic diversity in U.S. honey bee populations has declined, in large part due to the introduction of parasitic mites that have decimated both managed and feral (wild) honey bee populations. The U.S. beekeeping industry is in need of germplasm preservation technology to facilitate selection of mite- and disease-resistant stocks and to bolster the genetic diversity of breeding populations. ARS scientists have embarked on a program to develop suitable protocols and techniques for the preservation of honey bee semen and embryos. To date, scientists have developed a fluorescent staining technique that allows for the direct assessment of honey bee semen (percent live vs. dead) and have used this technique to determine the minimum level of viable sperm necessary for artificial insemination (AI) of honey bee queens with preserved semen. This research has shown that honey bee queens inseminated with >50 percent live sperm had normal brood production for at least one season. ARS scientists also demonstrated the unique durability of honey bee semen stored at ambient temperatures and showed that the standard techniques currently employed for collecting and mixing sperm for use in honey bee AI programs reduced the viability of that sperm. **Impact:** Revised protocols for centrifugation of semen for AI programs have been published and are being adopted. Based on ARS findings, a number of queen breeders have adopted ambient storage techniques to provide flexibility for collection and use of semen at time intervals out to one week post-collection. The preservation of honey bee eggs has proven more difficult and no protocols that allow successful cryopreservation (freezing) of embryos have been established to date.

Management practices for promoting pollination by the blue orchard bee. The blue orchard bee, *Osmia lignaria,* is a solitary bee native to western North America and is a highly efficient pollinator, with a strong preference for nut and fruit trees. Using these bees for pollination, ARS scientists have demonstrated that commercial cherry harvests can be increased by over 50 percent. The lack of an inexpensive, durable, commercial nesting block coupled with lack of availability of large populations of blue orchard bees are the two most important factors limiting the expansion of this superior pollinator and its use in mainstream agriculture. ARS scientists: 1) conducted extensive fundamental and applied research on blue orchard bee biology, including wintering requirements, incubation temperature regimes, diapause induction and development, and fungicide toxicology related to sprays during crop bloom; 2) optimized rearing methods by developing, patenting, and licensing an affordable polycarbonate-based, "Solitary Bee Nesting Block" for the blue orchard bee and are seeking a patent for a complementary "Solitary Bee Emergence Box," which allows for the improved control of pollinator emergence during the bloom period of many early spring fruit crops such as almonds and cherries; 3) demonstrated that meadowfoam, *Limnanthes alba*, an oil-seed crop produced in the Willamette Valley of Oregon, is an excellent forage crop that can be used to increase the production of blue orchard bees; and, 4), showed that successful pollination of many crops requires only about 250 to 300 female blue orchard bees per acre. The ARS effort culminated in the publication of an 88-page manual entitled “How to Manage the Blue Orchard Bee as an Orchard Pollinator." **Impact:** The development of a simplified and standardized system for managing blue orchard bees fosters the use of this bee as a reliable pollinator of U.S. crops, including the expanding California almond crop. The diversification of our agricultural pollinator portfolio should increase profitability for U.S. growers.

Pollinator diversity and the restoration of wildlands. While managed bees are critical to U.S. agriculture, little is known about the abundance and diversity of native, wild bees that not only contribute to crop pollination, but also maintain the diversity of our native plant species. In addition, U.S. government agencies such as the Bureau of Land Management and the U.S. Forest Service annually seek tons of seed from native wildflowers for revegetation of rangelands and other wildlands, but are stymied by the exorbitant price of hand-collected wild seed. Little is known of the bees that pollinate these wildflowers, nor if particular species of bees can be managed on a commercial scale to produce seed. Based on comprehensive biological surveys of six different ecosystems, including the eastern Mojave Desert in Nevada, Yosemite National Park in California, and the Dugway Proving Grounds and Grand Staircase-Escalante National Monument in Utah, ARS scientists have conducted one of the most complete pollinator surveys on record and assembled the largest systematic data set on local and regional bee species in the world. Six hundred and forty three bee species were discovered within the Grand Staircase-Escalante National Monument, alone. The overall dataset included a record of flowers that bees were collected from, thus revealing the patterns of specialization and generalization among bee species and pollination activity in native plants. ARS scientists have also investigated the feasibility of agricultural production and marketing of wildflower species native to the Great Basin and adjacent ecological regions. Two plants, basalt milkvetch and royal penstemon, were found to attract potentially manageable pollinators (*e.g.*, mason bees and bumble bees), and, in collaboration with several seed growers, researchers now have plants in trial production. **Impact:** ARS survey information will assist land managers in their efforts to conserve bees and the pollination services that native bees provide, as well as establish baseline information to assess current and future impact of human activities on lands under Federal management. The development of farm production systems for wildflowers and other native plants necessary to restore our rangelands will achieve two goals – providing the necessary seed for land managers and a potential new income for U.S. farmers.

The honey bee genome project. ARS scientists played a crucial role in the selection of the honey bee for genome sequencing by the National Institutes of Health (NIH), in directing the genome project, and in the annotation process. Scientists were involved in the coordination of an international team of researchers, testing many of the candidate genes developed in this project, and identifying those showing promise for marker-assisted breeding and for characterization of healthy honey bees. In addition, ARS scientists successfully implemented systemic gene silencing (RNAi) in honey bees. **Impact:** Genes described by the bee genome project are now being used by researchers to determine the causes of beneficial (*e.g.*, reproduction, queen production, and immunity) and detrimental (*e.g.*, defensive behavior) traits in honey bees. Marker-assisted breeding using these traits will help in the development, verification, and maintenance of honey bee stock with desirable traits, and is already being used to confirm stress and disease pressures on U.S. honey bees. This information is relayed to regulators and other scientists in order to predict and mitigate new threats to bees. Most importantly, this project has established the honey bee as a model in research, attracting over 100 researchers to the field, with over 40 publications in prestigious journals spinning off of this effort in 2006 alone. This critical scientific infrastructure should greatly accelerate progress in finding solutions to problems of concern to beekeepers. Further, use of the RNAi technique will allow researchers to investigate involvement of a specific gene (*e.g.*, genes for resistance to diseases and parasites, reproduction, or ability to pollinate crops) by turning off the expression of that gene of interest and observing the effects on the bee.

Healthy bees for almond pollination. One of the advantages of the ARS distributed network of laboratories and expertise is our ability to coordinate a national response to issues of concern to industry. *E.g.,* representatives of the bee industry came to ARS in early-2006 with a problem: There are insufficient bees for early-season almond pollination in California. Responding, we hosted a meeting of ARS and university bee researchers, together with industry representatives, in Lincoln, Nebraska, in August 2006, and developed a testable program to determine if technologies and management tools are adequate to produce healthy bee hives for this use. The ARS Administrator has funded this effort, and research will commence in October 2006. This mini-areawide project will focus on preventing *Varroa* mite destruction of the colonies (using mite-resistant Russian bees developed at Baton Rouge), while building up colony health through feeding colonies various pollen-substitute diets (which were just patented by ARS Tucson) throughout the winter. The work will involve researchers from all four honey bee labs (Baton Rouge, Beltsville, Tucson, Weslaco) and cooperation from beekeepers. **Impact:** This project responds directly to the key expressed need of the bee industry (bee decline), involves the bee industry in solving the problem, addresses the shortage of bees for almond pollination, and uses recent discoveries by ARS beekeepers in a combined approach to see if, despite pressures on beekeeping, healthy bees can be raised with current technology.

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IIIa - Bees and Pollination

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ARS Research Projects

Location	Project Number and Title	Scientists (P= Principal Investigator)	Project Start Date
Arizona			
Tucson	#5342-21000-014-00D, Improving Crop Pollination Rates by Increasing Colony Populations and Defining Pollination Mechanisms (N)	Hoffman, Gloria D. (P) Sammataro, Diana Vacant	10/23/2004
Maricopa	# 5347-21410-004-00D, Evaluation, Improvement, and Development of New/Alternative Industrial Crops (C)	Coffelt, Terry A. (P) Dierig, David A.	7/24/2003
California			
Davis	# 5306-13210-001-00D, Sustainable Floriculture Production (N)	Jiang, Cai Zhong (P)	9/01/2002
	# 5306-21220-003-00D, Sustainable Management of Grapevine Diseases and Weeds (C)	Baumgartner, Kendra (P) 1 Vacant Steenwerth, Kerri Kluepfel, Daniel A.	3/14/2003
Riverside	# 5310-13210-008-00D, Salinity and Trace Element Management in Irrigated Agricultural Systems (C)	Grieve, Catherine M. (P) Wilson, Clyde 1 Vacant	12/23/2001
Georgia			
Tifton	# 6602-22000-036-00D, Sustainable Systems for Integrated Pest Management and Conservation and Enhancement of Natural Enemies (C)	Tillman, Patricia G. (P) Olson, Dawn Marie Lewis Wallace John	10/01/2005
Dawson	# 6604-13210-003-00D, Develop and Transfer Irrigated and Non-Irrigated Peanut Management Systems and Technology (N)	Sorensen, Ronald B. (P) Nuti, Russell Lamb, Marshall C.	10/22/2003
Byron	# 6606-21220-009-00D, Pecan Cultivation and Disease Management (N)	Wood, Bruce W. (P) Reilly, Charles C.	11/21/2003
Louisiana			
Baton Rouge	# 6413-21000-010-00D, Breeding, Genetics, Stock Improvement and Management of Russian Honey Bees for Mite Control and Pollination (N)	Rinderer, Thomas E. (P) De Guzman, Lilia Villa, Joseph D. Sylvester, H. Allen Danka, Robert G. 1 Vacant	10/01/2003
	# 6413-21000-011-00D, Development and Use of Mite-Resistance Traits in Honey-Bee Breeding (N)	Danka, Robert G. (P) Harris, Jeffrey W. Sylvester, H. Allen Rinderer, Thomas E. 1 Vacant	10/01/2003
New Orleans	# 6435-21000-011-00D, New and Improved Cultural Practices for Sustainable Sugarcane Production and Environmental Protection (N)	Johnson, Richard M. (P) Richard, Jr., Edward Viator, Ryan P.	10/01/2003
	# 6435-22000-012-00D, Developing Integrated	White, William (P)	5/17/2005

	Weed and Insect Pest Management Systems for Efficient and Sustainable Sugarcane Production (C)	Richard, Jr., Edward	
Maryland			
Beltsville	# 0500-00044-001-00D, Area-Wide Management of Agricultural Pests (C)	Faust, Robert M. (P)	11/15/2005
	# 1265-12210-001-00D, Management of Cover Crops for Enhancement of High Value Cropping Systems (C)	Teasdale, John R. (P) Coffman, Charles Roberts, Daniel P. Devine, Thomas E. Krizek, Donald T.	9/12/2003
	# 1275-21000-174-00D, Managing Diseases and Pests of Honey Bees to Improve Queen and Colony Health (N)	.Pettis, Jeffery S. (P) Evans, Jay Daniel Chen, Yanping	9/10/2003
	# 1275-21000-175-00D, Small Fruit Crops in Sustainable Production Systems (N)	Turechek, William (P) Wang, Shiow Ying	11/16/2003
	# 1275-21220-212-00D, Preservation of Honey Bee Germplasm (N)	Collins, Anita M. (P)	9/10/2003
Minnesota			
Morris	# 3645-11000-003-00D, Soil Carbon Cycling, Trace Gas Emission, Tillage and Crop Residue Management (C)	Johnson, Jane M.F. (P) Archer, David W. Gesch, Russell W. Reicosky, Donald C. Lachnicht, Weyers Jaradat, Abdullah A.	4/15/2006
	# 3645-21220-003-00D, Biological and Management Strategies to Increase Cropping Efficiency in Short-Season and High-Stress Environments (N)	Forcella, Frank (P) Archer, David W. Gesch, Russell W. Jaradat, Abdullah A. Papiernik, Sharon	11/1/2003
Mississippi			
Stoneville	# 6402-21000-004-00D, Develop Soybean Genotypes and Management Systems for Early Season and Stress Environments (C)	Koger, III, Clifford (P) Young, Lawrence D. Bellaloui, Nacer 1 Vacant	7/4/2003
	# 6402-21000-028-00D, Genetic-Physiological Team Research to Improve Production, Fiber Quality, and Competitive Ability of Cotton (C)	Meredith, Jr., William (P) Pettigrew, William Young, Lawrence D. Johnson, Joseph T. Zeng, Linghe	10/1/2003
	# 6402-21000-030-00D, Critical Biological Factors Determining Weediness (C)	Vaughn, Kevin C. (P)	5/17/2005
	# 6402-21410-004-00D, Alternative Crops and Value-Added Products for Mississippi (N)	Young, Lawrence D (P)	12/15/2004
	# 6402-22000-038-00D, Development of Pesticide Application Technologies for Spray-Drift Management and Targeted Spraying (N)	Thomson, Steven J. (P) Hanks, James E. Williford, Julius 2 Vacants	1/11/2003
	# 6402-22000-042-00D, Weed Biology and	Reddy, Krishna N. (P)	5/17/2005

	Ecology, and Development of Sustainable Integrated Weed Management Systems for Cotton, Soybean, Corn (C)	Bryson, Charles T. Molin, William T.	
Stoneville (con't)	# 6402-22000-056-00D, Augmentative Bioherbicide Strategies for Control of Invasive Weeds (C)	Boyette, Clyde (P) Weaver, Mark A. Hoagland, Robert	2/6/2006
Poplarville	# 6404-21000-006-00D, Small Fruit Cultural and Genetic Research for the Mid-South (C)	Spiers, James M. (P) Stringer, Stephen Smith, Barbara J.	3/26/2004
Ohio			
Wooster	# 3607-21000-009-00D, Improving Crop Protection Technology for Horticulture Crops (N)	Derksen, Richard C. (P) Krause, Charles R. 1 Vacant	10/29/2003
	# 3607-21000-011-00D, Develop Improved Technologies for Soilless Greenhouse Plant Production to Minimize Water, Labor, Agrochemical Inputs and Environmental Impact (N)	Locke, James C. (P) Krause, Charles R. Frantz, Jonathan	3/23/2006
	# 3607-21620-006-00D, Biological, Microclimate, and Transport Processes Affecting Pest Control Application Technology (N)	Zhu, Heping (P) Krause, Charles R. Reding, Michael E.	4/24/2003
Oklahoma			
Stillwater	# 0500-00044-012-00D, Areawide Pest Management Program for Russian Wheat Aphid and Greenbug (C)	Elliott, Norman C. (P) Burd, John D. Shufran, Kevin A. Porter, David R.	10/1/2001
Lane	# 6222-21220-002-00D, Yield and Quality of Vegetable Crops in Conventional and Organic Production Systems (N)	Russ, Vincent M. (P) Webber, III, Charles	8/1/2005
Oregon			
Corvallis	# 5358-21000-034-00D, Production Systems to Promote Yield and Quality of Grapes in the Pacific Northwest (N)	Tarara, Julie M. (P) Shellie, Krista Lee, Jungmin Martin, Robert R. 1 Vacant	11/16/2003
South Carolina			
Florence	# 6657-21000-005-00D, Enhancing the Sustainability of Cotton Production in the Southeast USA (N)	Bauer, Philip J. (P) Novak, Jeffrey M. Campbell, Benjamin	6/5/2004
Texas			
College Station	# 6202-22000-023-00D, Aerial Application Technology for Crop Production and Protection (N)	Hoffman, Wesley C. (P) Lopez, Juan De D. Westbrook, John K. Fritz, Bradley K. Martin, Daniel E. Lan, Yubin	9/24/2003
	# 6202-22320-002-00D, Ecologically-Based Management of Boll Weevils and Post-Eradication Crop Pests (C)	Westbrook, John K. (P) Esquival, Jesus F. Suh, Charles P.	12/17/2005

		Jones, Gretchen D. Spurgeon, Dale W. Nachman, Ronald J.	
Weslaco	# 6204-21000-009-00D, Pests, Parasites, Diseases, and Stress of Honey Bees Used in Honey Production and Pollination (N)	Adamczyk, Jr., John J. (P) Aronstein, Katherine Eischen, Frank A. Gregory, Pamela G.	10/15/2003
Lubbock	# 6208-21410-005-00D, Harvesting and Ginning Processes to Enhance the Profitability of Stripper Cotton (C)	Holt, Gregory A. (P) Pelletier, Mathew Buser, Michael D. 1 Vacant	5/29/2004
Utah			
Logan	# 5428-21000-010-00D, Pollination and the Development of Alternative Crop Pollinators (N)	James, Rosalind R. (P) Cane, Joseph H. Griswold, Terry L. Pitts, Singer Theresa	10/1/2003
West Virginia			
Kearneysville	# 1931-21000-012-00D, Small Fruit Production Systems (N)	Swietlik, Dariusz M. (P) Takeda, Fumiomi	11/28/2003
	# 1931-21000-015-00D, Integrated Orchard Management and Automation for Deciduous Tree Fruit Crops (N)	Glenn, David M. (P) Brown, Mark W. Miller, Stephen S. Tworkoski, Thomas Swietlik, Dariusz M. Leskey, Tracy C.	12/15/2003