United States Department of Agriculture

Agricultural Research Service

NATIONAL PROGRAM 303

Plant Diseases

ACTION PLAN

2022-2026

USDA-AGRICULTURAL RESEARCH SERVICE

NATIONAL PROGRAM 303 – PLANT DISEASES

Action Plan 2022 – 2026

Vision

Crops and landscapes protected from plant diseases using scientifically based, environmentally sound, and cost-effective methods.

Mission

Develop control strategies that are effective and affordable while maintaining environmental quality to reduce losses caused by plant diseases.

Relationship of This National Program to the USDA Strategic Plan

This action plan outlines research that directly supports the following goals and objectives of the USDA Strategic Plan for 2018-2022.

Goal 1. Ensure USDA Programs are Delivered Efficiently, Effectively, with Integrity and a Focus on Customer Service.

> **Objective 1.4.** Improve Stewardship of Resources and Utilize Data-Driven Analyses to Maximize the Return on Investment.

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 Disease.

Goal 3. Promote American Agricultural Products and Exports.

> **Objective 3.2.** Prevent or Resolve Barriers to Trade that Hinder U.S. Food and Agricultural Exports.

Goal 5. Strengthen the Stewardship of Private Lands Through Technology and Research.

> **Objective 5.1.** Enhance Conservation Planning with Science-Based Tools and Information.

Relationship of this National Program to the USDA Science Blueprint

This Action Plan fits under the general guidance of the USDA Science Blueprint, Theme 1: Sustainable Ag Intensification: Plant Production, Health, and Genomics. Additionally, this Action Plan advances OneUSDA Scientific Excellence through interconnectedness with other USDA agencies and mission areas. Research outlined in this Action Plan also supports Goal 2, Safeguarding American Agriculture, in the Animal and Plant Health Inspection Service Strategic Plan FY 2019-2023. This action plan specifically outlines research that supports: Objective 2.1: Prevent damaging plant and animal pests and diseases from entering and spreading in the United States to promote plant and animal health; Objective 2.2: Manage plant and animal pests and diseases once established in the United States to promote plant and animal health; Objective 2.3: Ensure effective emergency preparedness and response systems; and Objective 2.6: Provide and coordinate timely diagnostic laboratory support and services.

Relationship of this National Program to the USDA ARS Strategic Plan

This Action Plan supports the 2018-2020 ARS Strategic Plan, Goal Area 3: Crop Production and Protection, Goal 3.3: Improve and expand our knowledge of existing and emerging plant diseases and develop effective and sustainable disease management strategies that are safe to humans and the environment. Research in National Program (NP) 303 complements research in other Agricultural Research Service National Programs, particularly those in the Crop Production and Protection section, such as Goal 3.1 (Plant Genetic Resources, Genomics and Genetic Improvement), Goal 3.2 (Crop Production), and Goal 3.4 (Crop Protection and Quarantine).

Performance Measure
Provide scientific information to increase our knowledge of plant genes, genomes and biological and molecular processes to protect crops and cropping systems from the negative effects of pests and infectious diseases. Develop sustainable control strategies for crop pests and pathogens based on fundamental and applied research that are effective and affordable, while maintaining food safety and environmental quality.

Introduction
Sustainable crop production is essential to the U.S. economy and food security. The USDA National Agricultural Statistics Service reports the total value of all horticultural specialty sales in 2019 was over $13.8 billion, and in 2018 the total value of all principal crops (field crops, fruits and nuts, vegetables) was over $184 billion. The U.S. population has an annual growth rate of 0.6%; however, since the 1920s, land use for farming has remained steady at approximately 1 billion acres. As the population increases, yields and quality of food crops will need to increase on available farmland to maintain food security and farm profitability.

Plant diseases have a significant impact on yields and quality. These diseases result in billions of dollars in economic losses and management inputs each year to crops, landscapes, and forests in the United States. Plant diseases reduce yields, lower product quality or shelf-life, decrease aesthetic or nutritional value, and may contaminate food and feed with toxic compounds. Plant diseases are caused by abiotic factors and biotic organisms including fungi, oomycetes, bacteria, viruses, viroids, and nematodes. Control of plant diseases is an essential component of food security and also ensures an adequate supply of non-food crops for feed, fiber, energy, and horticultural uses. Effective control of plant diseases requires an understanding of the biology of these disease-causing agents.

To improve plant health, the outcomes and impact of NP 303 research and outreach activities include production of abundant supplies of high-quality crops for all citizens, supporting productive and sustainable agricultural and forest industries, and managing healthy landscapes. Additionally, proactive research addresses climate change and the increased safe global movement of plant material. This research is necessary to combat emerging domestic diseases and exotic diseases not yet found in the United States in order to protect our crops as well as to maintain and expand export markets for U.S. plants and plant products.

In order to prevent or reduce the spread of plant pathogens, rapid, reliable pathogen detection and identification procedures for accurate and timely disease diagnoses are of critical importance. As international trade of plant products increases and as the United States and its trading partners seek to protect themselves from the introduction of exotic plant pathogens, early and accurate detection will be critical. Therefore, NP 303 will focus on developing or improving diagnostics for existing, emerging, or exotic pathogens; developing or improving pathogen detection and/or quantification methods (*e.g.*, remote sensing); surveying pathogens to monitor for diversity and genetic changes; systematics, evolution, comparative genomics, and population genomics of pathogens; and understanding the etiology of exotic, emerging, or poorly understood plant diseases.

Critical to developing effective disease management methods is an understanding of the genetics, ecology, and epidemiology of pathogens; how the changing environment affects the spread of plant pathogens; and an in-depth knowledge of the fundamental biology of pathogen-host-vector interactions and the phytobiome. Therefore, NP 303 will also investigate the molecular, genomic, cellular, and organismal aspects of plant pathogens, plant-associated microbes, and their interactions with plant hosts; interactions of pathogens with vectors (including vector-plant interactions as they influence pathogen transmission and disease development and alternative hosts); ecology, epidemiology, and spread of pathogens and vectors; and impact of climate change on pathogens, their vectors, and disease expression.

Plant protection is a critical element for increasing or maintaining yields. It is estimated that without plant protection, 70 percent of crop yields could be lost to pests. In order to achieve plant protection, effective, safe, environmentally-sound, affordable, and sustainable strategies and tools are needed. Plant pathogens exhibit a remarkable ability to change and adapt, allowing them to overcome resistance genes in crop varieties or evade control strategies and chemicals that were once effective. The principal goal of this component is to improve plant health through the genetic, cultural, chemical, or biological manipulation of the host, pathogen, vector, plant-associated microbial communities, or beneficial organisms. This component includes research on: development, characterization, and deployment of genetic resistance (conventional or transgenic/intragenic) against pathogens or vectors; manipulation of cultural practices or plant-associated microbes to promote plant health or to manage pathogen or vector populations; pre-plant approaches to reduce pathogen pressure that includes optimization and synergistic methods using soil fumigants and alternatives for methyl bromide; development, characterization, and deployment of biological agents that reduce pathogen or vector populations or otherwise enhance plant health; improvements to the efficacy of chemical agents to control pathogen and vector populations; and development of integrated disease management systems to improve plant health and crop production.

Stakeholder Input

In developing this Action Plan, USDA ARS Scientists and National Program Leaders (NPLs) for Plant Diseases solicited stakeholder input that would: 1) inform ARS about the status of ongoing industry challenges; 2) identify priorities to direct strategic research planning activities; and 3) inform ARS management about industry issues as they make programmatic decisions. ARS representatives regularly communicate with stakeholders by participating in meetings and maintaining connections with professional organizations such as the American Phytopathological Society, the American Society of Agronomy, the Crop Science Society of America, and the American Society of Horticultural Science. Finally, this Action Plan was informed by the results from a Retrospective Review conducted by an external panel of industry members and academic scientists; this review provided a thorough evaluation of the effectiveness and impact of the ARS National Program for Plant Diseases from 2016 to 2020.

ARS Plant Disease Research Capacity

ARS conducts research under the ARS National Program for Plant Diseases at 24 different locations through 47 projects performed by 120 ARS scientists.

Component 1: Plant Pathogen Resources, Systematics, Genomics, and Diagnostics.

Effective and sustainable plant health management depends critically on our ability to understand the cause(s) of diseases and to identify and classify the causal and/or associated microorganisms and their vectors. Agricultural commodities are challenged on an ongoing basis by a plethora of endemic pathogens and diseases causing billions of dollars in crop losses annually. However, the United States food supply, and fiber, forage, landscape, and natural resources are also threatened by the emergence of new pathogens and strains that continually arise by migration, genetic mutation, or recombination. Furthermore, expanding globalization of agricultural and horticultural trade inevitably allows for the movement of exotic pathogens that could devastate United States agriculture if not detected and managed.

Consequently, the security of the United States food supply, and fiber, forage, landscape, and natural resources, depends in part on the timely detection and identification of novel pathogens or strains emerging within, or with the potential to be introduced into, the United States. This is true regardless of whether the introduction is accidental, deliberate, or via natural forces. Climate change, global agricultural expansion, and consequent international trade of commodities have made timely detection of known pathogens of mounting concern, and the identification of new and emerging pathogens increasingly important.

In the United States, the private sector offers diagnostic kits and reagents for plant pathogen identification. However, to be commercially viable these private sector diagnostic products are typically available for only a relatively small number of high-impact plant pathogens. Consequently, there is a critical need for publicly funded research into the development of new, rapid, sensitive, accurate, and inexpensive detection and diagnostic methods for nearly all existing, evolving, and emerging pathogens. There is also a need to standardize and integrate diagnostic tools and approaches across hosts. High-throughput sequencing of pathogen genomes and plant-associated microbiomes provides new opportunities for identifying changes in pathogen populations and mechanisms of pathogen emergence. The detection of pathogen-associated phenotypic traits such as the production of effectors, toxins, or antimicrobial resistance, etc. on plant agricultural products is also recognized as an ongoing challenge.

Collaborative efforts with the USDA Animal and Plant Health Inspection Service, the National Plant Diagnostic Network, state departments of agriculture, industry, stakeholder groups, regional diagnostic laboratories, and international agricultural research centers, will identify the most critical diagnostic needs and facilitate the development of standardized, validated, and optimized tools appropriate for end users, customers, and stakeholders. Research within this component will complement and draw from research conducted by the other components of NP 303 and NP 301, Plant Genetic Resources, Genomics and Genetic Improvement.

Problem Statement 1A: Characterize and Integrate Computational and Culture Resources, Genomics, and Systematics of Plant Pathogens.

Effective and sustainable plant health management strategies require ongoing monitoring and characterization of pathogen genotypes, physiological specialization, host-range, environmental sensitivities, and other pathogenicity-related traits. Pathogens continually emerge, evolve, and adapt across all man-made and natural ecosystems. In many cases, the causal agents of exotic, emerging, or even endemic diseases have not been accurately identified, or may be unknown to science. Some destructive plant diseases are caused by pathogen complexes or organisms that cannot be cultured and can only be distinguished through their genetic signatures or high-resolution microscopy. In other cases, morphologically identical variants of the same pathogen species differ in pathogenicity on host plant species or varieties. These differences in pathogenicity can be due to relatively minor alterations in gene sequence, gene expression, or in secondary modification of proteins and other metabolites. In the current era of high-throughput nucleic acid sequencing, new technologies are now readily available whereby the whole genome or transcriptome of newly emerging pathogens or even the entire microbiome residing within an ecosystem can be sequenced simultaneously. These genomic approaches rely heavily on computational resources and tools. All of these state-of-the-art tools and technologies are now routinely employed and allow for the rapid development of detection methods and the integration of morphological, genotypic and phenotypic data in a way that was not previously possible. Knowledge developed by this program, based on comparative genomic, population genomic, and phenotypic approaches, provides a biological framework for continued and in-depth investigations of pathogen biology and ecology. This is necessary for effective plant health management and to reduce losses due to plant diseases.

Research Needs

The taxonomy of plant pathogens and their vectors is critical information needed for understanding disease etiology, transmission, and control, but there are large gaps in knowledge for many groups of pathogens and viral vectors. Comprehensive knowledge about the etiology and systematics of domestic and exotic plant pathogens and viral vector species via structural, molecular, genomic, and other approaches are needed. Classification systems for accurately predicting biological properties critical to disease diagnosis and control are also required. High-throughput sequencing combined with computational approaches will provide the opportunity for understanding the evolution of pathogen populations in almost real-time, yet computational approaches require centralized databases and standardized resources. Many ARS laboratories have developed in-house resources such as culture collections, computational pipelines, and related assets, but these tools and resources are not easily transferable to other locations or laboratories. Hence, there is a real need to integrate databases; strain collections; and genomic, systematics, and computational tools and resources across research groups.

Anticipated Products

- Pathogen genome sequences that can be used in systematics, population genetics and evolutionary studies, and for developing diagnostic molecular tools which can inform strain identification, adaptation, transmission, pathogenicity, etc.
- Assays for rapid identification of pathogens using genome sequences and machine learning.
- Pathogen surveys (particularly at points of entry) that monitor pathogen diversity and genetic changes in pathogen populations.
- Identification of vectors of existing, new and emerging viruses.
- Characterization of key genetic, biological, and ecological features of exotic plant pathogens in advance of their introduction into the United States.
- Phylogenetic systems for classifying and understanding pathogen evolutionary relationships that are linked to, and integrated with, robust voucher specimen collections and databases.
- Characterization of microbe/pathogen complexes responsible for important plant diseases that currently have unknown etiology and ecology.
- Dedicated and curated culture collections and genomic databases that provide references for re-emerging and newly emerging pathogens.
- Computational resources and pipelines, large integrated databases, and infrastructure with cloud-based services for rapid response, identification, and data mining.

Potential Benefits

- Enhanced knowledge of pathogen genetic diversity, especially with respect to pathogenicity and evolution, thereby enhancing the ability to predict disease outbreaks.
- Improved taxonomic description and classification of pathogen groups that utilize systematic, morphological, biological, and molecular data.
- Rapid identification of novel pathogen strains, variants, and newly emerging pathogens.
- Integrated databases and computational resources that lead to pathogen characterization.

Problem Statement 1B: Develop and Improve Plant Pathogen Diagnostics, Detection and Identification.

Accurate and accelerated methods to identify the causes of plant diseases are critical for disease management and for the safe movement of agricultural and horticultural products. Disease symptoms may be subtle or shared by one or more pathogens in such a way that the disease cannot be diagnosed through visual examination. Accurate diagnoses are often dependent on pathogen-specific molecular, biochemical, or genomic tests. Serological or nucleic acid-based tests are readily available for many high-impact pathogens of major commodities but are lacking for most pathogens, especially those affecting minor and specialty crops. Some pathogens may change rapidly, requiring ongoing modifications of diagnostic tools. While some diagnostic tests can readily identify a pathogen, in most instances this provides no information about pathogen viability and whether or not the pathogen has the potential to cause disease. This problem is particularly intractable in cases with complex communities such as seed-borne and soilborne pathogens and associated microbes. Still other pathogens are fastidious and are not easily cultured, propagated, visually identified, or separated from the host material. There may be no effective sampling methods available for detecting pathogens within the soil or in some plant materials. This is especially true for pathogens that infect large, fibrous or woody plants. New and existing technologies to rapidly diagnose pathogens need to be explored, including the use of robotics, automation, spectral analysis, x-ray micro CT analysis, and biosensors.

Research Needs

Plant pathogens continue to evolve and emerge, and thus diagnostic methods need to be continually adapted and improved for effective control. Furthermore, there is a need for standardizing diagnostic tools and approaches across research and diagnostic laboratories. Some diagnostic tools need to be developed to detect yet unknown pathogens and might rely on tools such as high throughput sequencing of microbiomes. For all diagnostic methods, statistical approaches and guidelines are needed that provide information on biological significance of any finding. Novel technologies such as biosensors and automated detection are needed. Many ARS laboratories have developed resources for pathogen detection and diagnosis, but these tools and resources are not easily transferable to other diagnostic laboratories. Hence, there is a real need to standardize diagnostic tools and resources and guidelines on biological relevance across research groups.

Anticipated Products

- Inexpensive, user-friendly, and/or real-time diagnostics to detect and identify plant pathogen species, strains, or pathotypes, using limited amounts of input material for general use.

- Standardized diagnostic assays that are integrated across pathogens by hosts.
- Improved statistical approaches for validating current and new diagnostic tests.
- More effective methods, such as nucleic acid, protein, transcriptome, or metabolite biomarker systems or microscopy, for distinguishing pathogen genotypes, viability, and revealing biological relevance.
- Diagnostic methods capable of concurrently detecting and identifying several pathogens and/or their traits of interest such as toxins, effectors, antimicrobial/fungicide resistance, etc.
- Diagnostic keys, images, compendia, and other guides for identifying pathogens and diseases.
- Improved methods for selection of diagnostic reagents (*e.g.*, PCR primers, antigenic targets, probes for precision microscopy) and systematic information from genomic data.
- Biosensors and automated detection methods, such as plant reporter genes, canine and standard volatile detection, robotics/automation, spectral analysis, x-ray micro CT, etc., for plant pathogen detection.
- Knowledge of biological relevance and viability of pathogens and viral vectors when detected in a diagnostic assay.
- Key contributions to national and international consortia for global pathogen surveillance through strategic partnerships and alliances.

Potential Benefits

- Quicker, more effective, and more broadly applicable (from plants, soil, air, etc.) pathogen detection and identification methods.
- Improved taxonomic description and classification of pathogen groups that utilize systematic, morphological, biological, and molecular data.
- Rapid, accurate and standardized identification of plant pathogens worldwide by diagnosticians.
- Control or eradication of invasive pathogens accelerated by early detection and by taxonomic and other knowledge obtained prior to their introduction into the United States.
- Critical information on biological relevance of diagnostic methods.
- Rapid pathogen detection and scientific data to facilitate the safe import and export of agricultural products and other plant materials while minimizing the potential for introduction of exotic pathogens.
- Facilitate Pest Risk Assessment protocols and support U.S. quarantine programs.

Component 1 Resources:

The research needs under this component are being addressed at the following 19 ARS locations:

- **Beltsville, Maryland:** Food Quality Laboratory (FQL); Genetic Improvement of Fruits and Vegetables Laboratory (GIFVL); Soybean Genomics and Improvement Laboratory (SGIL); Molecular Plant Pathology Laboratory (MPPL); Mycology and Nematology Genetic Diversity and Biology Laboratory (MNGDBL); National Germplasm Resources Laboratory (NGRL); Sustainable Perennial Crops Laboratory (SPCL); Sustainable Agricultural Systems laboratory (SASL)
- **Charleston, South Carolina:** U.S. Vegetable Laboratory (USVL)
- **College Station, Texas:** Insect Control and Cotton Disease Research Unit (ICCDRU)

- **Corvallis, Oregon:** Horticultural Crops Research Unit (HCRU)
- **Davis, California:** Crops Pathology and Genetics Research Unit (CPGRU); National Clonal Germplasm Repository (NCGR)
- **Fort Detrick/Frederick, MD:** Foreign Disease-Weed Science Research Unit (FDWSRU)
- **Fort Pierce, Florida:** Subtropical Plant Pathology (STPP)
- **Ithaca, New York:** Emerging Pests and Pathogens Research Unit (EPPRU)
- **Parlier, California:** Crop Diseases, Pests, and Genetics Research Unit (CDPG)
- **Peoria, Illinois:** Mycotoxin Prevention and Applied Microbiology Research Unit (MPM)
- **Pullman, Washington:** Wheat Health, Genetics, and Quality Research Unit (WHGQRU)
- **Raleigh, North Carolina:** Plant Science Research Unit (PSRU)
- **St. Paul, Minnesota:** Cereal Disease Laboratory (CDL)
- **Salinas, California:** Crop Improvement and Protection Research Unit (CIPRU)
- **Stuttgart, Arkansas:** Dale Bumpers National Rice Research Center (DBNRRC)
- **Urbana, Illinois:** Soybean/Maize Germplasm, Pathology, and Genetics Research Unit (SMGPGR)
- **Washington, District of Columbia:** Floral and Nursery Plants Research Unit (FNPRU) (also in Beltsville, MD) and United States National Arboretum (USNA)
- **West Lafayette, Indiana:** Crop Production and Pest Control Research Unit (CPPCRU)
- **Wooster, Ohio:** Corn, Soybean and Wheat Quality Research Unit (CSWQRU)

Component 2: Biology, Ecology, and Epidemiology of Plant Pathogens.

Understanding how plant pathogens interact with their host and environment, and how they survive outside of their host, are keys to developing a systems approach for long-term management strategies for plant diseases. This fundamental knowledge may allow us to target weak links in the different phases of the pathogen life cycle that can be used for disease management. This research will span the pathogen disease cycle from the molecular characterization of these pathogens and their virulence factors, to their interactions with vectors, hosts, phytobiome, and environment. Knowledge of this network of pathogen interactions allows employment of a systems approach for managing diseases. Advances in remote sensing, artificial intelligence, and diagnostics continue to enhance our ability to produce predictive models of epidemiology, which provide critical output for disease management decisions. Pressing concerns arise from vector-transmitted plant diseases, with greatly increased complexity of pathosystems, as there is a need to consider additional vector-pathogen-host interactions.

This research component provides the fundamental knowledge to characterize the pathogen lifecycle, epidemiology, and interactions with hosts, vectors, and the environment, which can be used to develop innovative disease management strategies. Research within this component will complement and draw from research conducted by the other components of NP 303, as well as NP 301, Plant Genetic Resources, Genomics and Genetic Improvement, and NP 304, Crop Protection and Quarantine.

Problem Statement 2A: Advance an Understanding of Fundamental Pathogen Biology.

Plant pathogens, including bacteria, fungi, nematodes, oomycetes, viroids, and viruses regularly cause significant yield and quality losses across all diverse cropping systems (*e.g.*, vegetables, cereals, tree crops, ornamentals, etc.). Basic systematic, morphological, and ecological information is still lacking for important pests, especially exotic pests imported into the United States. Understanding the biology of how these pathogens penetrate and colonize plants, and then reproduce and spread, is critical to our fundamental understanding of pathogen biology. This understanding will also fill knowledge gaps related to effective and durable management of the diseases they cause. Due to the reduced cost of next generation sequencing, genome sequences are available for many agriculturally important pathogens. However, there are still gaps in reference genome sequences for many pathogens, especially those species with large or complex genomes. Additional sequencing, assembly, and annotation of these genomes in conjunction with the generation of transcriptomics, proteomics, and metabolomics data are needed to investigate the genes, biochemical pathways, and small molecules involved in fundamental pathogen biology.

Despite marked progress, there are still large gaps in our understanding of pathogen biology, especially in how pathogens interact with their hosts to modulate and subvert the defense response to gain entry to the plant, colonize, and reproduce. Although there are some commonalities in how classes of pathogens modulate responses from their respective hosts, there are many more differences than similarities. In addition, our knowledge of how pathogens interact in complex communities associated with host tissue is severely limited. Even within a group of pathogens, there may be differences in the genome content and the number and functions of gene products. This all highlights the need to understand the biology of each agriculturally important host-pathogen and host-vector-pathogen interaction. In addition to genomics and other -omics tools being used to fill these knowledge gaps, complementary use of traditional and newer technologies is needed to identify and functionally characterize the components important in all aspects of the pathogen’s life cycle. Recent studies have indicated that some vector ‘species’ are aggregates of multiple cryptic species differing in host-specificity and viral transmission specificity, requiring sub-micrometer resolution microscopy for differentiation. This research should include studies in biochemistry, cell biology, vector taxonomy, biology and transmission, microscopy, molecular genetics, metagenomics, bioinformatics, and evolutionary biology, as well as other interdisciplinary fields of study that can contribute to a better understanding of pathogen biology.

Research Needs

Basic pathology studies, as well as development of omics-based resources for economically important pathogens (bacteria, fungi, nematodes, oomycetes, and viruses), for future functional characterization are still needed. Further research is needed to elucidate mechanisms used by each pathogen to colonize their respective host or hosts, which will be accomplished through the use of genome sequencing, transcriptomics, proteomics, and metabolomics. Studies need to use the currently available datasets to functionally characterize genes and gene classes for their role in pathogen growth, transmission, survival, pathogenicity, virulence, host range, and life cycle, as well as identify genetic components that can be targeted for disease management. Targets for disease management will include pathogen loci important in virulence and pathogen effector proteins that can be used for high throughput screening of germplasm. Fundamental research in genomics, evolution, and molecular plant-pathogen interactions, including molecular biology, cell biology, biochemistry, and microscopy, is needed to fill gaps in understanding the biology of each pathogen and, where relevant, the respective vector and how pathogens and their vectors evolve with their respective host plant.

Anticipated Products

- Functionally characterized virulence components capable of triggering plant defense responses.
- Newly identified pathogen effectors involved in pathogenicity and virulence that can be targeted for disease suppression.
- Reliable pathogen-derived biomarkers important for pathogen traits and critical pathogen genes to serve as targets for the development of fungicides, bactericides, or other biocidal agents.
- Linking of genotype to phenotype in pathogens and pathogen populations.
- Increased knowledge of pathogen and vector biology associated with the pathogenic life cycle.
- New means of identification and differentiation of vector species, including cryptic species.
- New technologies for evaluating the role of pathogen genes and gene products in pathogenicity and transmission.
- Detailed understanding of mechanisms of pathogen genome adaptation as a result of selection pressures applied by hosts, pesticides, and other agronomic and environmental factors.
- Disease control options made available due to the improved understanding of pathogen and vector biology.
- High-resolution, colorized images that can be produced to enhance our understanding of pathogen ecology and basic biology of important pests and diseases affecting agriculture.

Potential benefits

- A better understanding of how different host pathogen interactions evolve through comparative analyses.
- Faster development of germplasm that is resistant through identification of virulence factors important to pathogen survival on the host.
- The functional characterization of pathogen virulence components to provide tools necessary to characterize the corresponding host targets leading to novel control strategies.
- New knowledge of vector biology and interactions, offering new targets for vector control to limit virus dispersal.
- An understanding of pathogen adaptation potential regarding environmental changes (climate change), changes in agronomic traits, deployment of resistance genes, and/or the use of new chemical controls to enable the breeding and production of profitable crops.

Problem Statement 2B: Understanding and Integrating Systems-Based Approaches to Disease Biology.

Disease is a complex, multi-factorial, intricate process involving networks of interactions between the pathogen, host plant, and environment. It is likely other organisms and microbes, including insects, bacteriophages, mites, and fungal vectors, are involved in exacerbating or mitigating disease initiation and development. Discovery platforms have focused on single organisms to understand the disease process. However, these studies have not fully captured the entire complexity of this phenomenon. Furthermore, gene expression, regulation, and interacting signaling pathways are far more complex than initially thought. Understanding all facets of disease biology requires an in-depth knowledge of communication and interactions among and between different organisms. For example, some viruses appear to modify the plant host to render the microenvironment more suitable for the vector to feed and to shelter from predators, and potentially to affect vector fecundity and longevity. Hence, ARS will conduct coordinated and collaborative research to develop systems-based approaches aimed at understanding multiple components of disease and identifying critical host, vector, and pathogen factors contributing to the infection process, and how they interact. The results from these studies will generate significant fundamental breakthroughs that will be utilized to develop new control strategies targeting key mechanisms and components of disease development, virulence, and pathogen transmission.

Research Needs

An in-depth, fundamental understanding of the mechanisms and components is needed to evaluate how plant pathogens cause disease; trigger or suppress host defenses; and survive, reproduce, and interact with vectors. Omics-based technologies will be integrated to gain insights into the mechanisms of dynamic plant-microbe-pathogen and vector interactions. Fundamental knowledge is needed regarding the initiation, establishment, and spread of plant disease caused by microbial pathogens and nematodes. Structural and functional information of pathogen avirulence effector genes are needed to discover novel-plant disease resistance or susceptibility genes, and to augment classical epidemiological studies to help predict outbreaks of new diseases.

Anticipated Products

- Development and application of new approaches in synthetic biology, traditional breeding, and molecular biology leading to new management tools and strategies.
- Incorporation of plant disease resistance genes into strategically pyramided crops in response to dynamic, real-time changes in pathogen populations.
- Novel disease control tactics and mitigation strategies developed using molecular, genetic, and protein targets identified via systems-based approaches.
- New vector control measures including interference in ability of the pathogen and vectors to modify the host environment to facilitate protection and reproduction of the vector.
- Identification of bacteriophages and understanding of functions of bacteriophages in regulation of bacterial virulence and fitness in environment.
- Techniques for phenotypic characterizations of pests, pathogens, and parasite-host interactions based on real time observational tools that include high resolution microscopy, reflectance spectroscopy, and x-rays.
- Development of molecular tags that visually identify and track genes and/or monitor proteins and their interacting partners inside hosts and pathogens to provide new biological insights and to complement omics-based research.
- New knowledge of the fundamental mechanisms governing pathogenicity, virulence, and vector transmission.

Potential Benefits

- Discovery and characterization of novel genes, proteins, molecular regulators, and signaling pathways to provide specific targets to interfere with pathogen-host and/or pathogen-vector interactions.
- Innovative, environmentally friendly, durable disease management strategies that are deployed in the field, in storage, and during shipping, based on newly identified molecular targets.

- Improved knowledge of the interactions between bacterial pathogens and their phages to facilitate effective control of plant bacterial pathogens.
- Innovative approaches, tools, and detection methods to help analyze the function of newly discovered genes, proteins, and small molecules involved in pathogenicity, virulence, and pathogen spread.

Problem Statement 2C: Characterize Microbial Ecology and Epidemiology of Plant Diseases.

Plant disease epidemics result from combinations of susceptible hosts, an abundance of virulent pathogens, and favorable environmental conditions. Understanding the biology of these interactions is essential for developing disease forecasting models and aiding pathogen management. In addition, knowledge of the mechanisms of pathogen dispersal, including vectors, weather patterns, and human activities, that facilitate disease to increase over space and time will aid in predicting the onset of an epidemic. A fundamental understanding of pathogen ecology and life cycle, including reproduction and survival in hosts and hostile environments (*i.e.*, soil, water, and on plant surfaces), is needed to formulate epidemiological models for disease prediction and management strategies. Additionally, understanding the impact of changing climate and weather patterns, severe weather events, and atmospheric dispersal patterns on initiation and spread of epidemics is vitally important to predict and mitigate plant disease epidemics. High throughput sequencing technologies will be used to monitor population dynamics of pathogenic organisms and to provide clues to traits important for pathogen fitness and disease spread. Remote sensing technologies and metadata analyses will also provide valuable information to enhance disease forecasting and other predictors that will inform management of epidemics. Taken together, this knowledge will be used to design improved methods for monitoring pathogen populations and their movement to facilitate development of expert systems for disease forecasting and to provide the basis for alternative approaches to disease management and control.

Non-pathogenic microbes have a profound influence on plant health and productivity. Cultural controls, such as cover crops, promote the development of complex microbial communities that prevent disease in both organic and conventional systems. Therefore, high-throughput technologies can be used to assess microbial communities in healthy or disease suppressive soils, or plant microbiomes to identify community structures that may prevent disease, even in the presence of virulent pathogens. Research in NP 303 will contribute to phytobiome research using -omics (*e.g.*, metagenomics, metabolomics, phenomics) approaches to characterize microbial communities associated with plants including viruses, prokaryotes and microbial eukaryotes in the rhizosphere, phyllosphere, carposphere, and the endophytic space.

Research Needs

New methods for determining the genetic diversity and population dynamics of pathogens and associated microbes in the field need to be developed by way of population genetic and metagenomic approaches. Monitoring emerging and transitioning diseases is necessary to determine pathogen load and inoculum dispersal patterns (locally and globally), including methodologies for the use of remote sensing for predictions of early disease development and pathogen spread. Development of robust statistical methods to quantify relationships between disease levels and economic losses will be addressed to provide better methods for yield loss assessments. Plant disease forecasts will require improved sampling methodologies to monitor inoculum sources and spread of pathogens to determine optimal and timely management options aimed at reducing crop inputs costs without increasing risk of crop loss. Phytobiome research will be used to understand the microbial community components that sustain and enhance plant health.

Anticipated Products

- Robust statistical models to quantify the relationship between disease severity and crop production and the resulting economic impact.
- Mathematical and/or statistical models for forecasting disease epidemics with a user-friendly interface for growers.
- Sampling methodologies that incorporate the use of molecular diagnostic tools for improved disease prediction.
- Increased knowledge of pathogen life cycles to identify vulnerabilities that may be targeted for improved disease management.
- Knowledge of microbial communities associated with healthy or disease-suppressive plant environments.
- Better understanding of environmental effects and climate change on pathogen biology, epidemiology, and disease development.

Potential Benefits

- Use of remote sensing will allow efficient application of disease management controls.
- Predictive models for stakeholders and customers to allocate resources for increased crop productivity, targeted application of chemical treatments, and informed deployment of pathogen-resistant plants.
- Reduction of production input costs, improved product quality, and prevention of yield losses.
- Accelerated and informed breeding of crops for resistance.
- Application and cultivation of microbial communities will promote stable plant health in organic and conventional systems.

Problem Statement 2D: Identify the Biological and Ecological Factors of Pathogen Vector Efficiency.

Plant diseases are often transmitted by other organisms, such as insects or nematodes, which spread the pathogen to different hosts. These vectors are capable of transmitting plant pathogens from all major types of disease-causing agents, including bacteria, fungi, viruses, and others. The problem is particularly acute for diseases which have no curative options, and the only control option is to disrupt the transmission process. The development of successful control options for these diseases relies on controlling the vector population or reducing the efficiency of vector transmission. Advances in molecular techniques, proteomics, transcriptomics, and metabolomics have accelerated research in this area. The multidisciplinary nature of this research requires training and development of scientists with a broad skill set, needed to engage these emerging diseases.

The efficiency of vector transmission is dependent on a variety of biological and environmental factors that are specific to each vector-based plant disease. Broadly, vector efficiency is dependent on the probability of the pathogen being acquired by the vector and the probability of the vector inoculating the host with the pathogen. Recent advances in this area highlight the complexity of the interactions in this space with some effects arising from highly specific molecular interactions to broad environmental interactions. In many vector-pathosystems, the general factors effecting pathogen transmission are known, but a significant knowledge gap persists regarding the specific factors for each vector-based plant disease. Understanding these parameters will enable the development of novel strategies to suppress or stop the transmission cycle.

Research Needs

Research is needed to identify the key determinants of vector efficiency for important vector-based plant diseases. Studies are needed to evaluate the multipartite interactions between the vector, pathogen, and host to unravel how these interactions are mediated by abiotic and biotic factors; identify the biological, biochemical, molecular, and ecological features of vector efficiency; develop strategies to reduce or inhibit the transmission of vector-based pathogens; determine the role of host range, host preference, and host mediated factors in vector efficiency; evaluate the role of environmental factors in vector efficiency and the impact of climate change on vector-based plant diseases; and determine the role of microbial ecology in vector efficiency with a focus on vector-pathogen symbionts.

Anticipated Products

- Discovery of compounds that inhibit the efficient transmission of pathogens by vectors.
- Identification of alternative hosts to incorporate into management strategies.
- Identification of molecular mechanisms in acquisition, replication, and transmission of the pathogen.
- Understanding the role of microbial ecology and symbionts in vector interactions.
- Knowledge of the impact of environmental conditions on vector efficiency.
- Training and development of multidisciplinary scientists to engage emerging diseases.

Potential Benefits

- Improved knowledge of pathogen-vector interactions which can lead to new management tools and strategies
- Development of new plant disease management strategies to reduce transmission of disease agents.
- Identification of genes or pathways to provide specific targets to interrupt pathogen-host or pathogen-vector interactions.
- Deployment of innovative disease management strategies based on newly identified molecular targets to reduce disease pressure and spread.

Component 2 Resources:

The research needs under this component are being addressed at the following 23 ARS locations:

- **Beltsville, Maryland:** Molecular Plant Pathology Laboratory (MPPL); Soybean Genomics and Improvement Laboratory (SGIL); Electron & Confocal Microscopy Unit (ECMU); Food Quality Laboratory (FQL); Genetic Improvement for Fruits and Vegetables Laboratory (GIFVL); Sustainable Perennial Crops Laboratory (SPCL); Sustainable Agricultural Systems Laboratory (SASL)

- **Charleston, South Carolina:** U.S. Vegetable Laboratory (USVL)
- **College Station, Texas:** Crop Germplasm Research Unit (CGRU); Insect Control and Cotton Disease Research Unit (ICCDRU)
- **Corvallis, Oregon:** Horticultural Crops Research Unit (HCRU)
- **Davis, California:** Crops Pathology and Genetics Research Unit (CPGRU)
- **Dawson, Georgia:** National Peanut Research Laboratory (NPRL)
- **Fort Detrick/Frederick, MD:** Foreign Disease-Weed Science Research Unit (FDWSRU)
- **Fort Pierce, FL:** Citrus and Other Subtropical Products Unit (CSPRU); Subtropical Plant Pathology (STPP)
- **Geneva, New York:** Grape Genetics Research Unit (GGRU)
- **Ithaca, New York:** Emerging Pests and Pathogens Research Unit (EPPRU)
- **Jackson, Tennessee:** Crop Genetics Research Unit (CGRU)
- **Parlier, California:** Crop Diseases, Pests, and Genetics Research Unit (CDPG)
- **Peoria, Illinois:** Mycotoxin Prevention and Applied Microbiology Reseach Unit (MPM)
- **Pullman, Washington:** Wheat Health, Genetics, and Quality Research Unit (WHGQRU)
- **Raleigh, North Carolina:** Plant Science Research Unit (PSRU)
- **Salinas, California:** Crop Improvement and Protect Research Unit (CIPRU)
- **St. Paul, Minnesota:** Cereal Disease Laboratory (CDL)
- **Stoneville, Mississippi:** Crop Genetics Research Unit (CGRU)
- **Stuttgart, Arkansas:** Dale Bumpers National Rice Research Center (DBNRRC)
- **Urbana, Illinois:** Soybean/Maize Germplasm, Pathology, and Genetics Research Unit (SMGPGR)
- **Washington, District of Columbia:** Floral and Nursery Plants Research Unit (FNPRU) (also in Beltsville, MD) and United States National Arboretum (USNA)
- **West Lafayette, Indiana:** Crop Production and Pest Control Research Unit (CPPCRU)
- **Wooster, Ohio:** Corn, Soybean and Wheat Quality Research Unit (CSWQRU)

Component 3: Plant Health Management.

The development of effective plant health management systems is highly dependent on the ability to accurately identify pathogens and understand their biology and interactions with other organisms. The goal of plant health management is the deployment of multiple strategies that mitigate their impacts on crop productivity. Management systems are dependent upon integrated components that target specific pathogens, as well as general approaches that promote crop growth and suppress disease. Effective, safe, environmentally-sound, affordable, and sustainable strategies are needed to manage plant diseases threatening agricultural productivity as well as managed and natural landscapes in the United States and abroad. Many diseases are not adequately managed by methods available today, and others are controlled by chemicals that may not be available in the future due to environmental or safety concerns.

To address the full spectrum of plant diseases caused by endemic and exotic pathogens, new tools must be developed, optimized, and integrated into crop production systems. These tactics are likely to include methods to prevent the introduction of pathogens as well as mitigating problems that are endemic to production areas. Systems may employ durable plant host resistance that has been proven in the local climate and production system and can be paired with biologically-based and chemical control materials. Integration of non-chemical management tactics can be used to delay or mitigate pesticide resistance in pathogen populations and reduce the overall dependence on pesticides for the control of many plant diseases. Many new techniques and technologies have matured and can now be introduced into commercial production systems, where they must be evaluated and modified to fit within a specific crop production requirement or applied to novel crops or production practices. In addition, the impacts of production practices on plant productivity and potential impacts of new disease management systems on water resources and the environment must also be evaluated. The utilization of new functional genomics and microbiome characterization tools will lead to significant progress in our understanding of the mechanisms associated with disease control and suppression. Additional information on physical barriers, improved plant architecture, and secondary mechanisms of disease suppression will increase tools available for plant protection. Deployment and integration of this knowledge into disease management systems will rely on cross-cutting, interdisciplinary programs.

Research within this component will complement and draw from research conducted by the other components of NP 303 and NP 301, Plant Genetic Resources, Genomics and Genetic Improvement; NP 304, Crop Protection and Quarantine; NP 305, Crop Production; and NP 306, Product Quality and New Uses.

Problem Statement 3A: Develop and Deploy Host Resistance.

Host resistance is a direct and environmentally benign method to control plant diseases. Resistance is most often directed toward the pathogen, but resistance to pathogen vectors can also be effective in management of some plant diseases. Unfortunately, durable and effective host resistance may not be available, or has not been identified for many plant pathogens and their vectors. Even in cases where resistance genes may be identified, developing cultivars resistant to pathogen(s) that maintain desirable agronomic and horticultural traits is a long-term project. In recent years, tremendous progress has been made in the identification and characterization of disease resistance genes and proteins, and new tools have been developed to integrate genomic and genetic data with crop improvement activities. Genomic selection, marker assisted selection and the use of quantitative resistance loci (QRLs) facilitate the identification of disease-resistant genotypes early in the breeding process. The application of next generation sequencing (NGS) of agronomic and ornamental crop genomes has greatly expanded our catalog of plant genes, but new methods are needed to establish the function and potential utility of these genes for improving disease resistance to multiple pathogens. Pathogen genes confirmed to result in disease can be applied to discover novel disease resistance genes.

Pathogen populations contain high levels of genetic diversity and can mutate quickly; thus, attaining stable disease resistance in crops is a constantly moving target and requires knowledge of the pathogen populations as well as access to diverse plant germplasm and plant pathogen collections. Genetic modification of plants using transformation technologies has been effective for developing disease-resistant plants – *e.g.*, virus-resistant plum, papaya, and squash – and this technology can circumvent or minimize the loss of important agronomic and horticultural traits. These examples rely on the introduction of foreign genes to achieve pathogen-derived resistance. Advances in plant transformation can eliminate foreign genes in favor of using gene regulatory sequences and resistance genes derived from the plant species being transformed. The use of these “intragenic and cisgenic” technologies may alleviate many of the concerns associated with transgenic plants expressing foreign genes. Research on host-pathogen interactions aided by bioinformatics will identify candidate genes from the host that are appropriate for the development of intragenic/cisgenic disease resistant plants. Recent advances in host genome editing with CRISPR systems may also enable the development of disease resistant plants by targeting host susceptibility genes and/or transcriptional factors.

Research Needs

Research is needed to evaluate new germplasm, wild relatives, and weedy species collections for their resistance reactions to established and emerging pathogens including bacteria, viruses, fungi, and nematodes, and to the vectors of these pathogens. Morphological understanding of the basis of resistance to pathogen vectors is required. The genomic information of these resistant genetic resources is needed to determine the role of resistance (*R*) genes, and their corresponding interacting genes to be identified to gain knowledge of regulation of the durability of resistance. A better understanding of the molecular basis of *R* gene mediated plant resistance to microbes and harmful crop pathogens under changing production systems and climate is necessary to identify genes or critical domains of *R* genes or susceptibility genes involved in plant innate immunity. Detailed characterization of microbe collections is needed to identify virulence shifts and pathogen effectors that can be used to guide *R* gene deployment into crop plants. This deployment will be best suited for the development of strategies aimed at achieving high yielding, good quality crops with durable resistance, through conventional breeding and/or genome editing approaches, in a holistic manner. Research into more durable non-host resistance mechanisms is required to improve long-term sustainability. Gene editing technologies must be explored, as they are likely to provide a useful tool for modifying target crop species.

Anticipated Products

- Disease and vector resistant cultivars, rootstocks, germplasm, and genetic stocks for developing new strategies for genetic studies and crop protection.
- Characterized genetic loci that mediate disease resistance genes that can be deployed.
- Characterized morphological traits for vector resistance that can be evaluated in breeding programs.
- Characterized pathogen effectors that can be used to predict crop vulnerability and *R* gene development.
- New resources for rapid *R* gene/susceptibility gene identification, deployment, and editing.
- Characterized plant germplasm and pathogen collections to identify novel disease resistant genotypes as well as susceptibility genes.
- Molecular markers that facilitate plant breeding via marker assisted selection for disease resistance.
- New and efficient methods for incorporating disease resistance genes or modifying disease susceptibility genes into or within annual and perennial crop plants and rootstocks.

Potential Benefits

- New insights on disease-resistance/susceptibility mechanisms, used to develop precise resistance without trade-offs in plant productivity and fitness.
- More accurate and timely assessment of crop damage due to changes in genetic profiles of pathogen populations under changing production systems and climate.

- New knowledge on genetic and epigenetic regulation of plant innate immunity to facilitate the development of failsafe mechanisms to enhance food security.
- The availability of new plant and microbe genetic material to benefit the development of strategies to prevent crop losses due to emerging and reemerging destructive crop diseases.
- Identification of new sources of defense-associated genes to speed resistance breeding.
- Durable disease resistance, leading to long-term sustainability of fumigant-dependent crops and dramatic reductions in pre-plant chemical fumigant use.

Problem statement 3B: Advance Biologically-based and Integrated Disease Management Strategies.

New tactics to combat multiple crop diseases caused by emerging and exotic pathogens and their vectors are necessary to manage the diverse array of pathogens that can simultaneously or sequentially diminish crop productivity or plant health in managed or natural landscapes. There is a critical need for developing new research that integrates system-specific plant-microbe-environment interactions, including crop disease management, cultural control, suppressive soils, host plant or gene-edited resistance, biological control, and/or the efficacious use of economical and sustainable chemical controls. Individual strains of microorganisms or resistance genes that suppress plant disease have been developed and are used today in commercial agriculture for the management of a limited number of plant diseases. Their efficacy and reliability can only be enhanced when combined with other tactics that include production, formulation, and application of new technologies. New disease management approaches that use cultural practices, biological control agents, and durable resistance genes are needed to deploy key biological control traits, including for control of diseases in organic production systems. Understanding the key elements of integrated disease management (pathogen detection, pathogen biology, ecology, and epidemiology) will enable their most effective and efficient use in developing a sustainable system. Such approaches can optimize plant health in commercial agriculture and landscapes and can minimize the impacts of local and global climate environmental changes that modulate disease development.

Research Needs

Research is needed to validate the integration of multiple control tactics into complete plant disease management programs based on interactions between the environment, host plant, and pathogen for conventional, organic, and controlled environment agricultural systems. Available control tactics include host resistance, biological control, suppressive soils, management and cropping practices, natural products, organic amendments, nanotechnology, and RNA interference (RNAi), as well as other cultural or chemical treatments. Knowledge of how these control tactics interact with each other, as well as how the environment, plant and pathogen biology, and pathogen diversity influence subsequent disease development and control are also needed to optimize overall success. New cultural practices and biological, chemical, or natural products must be characterized, tested, and integrated into disease management programs as they are discovered. This will allow the identification of interventions that provide the greatest level of disease suppression and improve control against pathogens that are resistant to single disease control measures. Because the widespread use of biological control in agriculture is impeded by unexplained variation in biocontrol efficacy, research is needed to understand the biological, chemical, and physical factors that affect the establishment of these agents and expression of their essential biological control traits. Methods for large-scale production, formulation, and application of biocontrol agents and other products for disease control must be developed to optimize the efficacy and reliability of these products for commercial use. Finally, disease forecasting and pathogen or microbial community monitoring tools need to be integrated into cohesive disease management programs to help enable the coordination of multiple disease control tactics and guide timely disease management decisions.

Anticipated Products

- New effective, economical, and sustainable disease management programs that integrate multiple plant disease control measures including plant resistance and cultural, biological, and/or chemical control.
- New plant disease management programs that target pathogens that have overcome single disease control tactics.
- New biological control agents and enhanced knowledge of biological traits and genes.
- Production, formulation, and application technologies that enhance the efficacy of biological control agents and natural products.
- New chemicals, amendments, or other products for disease control, or improved methods for using existing products, including nanotechnology and dual-function chemistries.
- Application and integration of RNAi and gene drive technologies with existing disease control tactics to improve disease management.
- Tools and methods for analysis of system-specific plant-microbe-environment interactions.
- Refined disease forecasting models, and improved pathogen or microbial community monitoring that help guide management decisions and/or evaluate the success of integrated disease control tactics for improving plant disease control.
- Improved plant health through a better understanding of how environment affects the success of both individual and integrated plant disease management tactics.

Potential benefits

- Effective integrated disease management strategies and programs economically viable and benign to human health and the environment.
- Increased crop productivity through implementation of new disease control strategies.
- Increased utilization of secondary mechanisms and physical barriers associated with plant host resistance.
- Reduced use and reliance on chemical pesticides, through the adoption of integrated disease control measures, to mitigate harm these pesticides may do to human and environmental health.
- Mechanisms of biological control gained from characterization of the plant-pathogen-antagonist-vector-environment interactions, facilitating screening and deployment of new biocontrol agents and increasing effectiveness of existing measures employed for plant disease management.
- Effective cultural control methods, including the use of cover crops, soil amendments, and recommended cropping practices, to reduce disease pressure.
- Improved management, allowing control of pathogens that are resistant to single disease control tactics.

Problem Statement 3C: Develop Pre-plant Approaches to Reduce Pathogen Pressure for Commercial Crop Production Systems.

For more than half a century, control of most soil-borne pests has relied on the application of soil fumigants prior to planting. Since the international phase-out of methyl bromide and increased concerns associated with other soil fumigants showing deleterious human and environmental impacts, there is increased need for effective alternative approaches for the control of soil-borne pests. However, chemicals adopted as alternatives to methyl bromide and other soil fumigants are often limited in the spectrum of pests that they control; thus, combinations of fumigant and non-fumigant tools for control of larger groups of pathogens are desirable. In addition to methodologies for retaining fumigants in the soil and improving their efficacy, systems approaches are needed to provide alternative, non-fumigant-based soil-borne pest management, including the creation and maintenance of healthy and disease suppressive soils. Knowledge-based application of organic materials and passive solar heating can be useful as pre-plant soil disinfestation treatments to eliminate soil pests, without using synthetic chemical applications. These and similar approaches need to be validated in combination with optimized soil fertility practices to understand their impacts on soil chemical and physical properties. A greater understanding of soil microbial communities and the mechanisms of their disease repressive activities will enhance the usefulness of biologically-based management tactics in commercial crop production systems. Applications of improved tools for assessing and predicting pathogen loads in soils are needed to determine efficacy of pest control provided by environmentally-benign approaches. Increased understanding of inoculum sources in production systems will facilitate use of clean propagation material and help to mitigate pathogen pressure and reduce fumigant use. A better understanding of the interactions between pests that were previously controlled by soil fumigants and those emerging as a result of the use of alternatives is needed to develop effective pre-plant approaches to reduce pathogen pressure for commercial crop production systems. All pre-plant crop protection tools should be integrated into production systems, considering management practices and environmental impacts, and their potential impact on efficacy of the applied technologies.

Research Needs

Research is needed to develop improved tools for soil microbiome analysis for potential pathogen identification as well as for the characterization of beneficial microbial communities and the influence that management tactics have on these communities. It is critical that methods such as biosolarization, anaerobic soil disinfestation, cover crop incorporation, and organic amendments for disease control are coupled with studies on plant nutrition and environmental impact assessments in order to determine requirements for long-term sustainability and crop productivity. The ability to combine individual management tactics, such as chemical or biological crop protection products, plant disease resistance, and other pest management approaches, such as herbicide applications, and crop specific modifications to these methods, must demonstrate compatibly and not cause a loss of efficacy or plant productivity. These methods must be considered within the context of environmental stewardship and the ability to adapt to the utilization of local resources, including crop production with degraded water sources. In addition to investigating methods for improving pathogen control in soil, it is necessary to consider pre-plant disease management strategies for soilless systems, such as hydroponic and controlled environment atmospheres, which are highly dependent upon the introduction of pathogen-free seeds and clean planting material for disease prevention, as well as tools for pathogen management, such as resistant rootstocks, to mitigate disease after pathogens have been introduced to the system.

Anticipated Products

- Improved fumigant/non-fumigant combinations that result in increased broad-spectrum pest control efficacy.
- Methods for generating and maintaining clean propagation material for annual and perennial crops.
- Disease and nematode resistant rootstocks and modified crop production practices specific to grafted plants.
- Scion and rootstock combinations that overcome abiotic and biotic stress.
- New technologies for improved disease prevention and pathogen control for hydroponic and controlled environment systems.
- Modified plant fertilization strategies compatible with pre-plant soil treatments such as organic amendment incorporation or anaerobic soil disinfestation.
- Improved understanding of organic amendments on soil biological, chemical, and physical characteristics and their interactions.
- Additional commercially-viable biological control agents and formulations developed for pre-plant and post-plant soil treatment and an understanding of their limitations based on climate and production system constraints.
- Commercially acceptable (effective, feasible, affordable) pest and pathogen management systems.
- Systems approaches to create and maintain healthy and suppressive soils that are adaptable to regional needs and cropping systems.
- Increased predictive tools for monitoring soil-borne pathogens and methods of identification of beneficial organisms associated with disease suppressive soils.

Potential Benefits

- Reduced use of soil fumigants will reduce deleterious environmental impacts.
- Improved pest control for organic and other emerging sustainable production systems, including controlled environment agriculture.
- Increased utilization of degraded land and water resources.
- Reduced environmental impact of fumigant and non-fumigant pre-plant practices.
- Integration of new chemicals, increased efficacy of biocontrol agents, and appropriate cultural management tools, allowing continued profitable production of high-value crops currently dependent on soil fumigation.
- Avoidance of future dependence on any single chemical pesticide.
- A more thorough understanding of soil chemical, physical, and biological properties as they relate to pest and pathogen interactions, allowing more effective control.
- Efficient use of scarce, arable land with improved pest control in fumigant buffer zones.

Component 3 Resources:

The research needs under this component are being addressed at the following 26 ARS locations:

- **Beltsville, Maryland:** Food Quality Laboratory (FQL); Genetic Improvement for Fruits and Vegetables Laboratory (GIFVL); Mycology and Nematology Genetic Diversity and Biology Laboratory (MNGDBL); National Germplasm Resources Laboratory (NGRL); Soybean Genomics and Improvement Laboratory (SGIL); Sustainable Agricultural Systems Laboratory (SASL); Sustainable Perennial Crops Laboratory (SPCL)
- **Canal Point, Florida:** Sugarcane Field Station (SPRU)
- **Charleston, South Carolina:** U.S. Vegetable Laboratory (USVL)
- **College Station, Texas:** Crop Germplasm Research Unit (CGRU); Insect Control and Cotton Disease Research Unit (ICCDRU)
- **Corvallis, Oregon:** Horticultural Crops Research Unit (HCRU)
- **Davis, California:** Crops Pathology and Genetics Research Unit (CPGRU); National Clonal Germplasm Repository (NCGR)
- **Dawson, Georgia:** National Peanut Research Laboratory (NPRL)
- **Fort Pierce, FL:** Citrus and Other Subtropical Products Unit (CSPRU); Subtropical Plant Pathology Unit (STPP)
- **Geneva, New York:** Grape Genetics Research Unit (GGRU); Plant Genetic Resources Unit (PGRU)
- **Ithaca, New York:** Emerging Pests and Pathogens Research Unit (EPPRU)
- **Jackson, Tennessee:** Crop Genetics Research Unit (CGRU)
- **Orono, ME:** New England Plant, Soil, and Water Laboratory (NEPSWL)
- **Peoria, Illinois:** Crop Bioprotection Research Unit (CBP)
- **Pullman, Washington:** Wheat Health, Genetics, and Quality Research Unit (WHGQRU)
- **Raleigh, North Carolina:** Plant Science Research Unit (PSRU)
- **Riverside, California:** National Clonal Germplasm Repository for Citrus & Dates (NCGRCD)
- **Salinas, California:** Crop Improvement and Protect Research Unit (CIPRU)
- **St. Paul, Minnesota:** Cereal Disease Laboratory (CDL)
- **Stoneville, Mississippi:** Biological Control of Pests Research Unit (BCPRU); Crop Genetics Research Unit (CGRU); National Biological Control Laboratory (NBCL)
- **Stuttgart, Arkansas:** Dale Bumpers National Rice Research Center (DBNRRC)
- **Tifton, Georgia:** Crop Genetics and Breeding Research Unit (CGBRU)
- **Urbana, Illinois:** Soybean/Maize Germplasm, Pathology, and Genetics Research (SMGPGR)
- **Washington, District of Columbia:** Floral and Nursery Plants Research Unit (FNPRU) (also in Beltsville, MD) and United States National Arboretum (USNA)
- **Wenatchee, Washington:** Physiology and Pathology of Tree Fruits Research Unit (Tree Fruit Research Lab)
- **West Lafayette, Indiana:** Crop Production and Pest Control Research Unit (CPPCRU)
- **Wooster, Ohio:** Corn, Soybean and Wheat Quality Research Unit (CSWQRU)

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