USDA

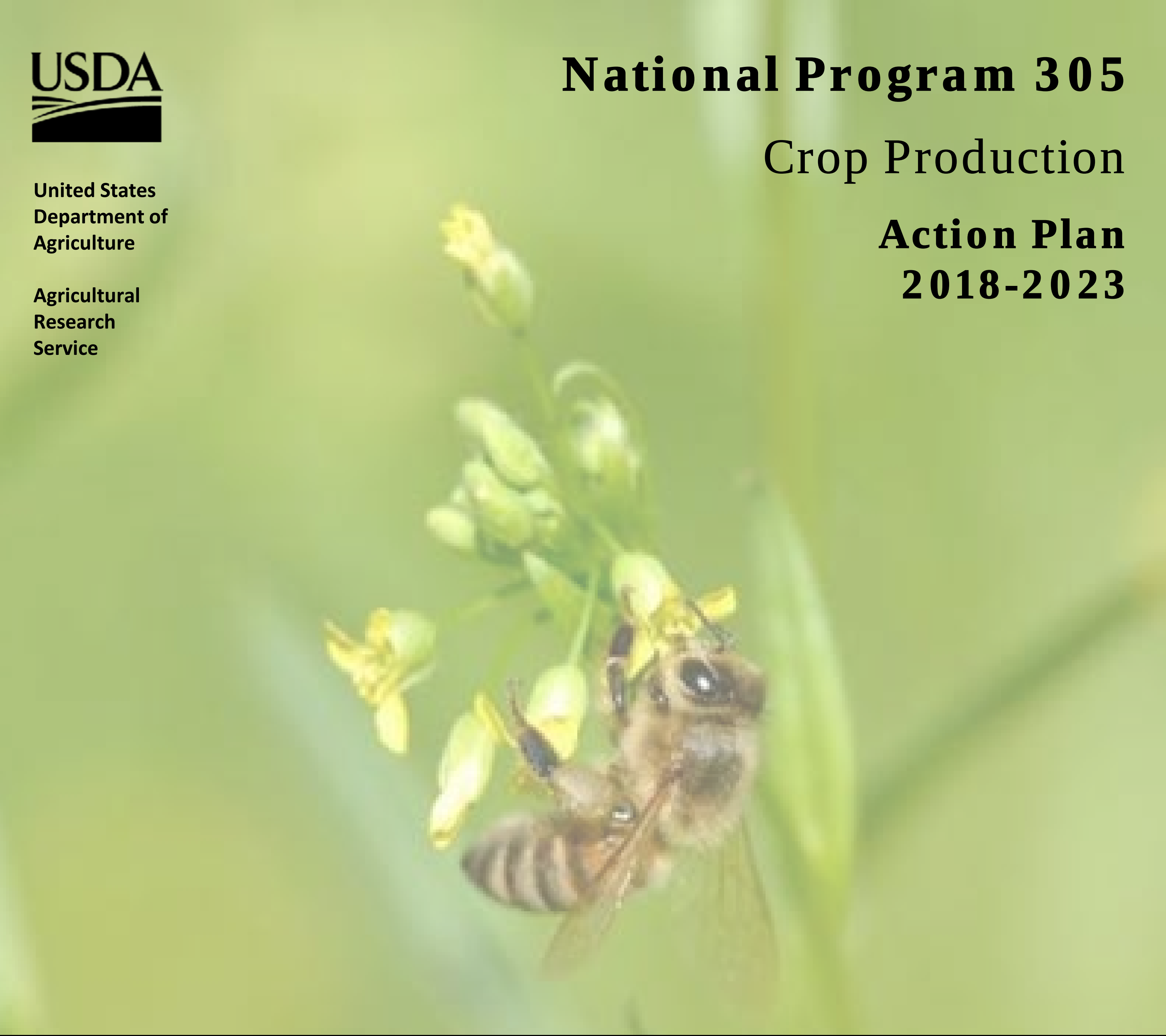
United States
Department of
Agriculture

Agricultural
Research
Service

National Program 305

Crop Production

Action Plan 2018-2023



USDA AGRICULTURAL RESEARCH SERVICE

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Vision

The vision for National Program (NP) 305, Crop Production, is to enable the genetic potential in ARS crop cultivars to be fully realized through optimal crop production, during production, and to deliver with crops to keep plants safe from pests and diseases to produce greater yields and higher quality products for increased profitability, while protecting pollinators and lowering environmental impacts (Fig. 1, below).

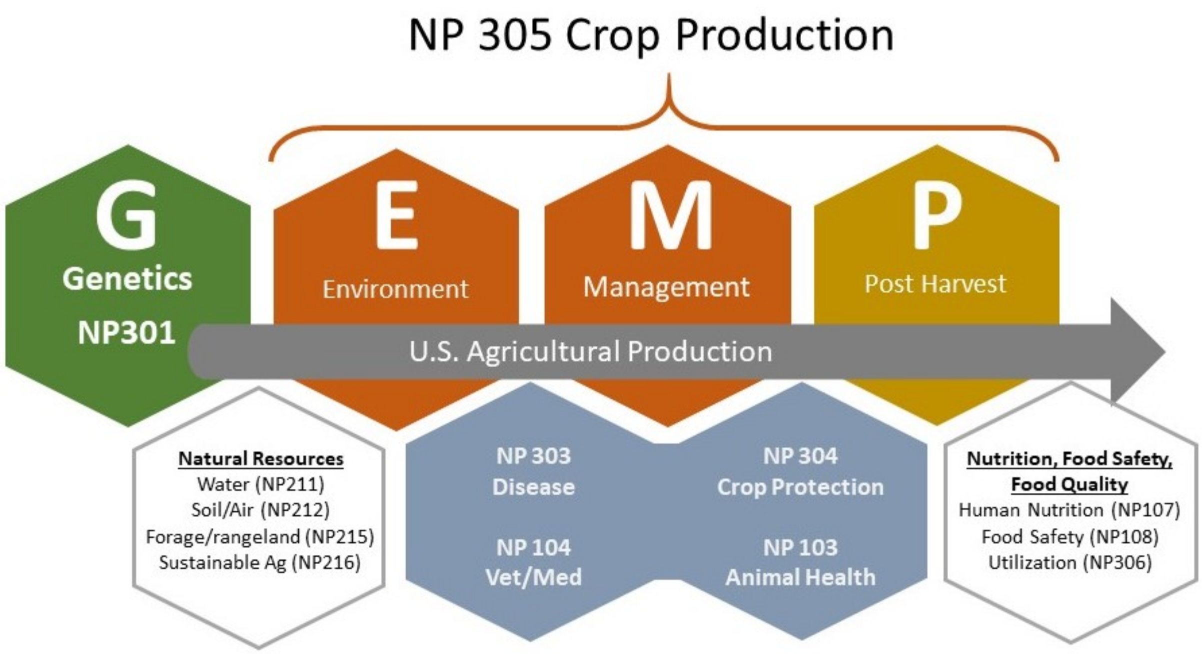

Fig. 1. General model for agricultural research components in NP305. Genetics research (G) seeks to maximize genetic potential of crop plants through breeding. Environment (E) is the conditions occurring when crops are grown, including climate, weather, soil, air, water, and other agroecosystem components. Management (M) is the general role of the farmer to manipulate the environment for producing the highest yield and quality based on a plant's genetic potential. Post Harvest (P) refers to post-field production and processing research for food safety, security, and product utilization.

Mission

The mission of NP305 is to enhance U.S. agricultural crop productivity, efficiency, and sustainability, and ensure a high quality and safe supply of food, fiber, feed, ornamental, and industrial crops for the nation. NP305 is the home of research dedicated to solving the challenges in agricultural production, including sustaining the health of critical plant pollinators.

Relationship of this National Program to the USDA Strategic Plan

This Action Plan outlines research that supports primarily the following objective in the USDA Strategic Plan for FY 2018-2022:

- Goal 2 – Maximize the ability of American agricultural producers to prosper by feeding and clothing the world.
    - Objective 2.2 - Increase agricultural opportunities and support economic growth by creating new markets and supporting a competitive agricultural system.

Research outlined in this Action Plan also supports the following USDA Strategic Plan objectives:

- Goal 2 - Maximize the ability of American agricultural producers to prosper by feeding and clothing the world.
    - Objective 2.3 - Protect agricultural health by preventing and mitigating the spread of agricultural pests and diseases.

- Goal 5 - Strengthen the stewardship of private lands through technology and research.
    - Objective 5.3 - Enhance productive agricultural landscapes.

Relationship of this National Program to the USDA Resource, Education, and Economics (REE) Action Plan

Research outlined in this Action Plan supports Goal 1, Sustainable Intensification of Agricultural Production; Subgoal 1A, Crop and Animal Production; and Subgoal 1B, Crop and Animal Health in the 2014 REE Action Plan.

Relationship of this National Program to the ARS Strategic Plan

Research outlined in this Action Plan supports Strategic Goal Area 3, Crop Production and Protection, in the 2012-2017 ARS Strategic Plan. Strategic Goal 3.1, Protect, expand, and enhance the United States' crop genetic resource base, increase scientific knowledge of crop genes, genomes, biological processes and systems, and deliver economically and environmentally sound technologies that improve the production efficiency, quality, health and value of the nation's crops.

Performance Measure 1.3.1: Develop knowledge, strategies, systems and technologies that maximize the production efficiency of our annual, perennial, greenhouse and nursery cropping systems; develop new technologies and tools contributing to improving these systems to meet current and future food crop production needs of diverse consumers, while ensuring economic and environmental sustainability and production efficiency, health, and value of our nation's crops.

Introduction

New technologies and methods are required to sustain and enhance the economic viability of crop production in the United States because input costs, such as energy, water, nutrients, pest management, and labor, are increasing. A system approach is necessary because new production strategies must be economically, environmentally, and socially sustainable. Research products that are needed include information, decision support tools such as software, improved devices such as more efficient spray systems, and accurate and reliable sensors. Information and tools must be integrated into overall production systems for specific crops and crop sequences, and rapidly transferred to growers. As the mechanism for delivering the genetic potential of crops from “seed to table”, NP305 research must continually refocus its efforts to support the research and development needs of changing production systems, climate and environmental shifts, economic drivers affecting U.S. farmers, and the advances in plant breeding, genetics, pest and weed control, and product quality and utilization.

As one of the most important components of crop production, NP305 includes bee pollination research. The honey bee (*Apis mellifera*) is the pollinator most often managed for commercial crop pollination. While the frequency of Colony Collapse Disorder (CCD) has decreased, honey bee populations continue to suffer. Bee health is threatened by pests, pathogens, pesticides, and poor nutrition. New techniques for management of honey bee diseases and pests are needed to maximize pollination. There is also an important need for conservation and in some cases commercial development of non-*Apis* bees (all bees other than honey bees) that effectively pollinate crops such as alfalfa, tree fruits, or greenhouse crops. As part of that goal, NP305 seeks to maintain the health and encourage proper management of bee pollinators and honey production. NP305 supports research to develop knowledge, strategies, systems, and technologies for a diversity of crops in a range of production systems, while increasing environmental quality and worker safety.

The NP305 Action Plan focuses on the most critical issues and needs of U. S. production agriculture. It comprises two major Research Components: Integrated Sustainable Crop Production Systems; and Bees and Pollination. Anticipated research products for one component are often vital to the success of research conducted under another component. Each Research Component includes Problem Statements that were formulated in part from interactions with various stakeholder groups, including: the 5-year Retrospective Review reviewers; our Federal partners and stakeholders from USDA, including National Institute for Food and Agriculture (NIFA), Animal and Plant Health Inspection Service (APHIS), Economic Research Service (ERS), and Agricultural Marketing Service (AMS); U.S. Forest Service (FS), commodity and professional organizations; and academia.

Within ARS, NP305 connects to many other National Programs and often contributes to the goals of other National Programs. These connections include incorporating advances in crop genetics (NP301, Plant Genetic Resources, Genomics and Genetic Improvement), and plant disease (NP303, Plant Diseases), pest, and weed mitigation (NP304, Crop Protection and Quarantine) into agricultural production. NP305 also connects to post-harvest research on dietary choices (NP107, Human Nutrition), food waste, transport, and safety (NP108, Food Safety), and product utilization (NP306, Product Quality and New Uses). NP305 connects to research on natural resources including technology for managing water quality and quantity needed for agricultural production and ecosystem services (NP211, Water Availability and Watershed Management) and research on soil health, efficient nutrient management, air quality, and adaptation to the effects of changing weather patterns (NP212, Soil and Air). NP305 is also closely aligned with research to strengthen agroecosystems and enhancing natural resource stewardship (NP216, Sustainable Agricultural Systems Research).

In developing the Action Plan, we considered the following special challenges, including: balancing stakeholder and partner needs with fiscal and personnel resources; ensuring that the research provides accomplishments that have impact and can be translated into practice through technology transfer; collaborating nationally and internationally and focusing on relevant issues to ensure that targeted areas are addressed; ensuring that the Program has the capability to respond when requested to unexpected needs and/or issues; and recognizing that the Action Plan remains a living document subject to review and realignment when and where required or appropriate.

Component 1: Integrated Sustainable Crop Production Systems

This component encompasses ARS efforts to improve existing and develop new production systems for current and emerging crops. Production systems are highly complex and depend on the integration of multiple management components. Innovative technologies, methods, and strategies are vital to maintaining and improving profitability of production systems, conserving energy and natural resources, and promoting agroecosystem sustainability, including marginal lands or urbanized environments.

The focus of Component 1 research is to better understand key factors that limit crop production for economically important agronomic and specialty crops, which are grown in all types of production systems from open-field to fully enclosed crop production systems (e.g., greenhouses, shade houses, high and low tunnels, and vertical farming), which confer protection from environmental extremes and pests and pathogens (Fig. 2, below).

Figure 2. Production systems in U.S. agriculture. Plants in less protected environments such as field crops are subject to intense environmental exposure.

Research goals are to optimize the integration of biological factors (e.g., plants, pests, and beneficial organisms), physical factors (e.g., soil, water, sunlight, and nutrients), and/or machines at appropriate scales from within an individual plant to across the agricultural landscape. Component 1 research includes conventional high-input production agriculture, low-input systems, vertical systems, organic systems, and new crops. All types of farming enterprises and crops are considered; this includes field, greenhouse, orchard, and vineyard production platforms.

Research in Component 1 is expected to generate new knowledge, improved management strategies, new technologies, models and decision support aids, and new or improved sensors and equipment. These discoveries will be transferred to research partners (Federal, State, university, and industry), business partners, growers and/or extension specialists to apply in the field.

Research in this Component is divided into four main research areas (Problem Statements), as listed below. Research is based on a systems approach, combining four overlapping aspects of sustainable crop production (Fig. 3):

- Horticultural and abiotic stress management;
- Technology and human resources;
- Pest and disease management; and
- Crop-quality management.

Interdisciplinary research is required to understand critical crop management and production issues and interactions. The goal is to develop a coordinated, national research program that improves crop management and quality, mitigates the impacts of pests, weeds, and diseases, and ensures food security in the United States with sustainable, profitable crop production.

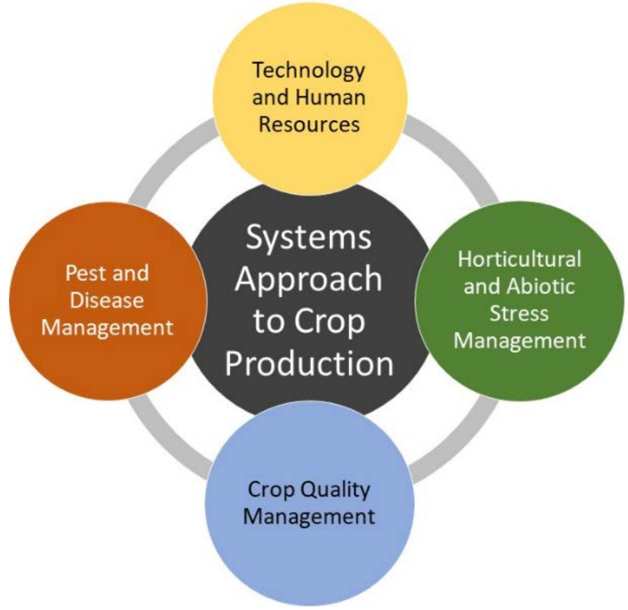

Figure 3. NP 305 Component 1 schematic.

Problem Statement 1A: Productive and Profitable Systems for Sustainable Production of Agronomic Crops.

Since 1948 the U.S. agricultural output has more than doubled, with an average growth rate of 1.49 percent a year. Much of this long-term success was achieved through the development of economically and environmentally sustainable cropping systems. However, greater demands on these cropping systems are occurring because of increased human population and demand for food security, loss of arable farmland due to urbanization, and reliance on agriculture to produce biology-based energy and feed stocks along with food, feed, and fiber. Even with higher prices for some commodities, profitability becomes more of a challenge over time because of rising production costs. Climate change adds another layer of complexity to agriculture because of its effect on the abundance and distribution of pests, and matching crops with suitable environments and pollinator availability. Climate change effects, coupled with urban encroachment into traditional agricultural areas, are already causing some agricultural production to move into less suitable regions and soil types. New, environmentally sound technologies, such as improved crop genotypes, alternative and multi-purpose crops, precision agriculture technologies, remote sensing, and safer pest control strategies are helping farmers develop integrated, modern cropping systems. National Program 305 meets these challenges by addressing the following research needs for agronomic crops.

<u>**Research Focus**</u>

ARS will seek to understand the input components that contribute to profitable production in traditional and alternative cropping systems, including inputs that promote agroecosystems sustainability and protect pollinators. ARS will investigate the interactions between the components within production systems (e.g., soil types, soil fertility, tillage, planting dates, seeding rates, species and varieties, irrigation, abiotic and biotic stresses, and pest management) and examine impacts on crop productivity and quality, sustainability, and beneficial biota. ARS will also integrate weed, insect, and pathogen management systems that effectively mitigate the negative effects of existing pests and prevent the adaptation of pests within current and prospective cropping systems.

Anticipated Products

- Increased system yield of winter cover crops (e.g., camelina) with select summer crops (e.g., soybean) in dual cropping systems that enhance total crop yields and net return or growers.
- Identification of cover crops compatible with corn production in the mid-south.
- Increased winter survival of winter crops in different soil types and climates.
- Increased sugarcane yields on high clay and poorly drained marginal lands.
- Increased crop and rotation longevity and stability.
- Sugarcane production systems that increase the number of ratoon crops harvested while maintaining productivity and profitability.
- Prevention and/or delay evolution of herbicide resistant weeds with cover crops and use of herbicide mixtures.
- Sugarcane varieties with resistance to economically yield-limiting diseases.

Potential Benefits

- Best management practices that integrate various components of crop production systems that maximize profitability and sustainability.
- Integrated tools and management practices for weeds, insects, and pathogens that maximize yields and agroecosystem sustainability.
- Land utilization strategies to maximize diversity and productivity, as knowledge is developed for traditional and alternate crops and varieties with respect to the soil type and other environmental variables.
- Strategies for integrating agroecosystem benefits including reduced soil erosion, improved water quality, and forages for pollinators with productive and profitable cropping systems capable of integrating crops for food, feed, fiber, and fuel.

Problem Statement 1B: Productive and Profitable Systems for Sustainable Production of Fruit and Nut Crops.

The U.S. fruit and tree nuts industry consists of a diverse array of crops and products that generate, on average, over $25 billion in farm cash receipts annually even though the production area is less than 2 percent of U.S. agricultural cropland. U.S. fruit and nut production systems face an ever-increasing rural-urban interface, persistent declines in water availability, labor shortages, and regulatory changes aimed at reducing adverse agroecosystem impacts and effects of climate change. U.S. fruit and tree nut production systems critically need management practices that not only minimize costly inputs, but also improve current production systems in historic growing regions and enable expansion into marginal areas to feed a growing national and global population, while simultaneously minimizing any negative impacts on agroecosystem and pollinator health. Within this paradigm, new knowledge and understanding of biological systems, innovative management tools, and rigorous and effective technology transfer are necessary to ensure continued global competitiveness of U.S. tree fruit and nuts, grape, and berry production.

Research Focus

ARS will seek to understand nitrogen management in the whole production system and characterize relationships between management indicators of soil quality and function, and biogeochemical cycles. ARS will test efficient water-conserving irrigation strategies and optimized fertilizer management that increase production, quality, and nutrient use efficiency for fruit and nut production and tailored to specific genotypes in a given location. ARS will also generate new knowledge of the physiological and genetic basis of abiotic stress tolerance, particularly resistance to drought, extreme weather events, and climate change to improve crop production and identify and characterize impacts on quality components of fruit. ARS will evaluate fruit, tree nut, and grape crop species germplasm for enhanced adaptability to environmental and soil constraints and improved production and profitability including the understanding root system attributes and mycorrhizal fungal taxa that support sustainable water and nutrient management.

ARS will identify chemical, biological, and cultural controls that target the most vulnerable stage of pests and pathogens in fruit and nut production systems to produce increased knowledge on the epidemiology, distribution, and population biology of diseases and pests of fruit, tree nuts and grapes. ARS will identify the most vulnerable stage of citrus hosts to infection by *Candidatus liberibacter asiaticus* and seek to understand host physiological response to disease development to develop new approaches for pest, disease, and abiotic stress scouting and surveillance. As part of this effort, ARS will evaluate scion/rootstock combinations for susceptibility to diseases such as huanglongbing (HLB), or citrus greening disease.

Anticipated Products

- Analytical methods to assess quality as influenced by crop production system.
- Irrigation strategies for fruit and grapes that enhance crop quality while conserving water usage.
- Enhanced spray coverage methods in tree crop canopies.
- Superior genotypes based on physiological and genetic traits for abiotic stress tolerance.
- Soil management strategies to improve properties and functions for sustainable crop production.
- Advances in machine harvesting technology for fresh market blueberry
- New technologies to remotely assess water requirements and irrigation issues in small fruits and grapes.
- Integrated chemical, biological, and cultural controls that target the most vulnerable stage of pests and pathogens in fruit and nut production systems.
- Tools to provide efficacious pest and disease management, and increased productivity and longevity in fruit and nut crops that simultaneously minimize any negative impacts on agroecosystems and pollinators.

Potential Benefits

- Increasing production and harvest efficiencies through automation and horticultural practices that promote a stable, diversified workforce.
- Improved efficiency of water and nutrient use, energy efficiency, reduced inputs, sustainability of soil quality and health of crop production systems. For example, Irrigation strategies and tools/equipment tailored to physiological responses of a given plant that conserve water and produce high quality crops.

- Expanded markets for fruits and nuts from optimal identification of superior cultivars, clones, rootstocks, and rootstock/scion combinations for improved crop quality on marginal soils and suboptimal conditions at various scales of production, and pest and disease resistance.
- Crop management practices and IPM tools that increase economic and ecological sustainability of grape, tree fruit and nut, and small fruit crops. For example, increased crop and soil health and longevity for sustainable and resilient crop production with reduced pesticide applications and greenhouse gas emissions.
- More abundant, nutritious, affordable, and diverse fruit and nut crops for consumers.

Problem Statement 1C: Productive and Profitable Systems for Sustainable Production of Ornamental, Nursery, and Protected Culture Crops.

Controlled environment production systems, including nursery, greenhouse, and other protected culture crops (low/high tunnel, vertical farms, etc.), offer greater control over the growing medium, growth environment, and agrichemical inputs during production compared to field-grown crops. These highly controlled systems offer high yields, enhanced quality, and/or more precise production windows. However, the increased control in these horticultural systems comes at a cost of higher labor and fuel costs, increased reliance on imported substrates, and an environment that enhances specific diseases and pests that are difficult to control. Within protected-culture production there are research opportunities to improve water, nutrient, and substrate utilization; improve energy use efficiency, increase the use of mechanization, further develop integrated disease and pest management concepts; and significantly reduce the potential impact of crop production on the environment, while simultaneously preserving productivity and crop quality.

<u>**Research Focus**</u>

ARS will seek to understand the relationship between environment (temperature, light, CO_2) and crop growth in controlled environment systems and identify substrate management techniques that improve crop growth and quality while reducing labor, fertilizer, water, or pesticide inputs. Modifying inputs in controlled environments will result in increased crop quality and lower pest pressure. ARS will integrate of studies on pest lifecycles with cultural, sanitation, and chemical control strategies that minimize crop damage including understanding water quality and pathogen treatment technologies to use irrigation water efficiently. ARS will increase knowledge of the molecular and genetic basis of abiotic stress tolerance including early detection of drought stress and develop advanced molecular techniques such as genome editing that could generate elite germplasm with drought stress tolerance and ethylene-insensitive traits for improved postharvest performance.

Anticipated products

- New irrigation and water quality strategies that maximize water use efficiency, reduce pest transmission, and optimize crop health.
- Photosynthesis-based models showing crop response to temperature, light, and CO2 levels in controlled environment systems.
- Novel substrate management techniques for improving input efficiency in container crops.
- Integrated Pest Management practices for reducing pesticide usage and improving plant health.

- Novel irrigation technologies for improving water use efficiency in controlled environment crops.
- Improved genome editing tool for enhanced postharvest performance.
- Tools to identify when initial, visually undetectable stages of water stress occur to better manage drought stress.

Potential Benefits

- Reduced energy costs in protected horticulture systems through improved energy use-efficiency.
- Reduced fertilizer, water, and agrichemical inputs due to modification of substrate properties.
- Reduced pesticide usage and improved crop health.
- Improved water management and water use-efficiency in protected horticulture and nursery crops.
- Improved postharvest performance of floricultural and nursery crops.

Problem Statement 1D: New and Improved Automation and Spray Application Systems for Sustainable Crop Production

A variety of application technologies and methods are required to address the many diverse cropping systems within the United States. Across the wide variety of crops and production systems, the detection, monitoring, and control of crop health and crop pests require consideration of, and adaption to, a variety of influencing factors, including crop type and structure, pest type and behavioral patterns, environmental conditions, chemical or alternative control inputs, and protecting pollinator health. Therefore, methods for rapidly assessing crop health and detecting invasive pests, partnered with improved application technologies, are needed. Technologies that support timely management decisions will guide precision, site-specific applications that enhance overall efficacy and productivity while reducing environmental impact and damage to non-target species while reducing operational and input costs.

<u>Research Focus</u>

ARS will improve application technologies and practices that address the diversity in cropping systems and environmental factors including understanding spray atomization, transport, deposition and drift from modern application technologies. ARS will use remote sensing and advanced data analysis technologies to identify crop structure, crop health, and pests to guide site-specific management using high-quality research data that are useful for risk assessment.

Anticipated Products

- Strategies and scientific guidance to support applicators and growers in improving effectiveness and to spray technology manufacturers to improve their products.
- New and improved spray equipment and methods for precision application of conventional and biological pest control agents with minimized inputs.
- New methods and tools to manage crop production and harvest practices and decisions.
- Science based data documenting modern, best management application technologies and methods to support spray drift risk management.

Potential Benefits

- Precise application of crop protection products for improved pest management efficacy, reduced damage to non-target species, and reduced waste. For example, guidance to applicators and producers on application technologies and methodologies for optimal on-target deposition.
- Improved site-specific crop and pest management support and spray application recommendations for improved crop yield and quality through an increased understanding of invasive species' behavior using automated remote sensing and computer vision system coupled with biological behavioral analysis.
- Reduced costs resulting from decreased system inputs including chemical, fuel, and labor. For example, site-specific variable application of fungicides for effective management of crop fungal diseases.
- Decision support systems that provide improved guidance to applicator and improve value of application services. For example, affordable and user-friendly remote sensing systems that allow aerial applicators to collect crop data and make site-specific application decisions.
- Advanced, automated crop production and protection systems that promote a sustainable and diversified work force.

Component 1 Resources:

- Davis, California
- Ft. Pierce, Florida
- Byron, Georgia
- Houma, Louisiana
- Morris, Minnesota
- Poplarville, Mississippi
- Stoneville, Mississippi
- Wooster, Ohio
- Corvallis, Oregon
- Mayaguez, Puerto Rico
- College Station, Texas
- Kearneysville, West Virginia

Component 2: Bees and Pollination

Bees are crucial for U.S. agriculture and ecosystem health. The honey bee is one of the most effective pollinators for fruit and nut crops such as cherries, apples and almonds, row crops such as cucurbits and melons, oilseed crops (sunflowers and canola), and berries. Given the pollinating potential of a honey bee colony due to its wide foraging area (> 1 mile), the large numbers of bees in a typical healthy colony (> 10,000), the ease at which honey bees can adapt to new environments, and the value of hive products, honey bees play critical roles in many specialty crop commodities. Non-*Apis* bees, including bumble bees, alfalfa leafcutter bees, and blue orchard bees, are also effective pollinators of agricultural crops, as well as many native plant species. Native bees, some living solitary or in small colonies, perform ecosystem services of value that cannot be estimated.

Research on honey bee nutrition conducted under the previous 5-year plan identified physiological responses of honey bees to pollen and protein supplements. The responses of honey bees to seasonal pollen sources provided evidence that nutrient levels in pollen from spring and fall flowers differ and align with the activities of honey bees during their yearly colony cycle. These research findings provide a foundation for future work in the planning and establishment of forage plantings to sustain honey bees, and for developing seasonal nutritional supplements for colonies when pollen is unavailable.

In conjunction with nutritional studies, the bee microbiome, which is the microbial community in the bee hive, including microbes found on food, wax, hive parts and in the gut of the bee, was described. Some results thus far have been surprising, such as gut microbiota differences between the queen and workers, and the lack of a microbial role in the storage of bee bread. Much work remains to be done in understanding the roles and interactions of the different microbial players. Since the microbiome plays a crucial role in bee nutrition, basic knowledge of the composition of microbial communities and how composition can change over time is necessary to understand the relationship of the bees to their environment, to help design improved artificial diets and forage, to help protect bees from pathogens, and to help interpret results from field and laboratory.

Included within the hive microbiome are potential pathogens, such as the microsporidians *Nosema apis* and, more recently in the United States, *Nosema ceranae*. Gene silencing technology has been used to improve the immune response of the honey bee to nosema infection, and the success of that approach suggests it may be applied to other pathogens. New diseases, as well as new routes for infection, continue to be identified and characterized by ARS laboratories. Disease represents one of several types of stressors that affects both *Apis* and non-*Apis* bees; other stressors include pests, agrochemical exposure, and temperature and nutritional stress. Research is needed to explore how bees respond to stress, as individuals and colonies, to identify symptoms and the role stress plays in bee colony losses.

In honey bees, the greatest sources of stress are *Varroa* mites and the viruses they transmit. Research determined that, in managed apiaries, the dispersal of mites on foragers occurs at levels that significantly contribute to mite populations in other colonies, particularly in the fall. The resulting high mite populations could be a major cause of overwintering colony losses and future studies should be directed at examining the role of the *Varroa*-virus complex and its effects on foraging, honey bee cognitive function, and mite behavior.

Another major goal of ARS honey bee research is the development of genetic stock that has both desirable beekeeping characteristics, such as strong colony growth and good honey production, as well as resistance to varroa mites. Development of “Pol-line” honey bees represents significant progress and will continue. New research will also focus on disease resistance, developing effective methods for quick and effective evaluation of genetic stock in the field, and improving cryopreservation of honey bee germplasm.

Considerable progress has been made in the last 5 years by ARS scientists in our understanding of the diversity, roles, and nutritional needs of non-*Apis* bees. Commercially-produced non-*Apis* bees, such as bumble bees and alfalfa leafcutter bees are key pollinators for greenhouse and dairy industries, respectively. Non-*Apis* bees are subjected to malnutrition and disease, and are exposed to agrochemicals, just as honey bees are. It is essential to clarify the taxonomy of non-Apis bees and determine their roles in agricultural and non-agricultural areas, and to identify the threats to non-*Apis* bee populations.

Pollination by bees in commercial agricultural systems almost always means exposure to agrochemicals such as pesticides and fungicides. New classes of pesticides and new application technologies are being developed to stay ahead of both native and invasive pest threats. The first step in resolving conflicts between crop protection and bee health is determining the exposure levels to bees and quantifying how such exposure affects the health and behavior of individual bees and bee colonies. The approach of ARS has included the development and application of new methods and tools to help researchers evaluate field-relevant, sublethal doses of agrochemicals on colony growth and activity. ARS is fostering collaboration among bee and field crop researchers to identify and promote research on bee friendly rotation crops, particularly oilseeds.

Component 2 is focused into three main research areas or Problem Statements, as listed below. A summary of these problem statements is shown in Figure 4.

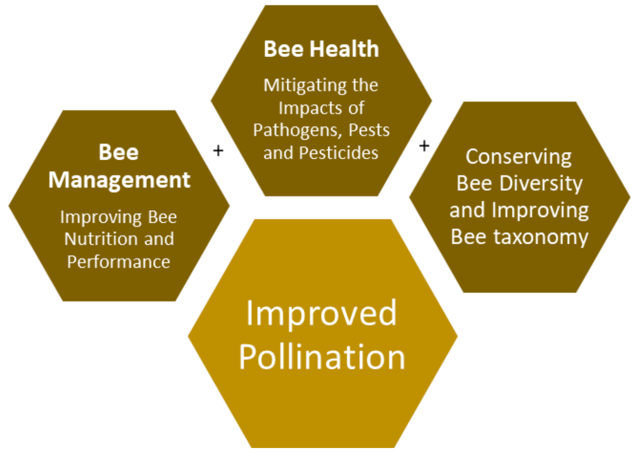

Figure 4. Relationships of ARS bee research Problem Statements in NP 305 and overall goals for improved pollination.

Problem Statement 2A: Bee Management—Improving Bee Nutrition and Performance

The growth and sustainability of bee populations depends on the quality of food available to them. The nutrients bees collect in nectar and pollen affect immunity, longevity, queen quality, colony activity, and resilience to stress. However, changes in climate and land use patterns and their effects on flowering plants are generating nutritional challenges to all pollinators. Therefore, determining the nutritional needs of honey bees and non-*Apis* species throughout their yearly cycle is essential for preventing queen and colony losses from malnutrition. Factors that affect the nutrient composition of nectar and pollen also need to be identified so that the nutritional value of pollinator plantings and crops requiring bee pollination can be managed and optimized.

Investigations into the gut microbiota of bees are required to obtain a complete picture of the effects of the nutritional landscape on bee health, since microbial communities are the fundamental interface between the environment and bee physiology. How seasonal pollens, protein, and carbohydrate supplements and commercial management practices affect the establishment and succession of gut microbes and the consequences for bee health and resilience to stress also require further study.

Data for studies measuring the effects of nutrition on colony health and activity usually are collected by intermittent, in-person hive inspections that disrupt normal hive activity. Methods to collect continuous data from colonies are needed to obtain a more complete picture of how the availability of resources and their quality affects colony homeostasis, thermoregulation and population growth.

Although some beekeepers overwinter hives in cold storage, most overwinter the hives outdoors and are hesitant to change their overwintering practices. ARS research indicates that overwintering colonies in outdoor apiaries is no longer profitable for preparing hives for almond pollination. Furthermore, the greatest colony losses occur over the winter due to inadequate forage and difficulties in maintaining low populations of varroa mites. Research is needed to develop Best Management Practices (BMP) for preparing hives for cold storage, and for defining the cold storage conditions that optimize colony survival.

The effectiveness of bee populations (particularly non-*Apis* bees) for crop pollination would be improved with a better understanding of how bees should be distributed in the agricultural landscape, and with improved nesting materials and sites. There also is a need for improved short- and long-term storage of non-*Apis* bees to enhance quality and availability. Information on pollinator population sizes that are crop and site specific would make pollination services from non-*Apis* bees more reliable and economical.

<u>Research Focus</u>

ARS will seek to understand the nutritional needs of bees throughout their yearly life cycle and develop scientific tools for monitoring bee and colony health and activity. ARS will determine plant growth conditions and practices that affect the nutrient composition of nectar and pollen and characterize microbial communities needed to maintain bee health and the effects of pesticides, supplemental diets and antibiotics on these communities. ARS will also determine effects of nutrition on queen quality and reliability. ARS will determine ideal timing and environmental and nutritional conditions that maximize survival of bees in cold storage over the winter and identify optimal nesting conditions and deployment conditions for bee pollination.

Anticipated Products

- Strategies for better bee nutrition and best management practices that optimize the nutritional value of pollen and nectar to bees.
- Tools for continuous monitoring of bee health and activity for preventative and/or evasive action.
- Best management practices for overwintering bee colonies in cold storage.
- Guides to pollinator deployment that improve forage, nesting conditions, and increase bee populations and crop yield.
- A roadmap for manipulating microbial communities for better bee health.

Expected Benefits

- Reduce non-*Apis* bee and honey bee colony losses from malnutrition and its impact on immunity, longevity, and reproduction.
- Reduce pollinator losses by improving bee nutrition is essential for consistently providing adequate bee populations for crop pollination and ensuring the productivity of U.S. crops that require bee pollination.

Problem Statement 2B: Bee Health—Mitigating the Impacts of Pathogens, Pests, and Pesticides

Parasites and pathogens strongly impact pollinator health, leading to increased management expenses and damaging losses. In addition, honey bees and other pollinators are sensitive to chemicals, including products needed for crop protection and for the in-hive control of honey bee pests. The arrival of the ectoparasitic mite *Varroa destructor* in Europe and North America led to devastating honey bee colony losses, in effect driving non-managed colonies close to extinction. This mite, coupled with the viruses it transmits between bees, is partially controlled by chemical treatments and management strategies. Unfortunately, pesticide sprays against *Varroa* have led to resistance in the past and can have adverse effects on bees themselves. There is an urgent need for better tools to control mites and the viruses they transmit.

Honey bees are also impacted by gut parasites, including the widespread microsporidian species *Nosema ceranae*. A key tool for treating *Nosema* was removed from the market in 2018, adding urgency to the development of new tools for this parasite. Bacterial diseases, including the highly regulated brood disease American foulbrood, cause both colony losses and an immense regulatory and treatment burden. Chemical stress can involve acute exposures that impact entire colonies as well as subtle and long-term exposures that affect behavior, longevity, and colony growth. The health risks for honey bees and other managed pollinators can be exacerbated by interactions among biological threats and between these threats and chemical exposure. Overall, commercial and small-scale beekeepers must replace over 40% of their colonies annually, a rate that has doubled in the past two decades. There is an urgent need to understand and mitigate the biological and abiotic threats faced by pollinators.

Research Focus

ARS will identify and characterize bee pathogens and parasites and identify causes of bee declines using an epidemiological approach. ARS will characterize pathogen transmission, host susceptibility, and infection mechanisms, including biotic and abiotic factors. ARS will determine the impacts of native microbiota of bees and beehive materials on susceptibility to parasites and other stressors including quantifying interactions of in-hive treatment chemicals with field-realistic rates of agrochemicals and the impacts of lethal and sublethal exposure to agrochemicals on bees.

ARS will also identify novel or repurposed small molecules, biopesticides, and chemical lures to attract and remove *Varroa* mites. ARS will also screen novel antiviral and anti-parasitic products including natural products that stimulate the immune response and direct antiviral controls.

Anticipated Products

- New sampling and diagnostic methods for bee pests and diseases.
- Development and release of effective pathogen, pest, and parasite treatments.
- Management recommendations for bees and their associated microbes aimed at minimizing disease impacts and colony losses.
- Colony management strategies for reducing viral movement at scales ranging from contact between bee, colony, landscape, and continent levels.
- New knowledge and/or tools, such as bee stocks and traits and their associated management techniques, that provide a foundation for improved IPM strategies for pest and disease control.
- Improved methods for pesticide risk assessment to reduce risk to bees.

Expected Benefits

- Effective alternatives for controlling mites, viruses, and gut parasites of honey bees, along with field-ready monitoring tools for parasites and diseases.
- Identification of particularly damaging chemical stressors and combinations will inform exposure risks.

- Integrated approaches for reducing impacts of disease and abiotic stress factors will help reduce high mortality rates, ensuring year-round availability of honey bees and other pollinators.

Problem Statement 2C: Conserving Bee Diversity and Improving Bee Taxonomy

In the United States, agricultural production and natural ecosystem health depend upon having numerous species and a strong genetic diversity of bees. Native bee populations are critical natural resources that need to be conserved for pollination of agricultural crops and plants in natural ecosystems. There is growing concern and evidence that these vital resources may be in jeopardy. Recent bumble bee research documents severe declines in some species and there is little information on the status of other native bees. Inventory, assessments of population sustainability, and studies of the effects of altered habitats are needed to determine the extent of species decline and as precursors to remedial efforts. Accurate taxonomic identification is critical given the approximately 4,000 species of bees in the United States. Formal revisions, user-friendly Web-based identification guides, and new methods of identification using molecular tools are in great need.

Knowledge of honey bee genetic diversity is also essential. Honey bees with genetically based resistance or tolerance to health threats will provide the most sustainable solution to problems caused by parasites and pathogens. Research to support the breeding of improved bees is long-term and multifaceted. Foundational work needs to identify specific traits or populations of bees with useful phenotypes, and these traits and bees need to be characterized for the physiological, behavioral, genomic and genetic factors that regulate resilience. The application of research findings ultimately requires collaborating with the beekeeping industry to breed and deliver bees that are valuable for the commercial sector. A further aspect of the work is to cryopreserve valuable genetic material for later use by bee breeders and researchers, or for conservation of endangered bee strains, subspecies, or species.

Research Focus

The research focus will be in two areas: honey bee genetic diversity and breeding, and the conservation of native bee biodiversity. For honey bees, ARS will quantify genetic diversity using molecular markers, and develop cryopreservation of key bee germplasm. ARS will also characterize traits and genetic stocks of honey bees for improved resilience to biotic and abiotic threats in order to breed honey bees with improved performance in commercial beekeeping operations. ARS will also select bee strains and species for specialized pollination needs.

In addition, ARS will conduct field surveys to sample for the presence of wild bees, both native and non-native bees as they occur in the wild. Bee diversity will be preserved through the National Pollinating Insects Collection in Logan, UT. In addition to the curation of pinned specimens, ARS will develop both morphologically-based and DNA-sequence-based methods for to improve bee taxonomy and systematics. ARS will contribute expert knowledge to the development of native bee health monitoring systems in collaboration with other government and non-government organizations, as appropriate.

Anticipated Products

- New knowledge on honey bee genetic diversity and preservation, and the development of honey bee breeding stocks.

- New knowledge of wild bee taxonomy, improved methods for bee identification, and methods for sampling bees for monitoring bee health.
- Tools for effective cryopreservation of valuable bee germplasm for industry use, research and genetic conservation.
- Foundational knowledge on bee diversity in the United States, which can be used by land managers for improved conservation.

Expected Benefits

- Understand honey bee diversity and taxonomy that is critical for breeding programs to improve pollinator effectiveness and health.
- Conserve the diversity of non-*Apis* bees, including bumble bees, alfalfa leafcutter bees, and blue orchard bees, which is essential for pollinating agricultural crops in addition to hundreds of species of native plants.

Component 2 Resources:

- Tucson, Arizona
- Baton Rouge, Louisiana
- Beltsville, Maryland
- Poplarville, Mississippi
- Logan, Utah