United States Department of Agriculture

Research, Education, and Economics
Agricultural Research Service

National Program 304

Crop Production and Quarantine






Action Plan
2025-2030

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USDA – Agricultural Research Service
National Program 304
Crop Protection and Quarantine
Action Plan 2025-2030

Vision

Pest management for sustainable agriculture.

Mission

To provide technology to manage pest populations below economically damaging thresholds through the integration of environmentally compatible strategies that are based on increased understanding of the biology and ecology of insect and mite pests, arthropod-vectored plant pathogens, and weeds**.**

Relationship to the USDA Strategic Plan

This Action Plan outlines research that supports primarily the following goal and objective in the USDA Strategic Plan for FY 2022-2026:

- Goal 1 – Combat climate change to support America's working lands, natural resources

  Objective 1.1 – Use climate smart management and sound science to enhance the health and productivity of agricultural lands;
  Objective 1.2 – Lead efforts to adapt to the consequences of climate change in agriculture and forestry; and
  Objective 1.4 – Increase carbon sequestration, reduce greenhouse gas emissions, and create economic opportunities (and develop low-carbon energy solutions).

- Goal 2 – Ensure America's agricultural system is equitable, resilient, and prosperous

  Objective 2.1 – Protect agricultural health by minimizing major diseases, pests, and wildlife conflicts;
  Objective 2.2 – Build resilient food systems, infrastructure and supply chain; and
  Objective 2.3 – Foster agricultural innovation.

- Goal 6 – Attract, inspire, and retain an engaged and motivated workforce that's proud to represent the USDA

  Objective 6.1 – Foster a culture of civil rights, diversity, equity, inclusion, accessibility, transparency, and accountability;
  Objective 6.2 – Establish a customer-centric, inclusive, high-performing workforce that is representative of America and the communities we serve; and
  Objective 6.3 – Promote USDA operational excellence through better use of technology and shared solutions.

Relationship to the USDA Science and Research Strategy

This Action Plan outlines research that supports primarily the following goals and objectives in the usda-science-research-strategy.pdf

- Priority 1 - Accelerating Innovative Technologies & Practices
  Goal 1.1 - Inclusive Innovation Culture;

  Goal 1.3 – Collaborative Intelligence Tools.

Goal 1.4 - Bioengineered Traits and Customizable Management Practices;
Goal 1.5 - Diversified Future Systems.

- Priority 2 - Driving Climate-Smart Solutions

  Goal 2.1 - Climate Change Impacts;
  Goal 2.2 - Climate Change Mitigation;
  Goal 2.3 - Adaptation to a Changing Climate;
  Goal 2.4 - Decision Support Tools.

- Priority 4 - Cultivating Resilient Ecosystems
  Goal 4.1 - Genomics & Genome Editing;
  Goal 4.2 - Microbiome Research;
  Goal 4.4 - Infectious Disease & Pests;
  Goal 4.5 – Biodiversity.
- Priority 5 – Translating Research into Action
  Goal 5.1 – Communication;
  Goal 5.2 – Education and Workforce Development;
  Goal 5.3 – Data Assets.

Relationship to the ARS Strategic Plan

This Action Plan outlines research that supports primarily the following goal in the [ARS Strategic Plan for 2022-2026]:

- Goal 1: Combat Climate Change to Support America's Working Lands, Natural Resources, and Communities
- Goal 2: Ensure America's Agricultural System is Equitable, Resilient, and Prosperous
  - Objective 2.1: Protect Agricultural Health and Minimizing Major Disease, Pests, and Wildlife Conflicts
  - Objective 2.3: Foster Agricultural Innovation

Alignment of the Action Plan with the vision of the ARS Strategic Plan: Finding Solutions to Agricultural Challenges with Agility, Innovation, and Relevance.

The National Program 304 (NP304) Action Plan integrates the principles of agility, innovation, and resilience to ensure that NP304 research efforts remain relevant, responsive, and effective in addressing the evolving needs of crop production and protection in the United States. Agility, innovation, and resilience (AIR) are guiding principles for executing the mission of the 2025-2030 NP304 Action Plan. Project coordination, interdisciplinary research, and stakeholder engagement will facilitate swift and agile responses to emerging threats posed by insect pests, insect vector-borne diseases, and weeds. NP304 scientists will pioneer groundbreaking solutions in crop protection and production through integration of advanced molecular and breeding technologies, collections, computational biology, machine learning, artificial intelligence, and/or digital agriculture in pest management. Such innovations will reduce the impacts that pests and weeds have on agricultural production, and the negative effects control tactics have on ecosystem health. Anticipated products and outcomes include the development of agricultural production practices and pest management strategies that are more resilient to effects of climate change, invasive species, and adaptations by pest insect and weeds populations. Research by NP304 scientists guided by principles of AIR will deliver farmers and stakeholders tools and resources that support U.S. agriculture:

1. **Agility**

- *Rapid Response*: NP304 scientists respond quickly to emerging challenges and stakeholder needs in crop production and protection by adjusting priorities, reallocating resources, or engaging in internal and external interdisciplinary research. These responses will be facilitated by participation of NP304 scientists in USDA ARS programs that foster research agility, such as the Grand Challenge Synergies and ARSX, as well as competitive, external grant programs.
- *Flexibility*: With support from the ARS administration and new directives from policy changes, NP304 scientists will be enabled to adjust research priorities based on changing circumstances, stakeholder needs, and emerging or changing threats to crop production and protection posed by invasive and endemic pests and weeds. NP304 research contributes to the USDA ARS agricultural biosecurity framework aimed to protect crops against emerging pests and pathogens by discovering and deploying crop protection technologies in the United States and abroad.

2. **Innovation**

- *Cutting-Edge Research*: The NP304 Action Plan outlines the directed use of innovative research approaches and technologies to address key challenges in crop production and protection. These include the use and development of advanced molecular, genomic, AI and machine learning models, robotic automation, and population suppression technologies to deploy tools and resources for the management of pest insects, insect-vectored diseases, and weeds. These technologies will be integrated into research supporting control tactics for pest and weed management, ecosystem and pollinator health, plant breeding, vector-borne plant disease management, and postharvest quarantine treatments.
- *Collaboration and Partnerships*: Collaboration with other research institutions, industry partners, and stakeholders is central to the NP304 Action Plan to foster innovation and leverage expertise across different government, academic, and industry sectors.

3. **Resilience**

- *Sustainable Practices*: The anticipated products and potential benefits from research outlined in the NP304 Action Plan will support agricultural crop production systems that are resilient to environmental, ecological, economic, and regulatory changes. These will include integrated pest and weed management strategies that minimize pest, pathogen, and weed adaptive responses and reduce environmental impacts in the face of shifting pest, pathogen, and weed demographics.
- *Risk Management*: Research outlined in the NP304 Action Plan will develop and integrate strategies that mitigate risks pests, pathogens, and weeds impose on crop production through fostering multidisciplinary research objectives, developing tools and models to assess risk, and using on-farm evaluations of insect pest, arthropod-borne disease, and weed management strategies.

Introduction

The United States produces an abundance of high quality, affordable food and fiber, planting more than a quarter of a billion acres of such crops worth more than $115 billion a year. While agricultural commodities represent about 6 percent of the total value of all products exported from the United States, insects, mites, arthropod-borne plant pathogens, and weeds cause considerable losses to these commodities, with losses estimated at tens of billions of dollars, a significant portion of the final commodity value. For example, postharvest losses for corn and wheat alone due to agricultural pests can amount to as much as $2.5 billion annually.

Pest and weed control methods face continuous challenges from natural and human-associated events. For example, shifts in agricultural practices can create new situations in which an existing insect or plant becomes a pest or a weed. Chemical controls may lose efficacy due to resistance or removal from the market, either because of environmental concerns, changes in regulatory status, changes in business plans, or changes in priorities by manufacturers. Increased global trade and climate change have worked in concert to accelerate the pace at which invasive pests and weeds are introduced and become established. Invasive species and loss of chemical control options threaten our food, fiber, and natural ecosystems and are a mounting concern. For example, the brown marmorated stink bug and spotted wing drosophila consume agricultural crops, while other invasive insects, such as the Asian citrus psyllid, transmit pathogens underlying devastating crop diseases. Some of these invasive insects, such as the Asian long horned beetle, emerald ash borer, and spotted lanternfly, decimate forests and/or urban landscapes. Weed species have evolved resistance to many herbicides, while the pipeline for new herbicide chemistries has slowed to a trickle, with the last new mode of action commercialized in row crops in the late 1990s. Invasive weeds have reduced biodiversity, displaced native species, and cost billions of dollars to control annually.

Integrated pest management (IPM) is the desired strategy for controlling insects, weeds, and diseases. IPM combines the use of pest surveillance to identify when and where pest control strategies are best applied with multiple control methods that are integrated to work optimally, while also being economical and environmentally safe. Pest control includes cultural, biological, physical, and chemical methods. By combining the use of several control tactics and monitoring the activity and population growth of a pest, growers can best target pest populations while maintaining the effectiveness of each control method. Maintaining an array of effective methods is important since control strategies, especially chemical methods, can be lost for a variety of reasons: pest/weed resistance, new regulatory requirements (arising from environmental or human safety issues), loss of public acceptance, and commercial considerations. The main goal of IPM methods is to systematically apply scientific knowledge to the biology of insects and weeds to achieve safe, harmonious, and economical systems that reduce pest problems below economic thresholds in a sustainable manner.

NP304 conducts fundamental research to create the knowledge base necessary to develop innovative control methods and IPM strategies as well as applied research to produce information, material products, and on-farm management tactics that improve pest and disease control in agriculture. The expected outcomes include reduced costs; better controlled pests with fewer non-target, human, and environmental effects; a reduction in existing pest populations; or limiting the establishment and spread of exotic organisms that may become invasive pests in agricultural production systems. These control strategies are applied in a variety of environments, from farm to storage, shipping, and packing facilities. The development, implementation, and improvement of pest insect, arthropod-vectored plant pathogen, and weed management and control strategies will maintain the competitiveness and vitality of U.S. agriculture, improve the quality and security of our food and fiber supply, and support the U.S. agricultural workforce.

Component 1: Systematics and Identification

The field of systematics builds our understanding of all life. Specifically, this field helps identify organisms by revealing their relationships in the context of evolution. Most biodiversity remains undescribed, and systematics is uniquely positioned to establish discovery of new organisms and explain how they relate. Systematics is the science of providing taxonomic information and developing hierarchic classifications that correspond to evolutionary history, thus allowing for the efficient communication of biological data. Taxonomy is the organization (e.g., diagnosing, identifying) of biological information into a classification system. ARS will continue to conduct research on the systematics, biodiversity, and taxonomy of target organisms. Taxonomic efforts focus on the identification of insects, invertebrates, and plants that are pests or potential pests of the Nation's crops and natural ecosystems, as well as insects and microbes that are possible natural enemies of invasive pests, especially those that show potential as biological control agents. Biological control leverages natural enemies of a target pest to provide management solutions. Taxonomic revisions are conducted, including descriptions of new species. Authoritative identifications are made for potentially invasive insects and weeds.

Systematics tools, including phylogenetics, cladistics, DNA bar-coding, and genomics, are used to categorize insects and weeds based on genetic and evolutionary relationships, supporting not only identification, but also understanding interrelationships, including understanding relationships at the level of populations, species, and higher levels of classification. Significant taxonomic expertise is required for the identification of new and existing economically important species, the interpretation of species concepts as new data are available, and the development of scientifically sound taxonomy which is the foundation for accurate identification and management. There are significant opportunities for interdisciplinary collaboration regarding insects, their hosts, and microbial communities. For example, there are approximately 4,500 invasive insect and mite species in the United States, of which more than 1,000 are considered agricultural pests. There are at least 3,000 weed species present in the United States, and new individuals continue to arrive, but we often do not understand how these plant species are taxonomically related.

While plants and arthropods often have physical characteristics that can be used to identify them, microorganisms typically lack distinguishing visible traits and require the use of additional magnifying tools and/or DNA analysis before an identification can be made. Microorganisms interact with both insects and plants and can have either beneficial or pestiferous influences on agricultural production. ARS scientists will use a range of traditional, digital, and rapidly advancing, next-generation molecular-genetic and identification tools to assemble a publicly available, web-based database and bioinformatic frameworks for addressing agricultural concerns. Particularly, augmentation and classical biological control programs critical to agriculture and natural resource management cannot be achieved without understanding taxonomy and systematics of pests and their potential biological control agents.

Problem Statement 1A: Insects, mites, and other invertebrate pests

A multitude of plant-feeding, predaceous, and parasitic insect and mite species are economically important to agriculture, commerce, and the natural environment as pests, invasive species, and beneficial organisms. More than 5 million insect species and 5 million mite species are estimated to exist. Because of this great species richness, there is a lack of taxonomic knowledge critical for correct identification. Despite more than 250 years of taxonomic effort, far more species of insects and mites are unknown to science than have been previously described and named. Research on economically important groups using new technologies almost always uncovers new species or cryptic species complexes. Without taxonomically-based species concepts, hypotheses of relationships, and associated specimen collections, information about geographic distribution and origin, biological characteristics, and genetic stability of insects and mites is questionable, which can undermine broader control or ecological studies. Systematics studies discern phylogenetic relationships among species. Phylogenies are predictive and provide insight into whether a new/unknown organism may be useful or harmful, particularly in the context of climate change and global trade. Biological control programs and augmentative technologies are highly beneficial to agriculture and the environment; taxonomy is paramount for correctly identifying both the target pest and its natural enemies. Taxonomic and systematic methods are essential to the process of finding new, successful agents and to avoiding the introduction of an unsuccessful or detrimental organism as a biological control agent. These methods are also essential to accurately detect detrimental, exotic species that are potentially invasive and acquiring and using the correct biological information to regulate and control them.

Research Focus

ARS will generate primary data and original scientific research on insect, mite, and other invertebrate pests, systematics using a range of digital, optical, and molecular tools. New and revised criteria for identifying species will be generated by ARS scientists through examining and curating accessions from the U.S. National Insect and Mite Collection and freshly collected specimens using an array of next-generation molecular/genomic techniques, bioinformatics, computer vision, modern illustration methods, and advanced microscopic imaging. Cutting-edge and exploratory methods will be used to elucidate phylogenetic relationships among pests and beneficial insects, mites, and invertebrate pests and to produce traditional and online identification keys that are essential for differentiating between native, adventive, and invasive species in the United States.

Anticipated Products

- New and more rapid publicly available research and reference materials, such as reliable conventional or computer vision/artificial intelligence identification and interpretation tools;
- Expanded and adequately curated U.S. National Insect and Mite Collection, especially with freshly collected field samples, consistent with worldwide collections and suitable for analysis by new technologies;
- Broad representation of economically important insects and mites as a resource for agriculture and pest management;
- Expanded public access to collection data in the form of digital libraries and databases;
- Comprehensive identification criteria for economically relevant species and the establishment of their classifications for use with genomic and morphological data; and
- Service identifications of insect, mites, and other invertebrate pests.

Potential Benefits

- Availability of impactful products and tools for known and potential economically important insect and mite species for use by ARS and our customers and stakeholders, including regulatory and quarantine agencies;
- Accurate and rapid identifications of key insect and mite species for customers and stakeholders, ultracold (cryo-) repositories of biological specimens and digital repositories of biological data; world-class dynamic collection represents spatiotemporal database to address future global challenges;
- Digital libraries and database access benefits industry, scientific community, local/state/national/international stakeholders providing the ability to diagnose and manage problems efficiently through technology transfer;
- Rapid and accurate methods for identification of pests and implementation of effective beneficial insect strategies for protection of agricultural and natural resources; and

- Reduced risk of invasion from insect and mite species via rapid response and collaboration with other laboratories and stakeholders.

Problem Statement 1B: Non-crop plants

Plant systematic relationships are mostly known at the family level, but for some problematic or understudied groups, taxonomy is still not clear at the genus and species levels. Molecular phylogenetics is required to accurately establish plant evolutionary relationships. Classical biological control of weeds relies on robust phylogenies and plant identification to assure that closely related desirable plant species will not be impacted by biocontrol agents. Researchers also must test if there is high host specificity to determine if biocontrol agents will only attack certain weed populations or genotypes. Taxonomic identification and relationships between plant species can become unclear when plants hybridize, a relatively common occurrence. Molecular tools are needed to identify weed hybrids that are often morphologically cryptic, since hybrids often respond differently to weed control than their parent species. In addition, there are co-evolutionary relationships among many plants, plant pests, and diseases. Failure to understand these relationships means failure at predicting alternate-host relationships of pests and diseases, diminishing the effectiveness of management and control strategies. Moreover, molecular phylogenetic approaches are also needed to identify and select for population-level genetic and phenotypic trait variation in native plant species and determine if these relate to their ability to compete with weedy invasives and withstand other environmental stresses.

Research Focus

ARS will generate primary data and original scientific research on weed, host plant, and native plant material systematics using a range of molecular, digital, and optical tools. New and revised criteria for identifying species and refining plant material selection will be generated by ARS scientists through examining and curating accessions from ARS germplasm collections and freshly collected specimens using an array of next-generation molecular/genomic techniques, bioinformatics, and machine-learning techniques. Cutting-edge and novel methodologies will be used to elucidate phylogenetic relationships among pathogens and existing and novel host plants, and to explore population-level genetic variation in desirable native plant species to assess their potential for plant material development in restoration/conservation efforts. These efforts will produce traditional and online identification keys that are essential for differentiating between native and invasive species in natural areas and weed and crop plants production systems of the United States and will contribute to developing and improving and implementing novel management practices.

Anticipated Products

- Improved taxonomic identifications and phylogenetic information for important plant groups including weeds, weed relatives, and non-crop plants that are hosts of crop pests and diseases;
- Tools for identification/diagnostics of weeds, alternative hosts, and resistant/competitive plant material;
- Novel control methods based on descriptions of reproductive strategies, including mating systems, timing of reproduction, and population genetics for important plants as necessary; and
- New information and vouchered herbarium specimens placed in appropriate national and international databases with geographical, genetic, systematic, and taxonomic data.

Potential Benefits

- Refined species concepts;
- Reduced negative effects from crop weeds and plant invasions through better understanding of plant functional attributes and inter-species relationships; enhanced understanding of reproductive strategies;
- Reduced negative effects from crop weeds and plant invasions;
- Enhanced understanding of reproductive strategies; safer, more rapid, and efficient implementation of species-specific and genotype-specific biological control and other weed management strategies; and
- Better prediction of alternate hosts of pests and diseases; and better prediction of the ecological range expansion potential of weeds and host plant species.

Problem Statement 1C: Microorganisms

Microorganisms perform myriad functions, both beneficial and harmful, in agricultural and natural ecosystems. Microbial associates of insects, mites, and other invertebrate pests, as well as those of crops and weedy plants, range from mutually beneficial to parasitic and pathogenic, thus directly impacting host survival and fitness. Despite their critical importance, microbes remain among the least characterized organisms on earth. For example, the number of fungal species that have been described, named, and placed within a systematics framework represent only a fraction (likely <5 percent) of the estimated number of fungal species on earth, leaving hundreds of thousands of fungi unnamed by science.

Microbial symbionts can influence the susceptibility of their hosts to biological and pesticide control approaches. For example, microbes that degrade chemicals may confer insecticide resistance, while symbionts can mediate susceptibility to entomopathogens. Invasive pests may harbor microbial symbionts that support invasion or could serve as targets for biocontrol. In other instances, insects may transmit microbes to plants and these microbes can cause serious and economically devastating crop diseases, such as the bacteria responsible for citrus greening or Pierce’s disease. Understanding, characterizing, and tracking these microbe-host interactions across complex ecosystems is an unresolved priority for agriculture. Systematics tools to rapidly identify microbes from diverse hosts and microbiome analysis will allow us to track how changes in microbial composition may have broad impacts on fitness or microbial assembly. These fundamental questions for biology are relevant to every U.S. crop, crop pest and weed. In turn, entomopathogens control populations of insects and other invertebrates in natural settings and can provide biocontrol services in agriculture. Their genomes also represent an untapped repertoire of genes or chemical products with potential for biotechnological development to control invertebrate pests and the spread of insect vector-borne plant diseases. Plant tissues host microbes growing within, called endophytes, that can either reduce or enhance non-native weed invasiveness, depending on the situation, as well as contribute to resilience of crop plants to various biotic or abiotic stresses.

Core ARS national culture collections, such as the ARS Entomopathogenic Fungi collection, provide identification, long-term storage, and systematics curation of microbes associated with insects and other invertebrate pests. These collections are key microbiological resources for reliable identification and description of these species. As a germplasm repository, they provide the raw biological materials, and associated metadata and genomic resources, for research and development of novel biocontrol agents or other control strategies based on microbial chemicals (biopesticides) or genes (RNAi or genetic engineering).

Research Focus

The paucity of knowledge of microbes and their associations with insects, mites, and other invertebrates, as well as endophytes of weeds and other plant hosts, hampers our ability to harness the full potential of these microbes for control of agricultural pests and diseases. Research on the systematics, population biology, evolutionary relationships, and host-interactions of microbial isolates are critical to develop control strategies for invertebrate pests and support plant health against biotic and abiotic threats on a changing planet. "Big data" computational approaches, such as comparative genomics, microbiome analysis, and development of novel bioinformatic approaches, are needed to support this research. This work necessitates the expansion of computing infrastructure to accommodate the ever-increasing amounts of such data, and the associated metadata, in all its forms. Better databases using digital photo identification and genomic data will enhance species identification and the accessibility of core ARS national culture collections.

Anticipated Products

- Curated, well-maintained, and expanded microbial culture collections;
- Timely distributions of microbial strains from core ARS national collections to customers, partners, and stakeholders for research and development;
- New and enhanced databases for discovery of microbial species, biodiversity metadata, and genetic/genomic diversity; and
- Publicly available tools for rapid identification of microorganisms that cause disease in plants or insects.

Potential Benefits

- Preservation and curation of microbial germplasm resources for reliable identification and research and development of safer, more effective control of invertebrate and weed pests;
- Better leverage of U.S. germplasm stocks via rapid access to microbial strains;
- Development of innovative control strategies founded on hypotheses generated from enhanced understanding of evolutionary relationships and host associations; and
- Rapid identification of microbes, allowing accurate and confident identification and post-release tracking of microorganisms approved for biological control and enabling post-release population tracking.

Component 1 Resources

- Albany, California: Western Regional Research Center
- Beltsville, Maryland: Invasive Insect Biocontrol & Behavior Laboratory
- Beltsville, Maryland: Bee Research Laboratory
- Beltsville, Maryland: Systematic Entomology Laboratory
- Beltsville, Maryland: Sustainable Agricultural Systems Laboratory
- Burns, Oregon: Range and Meadow Forage Management Research Laboratory
- Fargo, North Dakota: Insect Genetics and Biochemistry Research Unit
- Fort Lauderdale, Florida: Invasive Plant Research Laboratory
- Fort Detrick, Maryland: Foreign Disease–Weed Science Research Unit
- Hilo, Hawaii: Daniel K. Inouye Pacific Basin Agricultural Research Center
- Ithaca, New York: Emerging Pests and Pathogens Research Unit
- Logan, Utah: Forage and Range Research Unit

- Newark, Delaware: Beneficial Insects Introduction Research Unit
- Parlier, California: San Joaquin Valley Agricultural Sciences Center
- Peoria, Illinois: Crop Bio-protection Research Unit
- Reno, Nevada: Great Basin Rangelands Research Unit
- Sidney, Montana: Pest Management Research Unit
- Stoneville, Mississippi: Biological Control of Pests Research Unit
- Stoneville, Mississippi: Southern Weed Science Research Unit
- Stoneville, Mississippi: Crop Production Systems Research Unit
- Stillwater, Oklahoma: Wheat, Peanut and Other Field Crops Research Unit
- Wapato, Washington: Fruit and Vegetable Insect Research Unit
- The Office of National Programs Overseas Biological Control Laboratories with locations in Montpellier, France; Thessaloniki, Greece; Beijing, China; Hurlingham, Argentina; and Brisbane, Australia.

Component 2: Weeds

In agricultural settings, weeds reduce crop yields, impede harvests, damage equipment, and serve as secondary hosts for agronomically-damaging pathogens and insects. In addition to damages and lost revenues, U.S. growers spend more than 10 billion dollars annually to control weeds in agricultural settings. In natural systems and rangelands, invasive weeds cause habitat destruction, displace threatened and endangered species, reduce rangeland productivity, increase the risk of wildfires, and impede access to vital waterways essential to commerce and national security. Weeds in non-agricultural settings are particularly difficult to control due to challenges in terrain, accessibility, plant diversity, and the large size of infested regions.

In both agricultural and non-agricultural settings, herbicides have been the primary control method for more than 80 years. Decades of herbicide use has resulted in the evolution of herbicide resistance in many weed species with some weeds evolving resistance to multiple classes of herbicides. Additionally, there is growing awareness and concern of the environmental impacts and health risks of herbicides, leaving growers and land managers fearful of losing once-reliable weed control technologies that are necessary for profitable land use. Successes combatting weeds using biological control agents to supplement or augment herbicide control have occurred in some systems; however, such measures can be time consuming and costly to develop and evaluate, and may have unpredictable environmental risks. The combined effects of climate change and global commerce exacerbate the introduction and spread of weeds in seemingly unpredictable patterns. Taken together, these problems are exceptionally challenging and will require innovative and multidisciplinary approaches to solve. Weeds often display exceptional phenotypic plasticity, which allows them to thrive in conditions that limit the growth of other plant species. Consequently, there is a need to understand the mechanisms by which weeds resist natural stresses, avoid and/or resist control measures, and adapt to novel environments. The mechanisms underlying these traits need to be elucidated to better design systems to manage weeds and exploit these traits for improved crop performance.

ARS will leverage recent advances in robotics and machine learning, genome sequencing, gene editing, crowdsourcing and information analysis, biochemistry, plant physiology and development, and population genetics to develop novel, affordable, safe, and effective weed control strategies, and to anticipate and prevent the introduction and spread of weeds. Robotics opens opportunities to develop novel automated physical weed removal systems for controlling weeds. This will necessitate collaborative efforts between weed scientists and agricultural engineers as well as with the manufacturing industry and extension services to ensure adoption of these technologies. It is now possible to fully sequence large, complex weed genomes, which has already resulted in the availability of more than five dozen draft genomes of diverse problematic weeds. These genome sequences and advances in genome wide association studies and other population genetic tools can now be leveraged, along with existing DNA and herbarium collections from weed populations, with new and developing programs for identifying specific genes underlying non-target herbicide resistance, invasiveness, reproduction processes, range expansion, and plasticity of responses to environmental stress. Likewise, advances in gene modification should allow manipulation of these genes in natural weed populations through genetic approaches, such as gene-drive technologies. Crowdsourcing of information has proven effective for many businesses to predict the movement of goods, needs for services, and the localization of items. Collaboration with experts in information technologies should allow the use of these technologies to rapidly identify and map new weed invasions and predict the likelihood and direction of the spread. Combined with genetic and genomic resources, this information will allow the rapid identification of source populations for targeted biocontrol options, and even predict probable new invasions so protective measures can be rapidly developed and utilized. Advances in biochemistry, gene modification, and genomics can be combined to improve weed tolerance in crops, identify novel bioherbicides and RNAi-based weed suppressants, and develop crops with improved competitiveness with weeds.

Problem Statement 2A: New weed management technology, discovery, and development

Herbicides have long represented the most effective tools available to growers for weed management; however, their effectiveness has come under threat in recent years by the emergence of resistant weed biotypes that have now been reported for 23 of the 26 known herbicidal chemistries. Weed populations have also developed more complex resistance patterns over time. For example, it is not uncommon to encounter individual weed populations harboring resistance to multiple modes of action and exhibiting both target and non-target-based resistance mechanisms. Therefore, there is a critical need to identify new herbicides featuring novel modes of action and to develop technological alternatives to chemical weed control. Once realized, these new technologies will potentially provide growers with an arsenal of weed control options, thereby enhancing global food security and the ability for growers to prosper and keep pace with global demands. Research in genomics, genome editing, robotics, and artificial intelligence (AI) has advanced at a dramatic pace and now provides us with the technical and molecular capabilities to develop and deploy advanced weed management strategies such as allelopathic and weed-tolerant crops, AI-directed robotics for automated mechanical weed control, RNAi-based herbicides, and CRISPR/Cas-based gene drives. Moreover, nature has produced a wealth of specialized phytotoxic metabolites possessing novel modes of action, and this vast resource should be fully explored as a source of environmentally benign natural product-based herbicides that are less likely to be compromised by evolved weed resistance. Additionally, assessment of new and existing collections of weed populations, in conjunction with genomics technologies, will lead to the discovery of mechanisms for invasiveness and the adaptation and evolution of non-target and target site resistance to herbicides. These advancements could also potentially augment existing synthetic herbicides and prolong their utility as effective weed control measures.

Research Focus

Research will focus on the following customer needs: new natural product-based herbicides featuring novel modes of action, development of RNAi-based mitigation strategies, refinement of gene drive approaches for eliminating resistant weed populations in agricultural and natural ecosystems, refined AI-driven automated robotic systems for weed management, and portable technologies for growers to conduct sequence-based weed biotype evaluations. Research will also focus on the development of weed-suppressing and weed-tolerant crop varieties through the engineering of both allelopathic crops and crops resistant to yield loss due to weed infestations. Research will also be performed to improve our basic understanding of weed physiology, genomic organization, and ecology, as well as investigations focused on non-target and target-based herbicide resistance mechanisms, weediness characteristics, and seed bank dynamics. Studies on the effects of the soil microbiome (fungi and bacteria), microfauna, and soil invertebrates on seed longevity will also be conducted, with the potential for identifying new biocontrol options. Lastly, new web-based resources are also required to accommodate grower input on weed management problems, and to provide a platform for the rapid dissemination of newly developed information and technologies for growers.

Anticipated Products

- Robotic-based technologies capable of efficiently recognizing and managing weeds in agricultural and natural ecosystems;
- New bioherbicides featuring novel/complex modes of action;
- RNAi-based technologies for mitigating problematic weed biotypes and improved understanding of the specificity, feasibility, and efficacy of these approaches;
- Portable, grower-accessible systems for on-site genotyping of weed biotypes and herbicide resistant weed populations;
- Web-based resources for grower input on new problems and the rapid dissemination of new weed control innovations;
- Allelopathic crop varieties and varieties that reduce weed-induced yield loss;
- Development of gene drive technologies for mitigating problematic weed biotypes in agricultural and natural ecosystems; and
- An understanding of weediness evolution and genes for improving plasticity and adaptability of crops to biotic and abiotic stress.

Potential Benefits

- Reduced grower costs and labor input requirements for weed control;
- Reduced reliance on conventional synthetic herbicides in favor of more environmentally-benign bioherbicides possessing novel modes of action and/or nonchemical weed control technologies;
- Availability of an array of technological approaches to mitigate herbicide-resistant weed infestations;
- Increased crop production and profitability for growers;
- Improved crop varieties with enhanced, weed-like plasticity to environmental stressors; and
- Increased farm worker safety through reduced herbicide exposure.

Problem Statement 2B: Biological control and ecosystem research

Natural ecosystems support native flora and fauna while providing a host of critical ecosystem services and functions that support the broader human environment. The complexity of natural ecosystems and interconnectedness to agroecosystems requires a systems approach to weed management. This approach should include comprehensive biology, ecology, and population investigations, impact monitoring, integration of biological and cultural tactics, and habitat restoration research. Ultimately, a long-term, multi-faceted approach will integrate weed and ecosystem management to produce desirable and sustainable communities.

Conventional weed management strategies are often costly and impractical for the control of extensive weed infestations over large, inaccessible areas within natural environments. However, biological control can be an effective, environmentally sustainable, and cost-effective approach to manage invasive weed populations, particularly in ecologically-sensitive locations. Developing effective and sustainable management strategies for invasive weeds will require understanding the biogeography and environment where the weed occurs, critical stages of population growth and spread, the taxonomy of plants and their natural enemies, and the long-term management objectives for affected areas. Ecological research is required to optimize biological control contributions to weed management systems, evaluate safety of potential biological control for co-occurring species and habitat management goals, and identify additional integrated weed management tools that enhance biological control impacts. Innovative molecular-based biological control technologies, including those supported by genetics and genomics, are also needed to complement current biological, physical, and cultural control methods to diversify selection pressures and conserve chemical herbicide options.

Research Focus

ARS will develop and evaluate biological control agents, including host-specific invertebrates, bioherbicides, microbial pathogens, and emerging molecular-based technologies, and evaluate their interactions with both new and existing invasive weed populations. ARS will leverage its overseas laboratories to conduct foreign exploration and initial screening for potential biological control agents. Innovative weed control systems will target control resistant and hyper-invasive plant genotypes in natural and agricultural systems. ARS will evaluate the efficacy and ecological impacts of control tactics and determine how biological control agents influence critical aspects of invasiveness, such as weed biology, physiology, demography, dispersal, distribution, plant competition, and seed bank ecology. ARS will conduct pre- and post-release host specificity and efficacy evaluations on potential biological control agents using models to determine the life stage or plant structure of weeds most susceptible to these agents. Bioherbicide research will develop novel methods to reduce weed populations, formulate adjuvants or co-inoculants to promote weed-disease development, and determine the role of resident microbial communities in the success of introduced agents. ARS will elucidate the components of ecosystem viability and function by conducting research on plant community responses to invasion-mediated disturbance (e.g., changes in nutrient cycling, hydrology, populations shifts, etc.). Such research should develop basic biological information on native and non-native plant ecology, evaluate the effects of management on ecosystem performance, and quantify the benefits of ecosystem services that are restored or preserved. ARS will partner with other agencies and stakeholders to monitor weeds in valuable ecosystems using modern technologies (e.g., satellites, unmanned aerial systems, etc.) and develop new models to detect and forecast the spatial and temporal distribution of invasive weeds. Lastly, ARS will investigate the impact and risks of invasive weeds to our agroecosystems and how management options can mitigate their damage.

Anticipated Products

- Effective biological control agents to control invasive, non-native weeds;
- Enhanced biological control (agents and outcomes) through selection, breeding, and other molecular-based techniques;
- More effective ecosystem-scale weed management strategies;
- Foundational ecological knowledge at multiple scales (population, community, landscape, and ecosystem);
- Improved models of ecosystem response to disruption and degradation by weeds;
- Decision support tools for land managers to restore or conserve ecosystems; and

- Effective restoration techniques and tools to monitor outcomes.

Potential Benefits
- Enhanced crop and rangeland productivity;
- Increased ecological services and multifunctionality of the environment;
- Conservation of unique and intrinsically valuable populations, communities, and ecosystems;
- Reduced costs of and increased efficacy of controlling invasive weeds;
- Reduced synthetic herbicide use and reduced adverse impacts on natural ecosystems;
- Reductions in economic and environmental harm to natural and agroecosystems by invasive weeds and non-target impacts from other control methods;
- Increased biodiversity across multiple trophic levels from the restoration of local plant communities; and
- Preservation of waterways, water quality, outdoor recreation, and threatened or endangered species.

Problem Statement 2C: Integrated approaches to weed management

Integrated weed management (IWM) practices encompass combinations (additive or synergistic) of tactics including biological, chemical, cultural, and mechanical that are holistically combined into a broader set of agronomic and ecological goals. Thus, formulation of effective IWM practices must consider the vast number of agricultural, aquatic, horticultural, organic, natural, forested, and rangeland ecosystems that are continually evolving due to pressures from herbicide usage and resistance, climate change, environmental regulation, and invasive species. New technologies such as AI, gene drives, and robotics and the inclusion of a greater diversity of tactics such as biocontrol agents, bioherbicides, cover crops, buffer zones, and weed seed management are warranted to meet the needs of land managers. Incorporation and evaluation of these efficiently combined tactics, technologies, and evolving datasets into IWM approaches will make invasion, adaption, and survival of weedy species more challenging in these diverse ecosystems. Developing and evaluating a diversity of new methodologies is essential for the evolution of effective and sustainable IWM models and decision tools. Furthermore, it is critical to understand how integration of these combinations of tactics impact broader agronomic goals associated with soil conservation, environmental protection, cropping system yields, and farm profitability. The complexity associated with U.S. natural and rangeland ecosystems also dictates the need for IWM that facilitates habitat restoration and ecosystem services.

Research Focus

ARS will develop and evaluate holistic weed management systems to enhance agricultural productivity under diverse and changing climates and regulatory concerns and develop avenues of communication to ensure ARS research has a clear path to stakeholders. New discoveries will be translated into commercial applications that address stakeholder needs. Approaches will include development of new sustainable tactics to identify and combat herbicide resistant weeds in agricultural, aquatic, and rangeland systems. Integration of regionally appropriate cover crops into rotational cropping systems will be evaluated for their impact on weed-crop interactions, microbial communities, and ecosystem services. New datasets will be developed to update existing models for predicting and managing weed invasions by incorporating new technologies and climate change forecasts for crop, rangeland, and aquatic systems. Computational biologists and engineers will meld new and existing datasets to develop technologies and approaches to monitor weed populations and invasions. Robotics and AI will be integrated into developing models and approaches for helping growers to manage pests (e.g., databases for machine learning, identifying herbicide resistant weeds). Efforts on the development and evaluation of mechanical weed seed mitigation at harvest will be incorporated into new IWM models for reducing soil weed seed banks. Integration of conventional herbicides and novel bioherbicides will be evaluated to determine their utility in different cropping systems. Research will also determine the nature of resistance mechanisms in weeds and how herbicide co-products (for example, metabolites that reduce uptake, metabolism, and/or efficacy of herbicides) affect these processes to curtail herbicide resistance. Interagency collaborations with the National Oceanic and Atmospheric Administration, Animal and Plant Health Inspection Service, the U.S. Forest Service, and others will assist in modeling the impact of weed management tactics on endangered species and will create new datasets to predict global climate change effects on IWM approaches.

Anticipated Products

- New and improved datasets for developing adaptive decision tools that use AI and machine learning for optimizing IWM tactics;
- Wider adoption of a multi-tactic approach for combating herbicide resistance, defining and understanding crop-weed interactions and invasiveness, and improving crop management;
- Integration of new chemical and non-chemical tactics for managing weeds in conventional, organic, and specialty crops, and in natural, rangeland, and aquatic ecosystems;
- New prediction models that incorporate weed genomics-based tools for identifying, monitoring, and responding to the spread of herbicide-resistant and invasive weeds under changing climates;
- Integrated approaches for use of new bioherbicides and natural products with other management tactics for improved weed control;
- Refinement of IWM systems that target weeds at various life stages (e.g., systems including cover crops, competitive/tolerant crop cultivars, crop/herbicide rotation, robotics, and weed seed mitigation at harvest); and
- Improved knowledge for pairing biological control agents with herbicides or other chemicals to achieve additive and/or synergistic interactions with improved efficacy and reduced environmental impact.

Potential Benefits

- Sustainable and economic ecosystems that rely on IWM to minimize effects of weeds through environmental stewardship that improves resiliency under a changing climate, mitigates herbicide resistant weeds, and enhances crop productivity, ecosystem function/restoration, and rangeland quality;
- Sustainable food production systems and value-added ecosystems that improve consumer acceptance, health and safety, and rural economies;
- Mitigation strategies to reduce off-target effects of herbicides and biologicals on endangered species; and
- IWM practices that encompass the effects of weed management on insect populations, disease prevalence, ecosystem health, and crop production.

Component 2 Resources

- Albany California: Invasive Species and Pollinator Health Research Unit
- Beltsville, Maryland: Crop Systems and Global Change Research Unit
- Beltsville, Maryland: Systematic Entomology Laboratory

- Beltsville, Maryland: Sustainable Ag Systems Laboratory
- Brookings, South Dakota: Integrated Cropping Systems Research Unit
- Burns, Oregon: Range and Meadow Forage Management Research Unit
- Charleston, South Carolina: Vegetable Research Unit
- Davis, California: Invasive Species and Pollinator Health Research Unit
- Fargo, North Dakota: Weed and Insect Biology Research Unit
- Fort Detrick, Maryland: Foreign Disease-Weed Science Research Unit
- Fort Lauderdale, Florida: Invasive Plant Research Laboratory
- Gainesville (Tallahassee), Florida: Insect Behavior and Biocontrol Research Unit
- Houma, Louisiana: Sugarcane Research Unit
- Ithaca, New York: Emerging Pests and Pathogens Research Unit
- Kerrville, Texas: Knipling-Bushland U.S. Livestock Research Unit
- Oxford, Mississippi: Natural Products Utilization Research Unit
- Peoria, Illinois: Crop Bioprotection Research Unit
- Reno, Nevada: Great Basin Rangelands Research Unit
- Sidney, Montana: Pest Management Research Unit
- Stoneville, Mississippi: Crop Production Systems Research Unit
- Stoneville, Mississippi: Biological Control of Pests Research Unit
- Tifton, Georgia: Crop Protection and Management Research Unit
- Urbana, Illinois: Global Change and Photosynthesis Research Laboratory
- Wooster, Ohio: Application Technology Research Unit
- Office of National Programs Overseas Biological Control Laboratories with locations in Montpellier, France; Thessaloniki, Greece; Beijing, China; Hurlingham, Argentina; and Brisbane, Australia

Component 3: Insects and Mites

Arthropod pests, including insects and mites, cause billions of dollars in lost productivity to U.S. crop producers and damage natural ecosystems. Arthropod pests and associated microbial pathogens, and some tactics used for their control, also diminish the quality and safety of food for humans, livestock, and other domestic animals. Component 3 encompasses ARS efforts to control insect and mite pests and support beneficial interactions across agricultural landscapes. Impact of native and introduced arthropod pests will be investigated in multiple crop systems.

Research will focus on developing sustainable and resilient production practices that are agile and adaptable under changing climate, landscape, and economic conditions. For instance, climate and land-use changes may alter pest demographics (distribution, timing, and abundance) in relation to host availability and natural enemies, thereby affecting success of pest control tactics. Addressing such challenges will require inter- and trans-disciplinary research by ARS scientists. Introductions of invasive species have accelerated due to increased global trade and travel. Invasive arthropod pests collectively threaten virtually all U.S. crops and natural ecosystems. A single pest species can cost producers more than $1 billion in yield losses and control costs each year. For instance, the Asian long horned beetle alone is a $670-billion threat, with APHIS allocating $10 million per year for eradication efforts, and spotted wing drosophila causes an estimated $500 million in economic damage annually to U.S. fruit crops. Research will be undertaken to develop biological and cultural control practices that reduce or block pathogen transmission and develop selective insecticides and other tactics that minimize negative environmental impacts. Furthermore, ARS scientists will develop methods for early detection and response to invasive species, and to monitor shifting demographics among endemic pests. Insect resistance management (IRM) strategies are most effective at preserving the efficacy of valuable pest control tactics when applied as a component of integrated pest management (IPM) systems. Biological, ecological, and genetic interactions among pests, plants, and beneficial organisms will thus be investigated from field to landscape scales, and the resulting fundamental knowledge will be applied to improve both IRM and IPM tactics and strategies. Research will improve existing and develop novel ways to manage pests using technical advances in molecular biology and genetics, proteomics, physiology, biochemistry, genomics, computational biology, AI, and machine learning. Collectively these efforts will improve U.S. food security and help protect our nation's natural resources.

Research outcomes from this component will directly contribute to increased productivity across agricultural and horticultural cropping systems and increased export of U.S. agricultural products, all while better protecting our natural ecosystems. Novel and refined methods, including remote sensing, AI, machine learning, gene targeting, gene editing, RNAi technologies, symbiont and other plant vascular tissue delivery technologies, and biological control using predators, parasitoids, or entomopathogens, will provide resources for translational research and field-ready management strategies. When integrated with existing management practices, these tools will result in environmentally and ecologically sustainable systems-based approaches to pest management.

Problem Statement 3A. Early detection, prediction, and monitoring of pests, associated microbes, and beneficial control agents and pollinators

Invertebrate pests and associated microbes negatively affect all stages of agricultural production, processing, storage, and transportation; thus, the ability to detect, monitor, and predict their presence and movement is critical for effective control and management. U.S. agricultural production is threatened by both indigenous and invasive non-native invertebrate pest species that directly damage plants and in some instances vector plant pathogenic microbes. Invasive insect species, such as the spotted lanternfly, brown marmorated stink bug, and spotted wing drosophila, among others, threaten numerous agricultural crops through direct feeding. Other invasive invertebrates threaten entire agricultural industries by transmitting pathogens that cause devastating bacterial and viral diseases, such as the citrus psyllid that transmits the pathogen associated with citrus greening disease (huanglongbing). Phenotypes conferring resistance to one or more management strategy, including insecticides and cultural control practices, can arise and causal genes can subsequently and rapidly spread within and across pest populations. Furthermore, climate and land-use changes may influence the geographical host distributions, timing, and severity of both new and established agricultural pests. Early detection and response methods are needed for invasive pests and endemic pests that are expanding into new areas. A thorough understanding of the biology and ecology of beneficial and pest invertebrates and associated microbes, supported by modeling and active monitoring for the development of resistance traits, is essential for the advancement of cost-effective and environmentally safe pest monitoring strategies.

Research Focus

ARS will conduct research on population ecology, population genetics, genetic and genomic determinants of key traits, and the chemical ecology of agriculturally important pest and beneficial invertebrates and associated microbes. These research goals will be supported by mathematical models, computational biology, simulations, AI, and machine learning. The intent is to characterize invertebrate host preference and specificity, overwintering sites, and dispersal and movement between crops and alternate plant hosts. The research will determine the biotic and abiotic factors that affect the distribution of beneficial and pest arthropods across different agricultural and ecological landscapes, including a prediction of their survival under, and response to, shifting climatic conditions and control tactics. Effective arthropod monitoring requires targeted and sensitive sampling methods, necessitating the identification and development of semiochemicals, lures, improved traps, and remote sensing for target pests. Diagnostic tools to definitively identify or differentiate pests and associated microbes is essential, including the distinction of closely related species that have varied economic impacts. Factors that affect the induction and termination of insect diapause, dispersal, or migration will be investigated, as well as the role of pathogens and symbionts in the physiology, reproduction, and survival of these arthropods. Biomarkers will be developed to identify and monitor arthropod pests and plant pathogens associated with arthropod vectors. Research on methods to detect resistance to control strategies, including those based on plant-incorporated protectants (PIPs) and genetic modifications, will be pursued along with screening for resistant populations of target arthropod pests.

Anticipated Products

- Improved insect and microbe monitoring, detection, and sensing systems, and novel semiochemical and trapping approaches;
- Molecular-based diagnostic tools to identify or differentiate pests and associated microbes;
- Biomarker profiles for insect or microbe detection, including volatiles, proteins, and genes;
- Improved methods for early detection of pest resistance to control strategies;
- Pest identification and monitoring technologies, including development and optimization of acoustic, chemical, or visual cue sensors;
- Genomics data supporting deployment or enhancement of insect population control strategies;
- Models to predict distributions, population growth, and climate factors affecting emerging and invasive pest arthropods, associated microbes, or beneficial species;
- Predictive modeling for the agricultural community and stakeholder use;
- Economic threshold decision making tools or predictions for pest populations; and
- Population genetic structure models to identify movement of pest and beneficials species across agricultural landscapes.

Potential Benefits

- Increased production, exports, and economic marketability for U.S. agricultural products;
- Effective and sustainable management decisions for invertebrate and microbe control;
- Foundational knowledge on the biology, ecology, behavior, genetics, genomics and multitrophic interactions of insects, plants, and microorganisms;
- Improved prediction of impacts of native and non-native pest and beneficial invertebrates;
- Increased ability to rapidly respond to invertebrate and microbe pests;
- Improved ability to predict pest pressure within and among crops; and
- Technology transfer to stakeholders that will lead to improved invertebrate and microbe pest detection and management.

Problem Statement 3B. Develop new or improved management tools and knowledge to control pests

Insecticides and acaricides, including PIPs in genetically engineered crops, are often used prophylactically, and may negatively impact other aspects of integrated pest management (IPM). New and improved biological, behavioral, genetic, and cultural control methods integrated with new selective agents are needed to reduce agricultural reliance on broad spectrum pesticide chemistries. Challenges also remain in the development of strategies to deliver therapeutic molecules to plant vascular systems to improve plant health and to control plant-feeding arthropods, arthropod-borne plant pathogens or plant diseases. Novel strategies are required to apply host plant resistance, precision agriculture, biological control, and organic technologies into integrated pest management approaches. Changing climate, agricultural, horticultural, and natural ecosystems require swift, precise, and flexible arthropod management tools to adequately respond to shifting demographics of endemic, emerging, and invasive pest threats.

Research Focus

ARS research in Component 3B will focus on the development of new and improved tools, such as advanced molecular-based strategies (e.g., RNAi, genetic targeting, and symbiont technology) to identify, monitor, and control arthropods and arthropod-borne plant pathogens. ARS will develop and apply foundational knowledge of arthropod biology, pathology, vector biology, natural enemies, entomopathogens, genomics, molecular biology, plant-insect interactions, ecology, and pesticide resistance to develop novel and improved management practices incorporated into systems-based IPM strategies as part of Component 3C and other National Programs. These include precision tactics that improve interactions with and among beneficial organisms, animals, and natural resources at local and landscape scales while minimizing off-target and other negative environmental effects. Plant-insect interaction research may also encompass pollination, pollinator habitats, pests and pathogens of pollinators, and development of insect biotypes or arthropod genotypes that do not transmit plant pathogens. Research on potential management tools may range from biocontrol, bioactive peptides, insecticidal RNAs, neuropeptide mimics, banker plant strategies, cover crops, cultural control methods, and novel approaches for mass trapping and mating disruption (including semiochemicals, acoustics, and light). Molecular analyses, including DNA barcoding and metagenomic sequencing, will identify trophic links among pest, pathogen, and predator species. Research will also focus on improved systems for production of biocontrol agents, insecticidal formulations that selectively impact molecular or cellular functions of pest species, and approaches for molecule delivery that increase efficacy and limit off target exposures. Studies to evaluate efficacy and persistence of selective insecticides and PIPs will be conducted to enhance conservation of biological control agents. Many of these tools can be used in both conventional and organic agricultural systems. ARS Overseas Biological Control Laboratories will identify and evaluate classical biological control agents under quarantine and non-quarantine conditions, informed by knowledge of their biodiversity and ecological interactions in relation to target pests. Research will focus on the identification of plant or insect genes or resistance traits to aid plant breeders in the development of new crop varieties. Research on other approaches for pest management will also be developed, such as improvements to the sterile insect technique (SIT). Formulations of plant signaling compounds for influencing crop pest behavior will be developed to improve pest trapping and detection. For arthropod species that transmit plant pathogens, ARS will investigate the epidemiology of these interactions, including pathogen acquisition by the vector and subsequent plant infection and pathogen transmission. Research will focus on the development and delivery of new and improved molecules (synthetic or biological) to control arthropod vectors and/or block or suppress plant pathogen acquisition and transmission by insect vectors, the microbial communities associated with insect vectors (including interactions with entomopathogens, microbial symbionts, and host plants), assessing the impact of climate change on populations of pests and their natural enemies, and the management of pests in controlled environment agriculture (CEA).

Anticipated Products

- New and interdisciplinary approaches for controlling pests and associated vector-borne pathogens;
- Increased efficacy and optimal longevity of selective chemistries for pest management;
- Effective biological and microbial-based pest management tools, including attractants, repellents, and biopesticides that are alternative to broad spectrum pesticides;
- New production, delivery, and formulation processes for natural enemies, microbial control agents, plant-based delivery systems, RNAi-based control agents, and other technologies;
- Increased efficacy and cost effectiveness for SIT and population control programs;
- New tools for use in breeding and improved germplasm for host plant resistance to arthropods;
- Fundamental knowledge on the biology, ecology, behavior, genetics, and multitrophic interactions of insects, plants, and microorganisms;
- New biological control agents for pests and associated pathogens;
- Novel control strategies for arthropod-transmitted plant pathogens, including direct delivery and symbiont technologies;
- Molecular-based pest suppression tools;
- Management tools based on acoustic, chemical, and visual pest stimuli;
- Successful introductions of natural enemies for classical biocontrol of invasive and emerging pests; and
- New knowledge and tactics to support beneficial species in crops, rangelands, CEA, and natural systems.

Potential Benefits

- Minimized impacts on non-target organisms;
- Precision pest and pathogen management tools for use in integrated systems or as alternatives to broad-spectrum chemistries;
- Tools to suppress pathogens of plants and pathogens of beneficial insect species such as pollinators;
- Improved and novel methods for cultural control of crop pests;
- Optimized integrated and/or areawide IPM strategies;
- Public/private partnership on delivering pest control options;
- Strategies for securing the bioeconomy of the future; and
- Positive economic and cost-saving impacts for stakeholders.

Problem Statement 3C. Integrate management strategies to control arthropod pests

Synthetic chemical-based arthropod control and management practices are increasingly challenged by resistant pest populations as well as environmental and market-driven concerns. These pressures are ongoing despite the use of non-chemical control strategies that incorporate a wide variety of tools, such as crop rotation and deployment of both genetically engineered and conventionally bred pest-resistant crops. Quantifying potential benefits and drawbacks of selective insecticide use is essential for optimal implementation of systems-based IPM strategies, which also incorporate biological, behavioral, genetic, and cultural components, with the goal of reducing agricultural reliance on broad spectrum pesticides. Additionally, agricultural landscapes must be proactively managed to inhibit or resist pest proliferation. Environmental factors (e.g., soil and topography) can influence the distribution and density of pest populations in individual fields, creating opportunities for targeted management that would reduce both pesticide input cost and negative environmental impact. New strategies are needed to protect keystone pollinator species from habitat destruction, broad-spectrum insecticide exposure, pathogens, and parasites. Finally, there is a need to develop optimum combinations of methods for pest and arthropod-borne plant disease management in the field, as well as in CEA, which minimize or mitigate their negative impacts on the environment and human health. Developing the best methods to integrate sustainable pest management practices into complex agricultural production systems will maximize their effectiveness, minimize their environmental and economic costs, and increase agility and resiliency in responding to new stresses imposed by climate change, regulatory constraints, and invasive species. Success in this regard is critical to national food and fiber security while keeping U.S. farmers and agricultural sectors competitive in global markets.

Research Focus

Research will focus on testing combinations of management strategies using systems-based, dynamic-threshold approaches to IPM in field, greenhouse, and other controlled environments. Research on combined strategies will include management of insect resistance to environmentally benign control tactics, both multiple pest and weed (see Component 2) management strategies, as well as assessment of component compatibility with existing management schemes. This research will include augmentative and conservation biological control and the development and implementation of cultural control and new technologies. Under Component 3C, ARS will conduct research on the movement of biocontrol agents and their target hosts, development of control-tactic resistance, and ecological interactions among pollinators, predators, parasitoids, pathogens, and plants across different habitats, landscapes, and management practices. The agency's Overseas Biological Control Laboratories will investigate behavior and ecological interactions of exotic pests and natural enemies in their native environments. Research will be conducted on systems biology to facilitate the integration of data from the molecular to landscape levels into management schemes, including harnessing the capacity for integrated use of drones, AI, and machine learning technologies for high throughput data collection, identification, and analyses.

Anticipated Products

- Effective and integrated biologically-based pest control strategies applicable to diverse production systems;
- Improved pest and arthropod vector-borne disease control and increased numbers of beneficial organisms in cropped and non-cropped system management schemes;
- Improved decision-making tools for pest management, including refined economic thresholds and appropriate integration of novel technologies, such as drones, AI, and machine learning, into current production practices;
- Increased understanding of the influence of local and landscape environmental factors on multitrophic interactions among arthropods, plants, and microorganisms;
- Improved strategies for augmentation, release, and conservation of biological control agents;
- Expanded understanding of the complex ecological interactions that influence pests and/or beneficial organisms in production systems, which is critical to developing more effective pest management strategies;
- Improved data-driven foundation for integrative approaches for management of pest and beneficial organisms that will be disseminated to the public, stakeholders, and applicable Federal agencies to support decisions that will maintain U.S. market share and improve competitiveness; and

- Sustainable best management practices in agricultural production systems that improve agility and resiliency to new stresses, including regulatory challenges.

Potential Benefits

- Reduced reliance on broad spectrum insecticides, leading to enhanced human health and minimized negative environmental impacts of pest management;
- Improved pest control strategies that incorporate knowledge of pest dispersal and seasonal movement between crops and other habitats in the landscape;
- Enhanced pest control using predators, parasitoids, and entomopathogens in agricultural and landscape systems;
- Increased access to new or improved IPM systems, including dynamic pest thresholds and strategies that employ use of drones, AI, and machine learning, thereby reducing loss and increasing consumer acceptance;
- Increased ability to monitor and suppress pests and pest complexes at an areawide scale through cooperative employment of compatible integrated tactics;
- Increased longevity of environmentally benign control product efficacy through development of practical insect resistance management strategies;
- Increased pest control options allowing flexible and rapid response to new agricultural, environmental, or regulatory challenges, thereby providing resiliency in production systems;
- Increased abundance and richness of native pollinators in agricultural landscapes, thereby increasing resilience of crop production systems;
- Improved ability to protect crops from pests while protecting agricultural land and the environment for long-term sustainability and securing food and fiber production;
- Improved quality and security of the national food and fiber supply, while increasing cost-effectiveness, competitiveness, and vitality of U.S. agricultural production; and
- Increased ability to facilitate intra-agency, inter-agency, external stakeholder (e.g., non-governmental organizations, state agencies, universities, commodity associations, industry), and international cooperation for crop protection and solutions to ARS Grand Challenges.

Component 3 Resources

- Albany, California: Invasive Species and Pollinator Health Research Unit
- Ames, Iowa: Corn Insects and Crop Genetics Research Unit
- Ames, Iowa: Plant Introduction Research Unit
- Beltsville, Maryland: Invasive Insect Biocontrol and Behavior Laboratory
- Beltsville, Maryland: Sustainable Agricultural Systems Laboratory
- Beltsville, Maryland: Sustainable Perennial Crops Laboratory
- Brookings, South Dakota: Integrated Cropping Systems Research Unit
- Byron, Georgia: Southeastern Fruit and Tree Nut Research Unit
- Charleston, South Carolina: Vegetable Research Unit
- College Station, Texas: Aerial Application Technology Research Unit
- College Station, Texas: Insect Control and Cotton Disease Research Unit
- Columbia, Missouri: Biological Control of Insect Pests Research Unit
- Columbia, Missouri: Plant Genetics Research Unit
- Corvallis, Oregon: Horticultural Crops Research Unit
- Fargo, North Dakota: Insect Genetics and Biochemistry Research Unit
- Fargo, North Dakota: Sunflower and Plant Biology Research Unit

- Fort Detrick, Maryland: Foreign Disease-Weed Science Research Unit
- Fort Pierce, Florida: Subtropical Insects and Horticulture Research Unit
- Gainesville, Florida: Chemistry Research Unit
- Gainesville, Florida: Insect Behavior and Biocontrol Research Unit
- Hilo, Hawaii: Tropical Crop and Commodity Protection Research Unit
- Hilo, Hawaii: Tropical Pest Genetics and Molecular Biology Research Unit
- Houma, Louisiana: Sugarcane Research Unit
- Ithaca, New York: Emerging Pests and Pathogens Research Unit
- Maricopa, Arizona: Pest Management and Biocontrol Research Unit
- Newark, Delaware: Beneficial Insect Introduction Research Unit
- Parlier, California: Crop Protection and Quality Research Unit
- Peoria, Illinois: Crop Bioprotection Research Unit
- Salinas, California: Crop Improvement and Protection Research Unit
- Sidney, Montana: Northern Plains Agricultural Research Laboratory
- Stillwater, Oklahoma: Wheat, Peanut and Other Field Crops Research Unit
- Stoneville, Mississippi: Biological Control of Pests Research Unit
- Stoneville, Mississippi: Southern Insect Management Research Unit
- Stoneville, Mississippi: Crop Production Systems Research Unit
- Tifton, Georgia: Crop Protection and Management Research Unit
- Wapato, Washington: Temperate Tree Fruit and Vegetable Research Unit
- Wooster, Ohio: Applications Technology Research Unit
- The Office of National Programs Overseas Biological Control Laboratories with locations in Montpellier, France; Thessaloniki, Greece; Beijing, China; Hurlingham, Argentina; and Brisbane, Australia

Component 4: Postharvest Protection of Commodities

The importance of postharvest pest management is multifaceted, impacting food quality, safety, and security, as well as domestic and international trade. Moreover, finished food products that have been processed, packaged, and globally distributed for consumer sale represent the maximum economic investment for the commodity, so losses from pests are particularly expensive. Pests attack crops that span multiple agroecosystems and commodities, including corn, wheat, rice, sorghum, ornamentals, nuts, vegetables, and fruits, and can also be inadvertently moved from infested to non-infested areas throughout food supply chains. Chemical treatments can significantly reduce pest populations in raw and finished commodities, but their usage is increasingly constrained due to a combination of regulatory restrictions and the emergence of resistance, and effective alternatives are lacking. For this reason, the export of some commodities is dependent on the ability to eliminate their associated pests, weeds, and/or pathogens while maintaining quality, and the detection and elimination of insect pests is paramount to ensuring the safe global movement of agricultural commodities. ARS has already developed and applied cutting-edge methods that have led to the preservation of U.S. exports valued at billions of dollars; these have included new phytosanitary treatments for navel orangeworm, psyllids, stink bugs, and mites; optimized usage of new fumigant alternatives to methyl bromide; development of new and effective pest control tactics for reducing insecticide residues on human and animal food; and identification of new products, including essential oils, for horticultural use. In addition to IPM tactics, ARS has also made significant strides in implementing and interpreting pest monitoring programs in bulk grain storage and has developed genomic and molecular methods for predicting phenotypes that can be used to develop and implement next-generation pest management tools.

ARS will continue to conduct research that covers the full spectrum of needs in this area, from reducing and preventing pest infestation during harvest and storage, respectively, to improving pest detection and developing innovative and reduced-risk treatment methods based on sound biological, physical, and chemical components while maintaining commodity quality. Research outcomes from this component will directly contribute to the development of effective and resilient management strategies that will reduce pest damage in postharvest commodities, limit the spread of exotic pests within the United States, and ensure U.S. competitiveness in the international commerce of agricultural commodities. These advances benefit other nations as well, contributing significantly to world food security and biosecurity by preserving food quality after harvest and halting the introduction of invasive pests, weeds, and pathogens.

Problem Statement 4A: Manage Pests of Fresh and Durable Commodities

Pests negatively impact both fresh and durable commodities through direct feeding damage, contamination of food materials, and vectoring pathogens. They can result in reduced market access; rejected shipments; increased costs; and negative reactions by producers, processors, and consumers. There is a critical need for new and practical tools that are sensitive and effective to detect infestations of exotic pests for subsequent exclusion, control, and eradication. Information on the basic biology and ecology of pests in the field, orchard, or greenhouse during preharvest stage is required to determine the risk they pose and to enable an appropriate response to potential domestic and international threats. Information on the basic biology and ecology of pests in postharvest environments is also needed to improve detection, mitigation of infestation risk, and targeted interventions. While broad-spectrum chemical treatments have historically been used to control pests of fresh and durable commodities, the viability of such methods has declined due to regulatory changes, development of pesticide resistance, consumer preference, and increased focus on environmentally friendly management. New and improved monitoring and management tools and systems approaches for effective program integration are needed to respond to the reduced use of broad-spectrum chemicals and reduce the scope of treatment to areas where pests are active. There is a continuing need to improve current systems-based management strategies and to develop additional as alternatives to methyl bromide. The challenge is to develop complete systems approaches that span both pre- and postharvest environments and successfully integrate multiple elements, resulting in effective, environmentally sound, and economically feasible strategies that suppress or eradicate populations of pests of harvested commodities while minimizing damage to these commodities and maintaining market quality.

Research Focus

ARS will develop new and effective systems approaches to reduce the incidence of pests in postharvest fresh and durable commodities, which will also require improvements in methods for the prevention, detection, monitoring, and optimal management of pest infestations in commodities and products made from these commodities. In some cases, this will involve monitoring and interventions prior to harvest. Additionally, proactive strategies will be developed to improve pest control based on understanding of the biology, behavior, and ecology of emerging and systemic stored-product pests, regulatory decisions, and pesticide resistance. Improved monitoring tools and management programs for stored commodities will be developed and used to evaluate pest population temporal and spatial trends and elucidate when and where targeted treatments can be applied to prevent further infestation of stored commodities and reduce broad-spectrum applications. Temporal and spatial trends can be expanded to develop predictive models to evaluate and study how pests respond to climate change. Application of AI for improved pest detection and identification will improve ability to rapidly respond to pest activity. Behavioral studies will be conducted to develop new tactics to reduce and prevent infestations in commodities, while genomic and proteomic studies will be used to develop methods for predictive biology to understand the risk these pests pose to different commodities, as well as their susceptibility to insecticides and fumigants. Methods for analyzing large amounts of complex biological, genomic, and ecological data will be developed to integrate these data into existing management programs and/or develop new management strategies.

Anticipated Products

- Novel methods and strategies for detecting, identifying, monitoring, and managing pests of fresh horticultural crops, ornamentals, and stored fresh and durable commodities;
- Improved methods for use in decision-making systems to manage postharvest pests;
- Commodity-based systems approaches to ensure the safe import and export of commodities, minimizing losses due to pest damage while retaining crop quality;
- Systems-based approaches to prevent and minimize commodity losses and maintain quality at all stages of the marketing chain;
- Genomic tools and molecular methods for predictive biology;
- Precision integrated pest management tactics; and
- Developed and/or improved existing chemistries used to disinfest commodities.

Potential Benefits

- Reduced incidence of pest infestations and economic losses of postharvest commodities;
- Increased availability of high-quality commodities;
- Cost-effective and ecologically sound management strategies for postharvest pests;
- Enhanced U.S. production and distribution of agricultural commodities; and
- Improved U.S. Government compliance with international regulations.

Problem Statement 4B: Improve Existing Methods and Develop New Quarantine Treatments and Approaches

New or improved quarantine treatments for commercial commodities are needed to prevent the geographical spread of exotic/invasive pests and to guarantee the safety of commodity movement from agriculturally quarantined areas. Existing quarantine treatments that cause damage and quality reduction are unacceptable in the market; therefore, any method proposed for implementation must be effective and maintain commodity quality. Quarantine treatments that are practical, economical, and environmentally sound are urgently needed to replace methyl bromide to ensure the quality of commodities and enable their transport to processors in markets. Therefore, ARS will conduct studies to evaluate quality, storage characteristics, and marketability of commodities that are subjected to quarantine treatments and conduct research to mitigate negative impacts on the commodity and the environment from treatment.

Research Focus

ARS will conduct research to both improve current and develop new quarantine treatments to ensure quality of commodities in postharvest marketing channels. ARS will develop new and effective system-based approaches for detecting and identifying insects of concern and develop chemical and non-chemical techniques, based on insect biology and ecology principles, to control pest infestation on fresh commodities and to control storage pests in processed commodities that are susceptible to re-infestation and microbial contamination. ARS will conduct research to evaluate alternatives to methyl bromide fumigation that have minimal environmental impact for postharvest control of pests in fresh and durable commodities. ARS will establish management practices and technologies to maintain the quality of fresh commodities and to enhance market access.

Anticipated Products

- New or improved postharvest and quarantine treatments;
- New strategies to retain and enhance market access;
- Treatments with improved safety that maintain the postharvest quality of fresh produce;
- Methods for rapid detection and identification of pests; and
- Methyl bromide alternatives.

Potential Benefits

- Exclusion of exotic/invasive pests from the United States;
- Elimination of trade barriers for U.S. commodities;
- Retention or expansion of market access for U.S. commodities;
- Increased income for U.S. producers through increased trade;
- Increased availability of quarantine treatments;
- Reduced environmental impact of postharvest treatments;
- Reduced economic losses of commodities to postharvest pests;
- Enhanced U.S. production and distribution of commodities; and
- Improved U.S. Government compliance with international regulations.

Component 4 Resources

- Gainesville, Florida: Insect Behavior and Biocontrol Research Unit
- Hilo, Hawaii: Tropical Crop and Commodity Protection Research Unit
- Manhattan, Kansas: Stored Product Insects and Engineering Research Unit
- Miami, Florida: Subtropical Horticulture Research Unit
- Parlier, California: Commodity Protection and Quality Research Unit
- Salinas, California: Crop Improvement and Protection Research Unit
- Wapato, Washington: Temperate Tree Fruit and Vegetable Research Unit