USDA
AGRICULTURAL RESEARCH SERVICE

NATIONAL PROGRAM 303 – PLANT DISEASES
ACTION PLAN 2012-2016

[REVISED APRIL 2013]

United States Department of Agriculture
Research, Education, and Economics
AGRICULTURAL RESEARCH SERVICE

Cover Photo Credits: Clockwise from top left – Late blight on potatoes, Ken Deahl, ARS Beltsville, Maryland; Citrus greening (HLB) on orange, Tim Gottwald, ARS Fort Pierce, Florida; Color break on tulips, John Hammond, ARS Beltsville, Maryland; Stem rust on wheat, Yue Jin, ARS St. Paul, Minnesota; and Root knot on tomato, Nancy Burelle, ARS Fort Pierce, Florida.

AGRICULTURAL RESEARCH SERVICE
NATIONAL PROGRAM 303 – PLANT DISEASES
Action Plan 2012 – 2016

[REVISED APRIL 2013 TO INCORPORATE MERGER WITH NATIONAL PROGRAM 308, METHYL BROMIDE ALTERNATIVES]

Goal: National Program (NP) 303 Plant Diseases supports research to improve and expand our knowledge of existing and emerging plant diseases, and develop effective disease management strategies that are benign to human health and the environment and that are economically and ecologically sustainable.

Plant diseases caused by any number of pathogen types – including fungi, bacteria, viruses, viroids, phytoplasmas, and nematodes – cause billions of dollars in economic losses each year to agriculture, landscapes, and forests in the United States. Plant diseases can reduce yields, lower product quality or shelf-life, decrease aesthetic or nutritional value, and can sometimes contaminate food and feed with toxic compounds. Control of plant diseases is essential for providing an adequate supply of food, feed, fiber, and landscape crops, but effective control depends on an understanding of the biology and ecology of disease agents

The outcomes and impact of these research and outreach activities to improve plant health include the maintenance of abundant high quality crops for all citizens, productive agricultural and forest industries, and the healthy managed landscapes in our country. Additionally, climate change and the increased global movement of plant material necessitates proactive research on emerging domestic diseases and exotic diseases not yet in this country to protect our crops and to maintain and expand export markets for plants and plant products.

The specific components of the Plant Diseases, National Program 303 are:

Component 1: Diagnostics, Etiology, and Systematics. 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 pathogens. Projects or aspects of projects coded under this component may include research on: Developing or improving diagnostics for existing, emerging, or exotic pathogens; Developing or improving pathogen detection and/or quantification methods (e.g. remote sensing); Systematics, evolution, and population genetics of pathogens using molecular, morphological, and other criteria; and Understanding the etiology of exotic, emerging, and poorly understood plant diseases.

Component 2: Biology and Epidemiology of Plant Disease. Critical to developing effective disease management methods is an understanding of the ecology and epidemiology of pathogens as well as an in-depth knowledge of the fundamental biology of pathogen-host-vector interactions. Projects or aspects of projects coded under this component may include research on: Molecular, cellular, and organismal aspects of plant pathogens, and the interactions of pathogens with plant hosts; Interactions of pathogens with vectors (including vector-plant interactions as they influence pathogen transmission and disease development); Ecology, epidemiology, and spread of pathogens and vectors; and Impact of climate change on pathogens, their vectors, and disease expression.

Component 3: Plant Health Management. Effective, safe, environmentally sound, affordable, and sustainable strategies and tools are needed to manage plant diseases. As with most disease-associated organisms, plant pathogens exhibit a remarkable ability to change and adapt, allowing them to overcome resistant 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. Projects or aspects of projects coded under this component may include research on: Development, characterization, and deployment of genetic resistance (conventional or transgenic/intragenic) against pathogens or vectors; Manipulation of cultural practices to promote plant health or manage pathogen or vector populations; 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.

Component 4: Alternatives to Preplant Methyl Bromide Soil Fumigation. For more than half a century, the primary means of controlling most soilborne plant pathogens was application of soil fumigants, particularly methyl bromide, prior to planting. With the identification of methyl bromide as an ozone depleting substance in the Montreal Protocol (1992), the international phase-out of methyl bromide began along with the search for alternatives to methyl bromide and other soil fumigants. In developed countries, the complete phase-out of manufacturing and importation of methyl bromide occurred on January 1, 2005, except for quarantine/pre-shipment (QPS) uses and Critical Use Exemptions (CUEs). CUEs are granted on a case-by-case yearly basis by an international committee. The non-quarantine use of methyl bromide in the United States has been reduced by approximately 96 percent compared to 1991 baseline levels. Research is needed to address the remaining 4 percent of use, which consists of recalcitrant problems and new problems that have emerged as alternatives to methyl bromide have been implemented. For 2014, the United States requested CUEs for soil fumigation with methyl bromide for strawberry fruit production, and supplemental requests are being prepared for additional crops. Viable alternatives are needed for these remaining uses of methyl bromide as well as optimization of alternatives already in use. Currently registered, chemically-based alternative systems face existing and potential problems associated with township use limitations, emission control, and buffer zone restrictions.

Research in NP 303 complements research in other Agricultural Research Service National Programs, particularly those in the Crop Production and Protection Section, such as NP 301 (Plant Genetic Resources, Genomics and Genetic Improvement), NP 304 (Crop Protection and Quarantine), and NP 308 (Alternatives to Methyl Bromide).

Relationship of this National Program to the USDA and ARS Strategic Plans: Outputs of NP 303 research support both the USDA Strategic Plan for 2010-2015 and the ARS Strategic Plan for FY 2006-2011. NP 303 research and outreach activities are most applicable to the ARS

Strategic Goal 4, *Enhance Protection and Safety of the Nation's Agriculture and Food Supply*. Research and outreach activities develop, test, apply, or transfer effective scientific methods to prevent, detect, eradicate, or manage plant diseases.

Specifically, NP 303 supports the following Performance Measures under ARS Strategic Goal 4:

> **Performance Measure 4.2.3:** Develop control strategies based on fundamental and applied research to reduce losses caused by plant diseases, nematodes, arthropods, and weeds that are effective and affordable while maintaining environmental quality. Develop technically and economically feasible alternatives to preplant and postharvest use of methyl bromide.
>
> **Performance Measure 4.2.4:** Provide needed scientific information and technology that is environmentally acceptable to producers of agriculturally important plants in support of exclusion, early detection and eradication, control, and monitoring of invasive arthropods, weeds, nematodes, and pathogens; enhanced sustainability; and restoration of affected areas. Conduct biologically-based integrated and areawide management of key invasive species.
>
> **Performance Measure 4.2.5:** Provide environmentally sound fundamental and applied scientific information and technologies to action agencies, producers, exporters, and importers of commercially important plant and animal products in support of exclusion, early detection, and eradication of quarantine pests and pathogens.

Component 1: Diagnostics, Etiology, and Systematics

The management of a plant disease depends upon the ability to understand the cause of the disease, and to identify and classify the causal pathogen(s). In addition to endemic pathogens and diseases, agricultural commodities are frequently assaulted by emerging diseases caused by previously unknown pathogens, or new strains of endemic pathogens that arise by genetic mutation or recombination. Further, the expanding globalization of agriculture inevitably introduces exotic organisms that could devastate U.S. agriculture if left unchecked.

Consequently, the security of the U.S. food supply depends in part on the timely detection and identification of new pathogens emerging within, as well as those introduced to, the United States, regardless of whether the introduction is accidental, deliberate, or via natural forces. The history of crop protection in America is replete with occasions when the ability to detect or identify a plant pathogen or disease has resulted in enormous positive economic impact.

Although a robust commercial plant pathogen diagnostics industry in the United States supplies testing services and diagnostic reagents, it is still very much dependent upon the publically funded research institutes to conduct and transfer the basic research on pathogen identification, classification, and diagnosis. Furthermore, the commercial industry has limited its role to those pathogens that are of major economic importance and for which there are readily available reagents and reliable assays. Consequently, there is a critical need for continuous research into the development of new, rapid, sensitive, accurate, and inexpensive detection and diagnostic methods for all other existing, changing, and emerging pathogens. Research within this component will complement and draw from research conducted by the other components of

NP 303 and National Program 301, Plant Genetic Resources, Genomics and Genetic Improvement. Collaborative efforts with the USDA Animal and Plant Health Inspection Service (APHIS), State departments of agriculture, industry, stakeholder groups, regional diagnostic laboratories, as well as foreign national agricultural research centers and international agricultural research centers, will identify the most critical diagnostic needs and facilitate the development of standardized, validated, and optimal tools appropriate for the end user.

Problem Statement 1: Diagnostics, Etiology, and Systematics of Plant Disease

Definitive diagnostics are the linchpin that allows subsequent studies to characterize the pathogen populations and develop management strategies. Accurate and often rapid methods for identifying the cause(s) of a plant disease are critical for disease management and for the safe movement of horticultural and agricultural products. Although microscopic examination can identify many pathogens, accurate disease diagnoses may require more specific biochemical or molecular tests. Different pathogens may induce the same symptoms, or symptoms may be physically indistinguishable, or so similar that only a highly trained specialist can make a definitive identification. Serological or nucleic acid-based assays are readily available for many common pathogens of major crops, but are lacking for a majority of pathogens, especially those of minor and specialty crops. In other cases, the only reliable means of diagnosis and identification may be bioassays that require months to complete. Still other pathogens are fastidious and are not easily cultured or propagated and must be identified from the original diseased tissue. Also, there may be no effective sampling methods available for detecting some pathogens within some plant materials.

Etiology is the identification of the cause or causes of disease which may be one pathogen, the interactions of multiple pathogens, or the interactions of pathogens with other biotic and/or abiotic factors. Systematics is the naming, description, preservation, and classification of organisms, and the study of their distribution, evolutionary history, and environmental adaptations. Understanding and managing plant disease requires knowledge of both the etiology of disease and the systematics of the pathogen(s) responsible for the disease. The causal agents of many exotic and emerging diseases have not been identified. Similarly, certain diseases are thought to be caused by pathogen complexes or organisms that cannot be cultured, and their etiology remains unclear. Once known, an in-depth study of the systematics of the responsible pathogen often enables scientists to assess the potential impacts of a newly identified or introduced organism and may suggest management approaches. In many cases, morphologically identical variants of the same pathogen species differ in pathogenicity on host plant species or cultivars and these differences can be due to relatively minor alterations in gene sequence or expression, or in post-translational modification of proteins and other metabolites. Although genomic-, proteomic-, and metabolomic-based methods of classification are now being enlisted, these methods are not always available or applicable. Furthermore, the -omics approaches must be developed within a sound morphological and biological framework. The knowledge developed here provides a framework for continued and more in-depth investigations on pathogen biology.

Research Needs

The ARS national plant pathology research capacity is strong, yet the demands by many emerging and re-emerging diseases require that flexible national priorities be established for pathogen detection and diagnosis, and subsequent systematics research. In addition, expanded and well-maintained databases and specimen/culture collections to support these activities are needed. The systematics of plant pathogens is critical for understanding disease etiology, transmission, and control, but there are large gaps in knowledge about specific groups of pathogens. Comprehensive knowledge of the etiology and systematics of domestic and exotic plant pathogens will be developed via structural, molecular, and other approaches. Classification schemes for accurately predicting biological properties critical to disease diagnosis and control will be developed. Existing and new technologies will be applied to detect and identify plant pathogens in soils, plants, plant materials, agricultural products, disease vectors, and any other organism or material suspected of harboring a pathogen. Priority research targets will include pathogens that have: 1) a high impact on crop yield, quality, and producer income; 2) regulatory or quarantine importance; 3) importance to national biosecurity; or 4) application as model organisms for understanding virulence/avirulence, infection modes, or other basic mechanisms.

Anticipated Products

- New, rapid, reliable, economical methods with acute discriminating power for detecting and identifying plant pathogen species, strains, or pathotypes, often within hours or minutes of specimen examination, and often using limited amounts of plant or non-plant material.
- Diagnostic methods capable of detecting and identifying several pathogens concurrently.
- Inexpensive pathogen detection methods that do not require highly trained personnel or state-of-the art laboratory equipment and facilities.
- More effective methods, such as nucleic acid, protein or metabolite biomarker systems and *in vitro* screens, for distinguishing pathogen genotypes.
- New statistically-sound sampling methods that enable more efficient recovery/isolation of representative pathogen samples.
- Pathogen surveys that monitor pathogen diversity and genetic changes in critical pathogen populations.
- Characterization of the key genetic and biological features of exotic plant pathogens in advance of their introduction into the United States.
- Systematically valid, accurate, and comprehensive phylogenetic systems for classifying and understanding pathogen evolutionary relationships that are linked to, and integrated with, voucher specimen collections and databases.
- Diagnostic keys, compendia, and other guides for identifying pathogens and diseases.
- More accurate and comprehensive phylogenetic classifications that can predict agriculturally relevant aspects of pathogen biology.
- Discovery of pathogen complexes responsible for important plant disease that currently have unknown etiology.

Potential Benefits

- Quicker, more effective, and more broadly applicable (e.g., from plants, soil, air, etc.) pathogen detection and identification methods.
- Improved taxonomic description and classification of pathogen groups that utilizes systematic, morphological, biological, and molecular data.
- Enhanced knowledge of pathogen genetic diversity, especially with respect to pathogenicity and evolution, thereby enhancing the ability to predict disease outbreaks.

- Accurate 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.
- Agricultural losses minimized by the timely detection and identification of pathogens already present in the United States and by the subsequent application of control measures.
- Regulatory decisions based on rapid pathogen detection and scientific data will facilitate the export and import of agricultural products and other plant materials while minimizing the potential for introduction of exotic pathogens.
- More rapid and accurate pathogen assays (especially pre-plant) that accelerate breeding of durable resistance that is not limited to current, local populations of pathogens.

Component 1 Resources:
Nine ARS projects in NP 303 address the research problems identified under Component 1 and the scientists assigned to these projects are located at Beltsville, Maryland, and Wenatchee, Washington.

Component 2: Biology and Epidemiology of Plant Disease

In recent years an unprecedented innovation in life sciences has been employed to unravel the biology of how pathogens cause disease. Discoveries in the molecular characterization of plant pathogens and the fundamental nature of their interactions with plant hosts, vectors, symbionts, antagonists, and other associated organisms have contributed to our basic understanding of susceptibility, resistance, disease development, pathogen transmission, and host defense responses. This information has in turn been used to develop practical applications for disease management. Similarly, advances in bioinformatics, predictive modeling, and remote sensing have forged new opportunities to understand the dynamics of pathogen populations and disease epidemiology, and to determine how pathogens and their vectors survive and disperse in a wide variety of environments. This knowledge identifies targets of opportunity to interrupt the life cycle of pathogens and/or vectors to prevent disease or reduce its economic threat. Much of this work has focused on model pathogens, hosts, and vectors. Now opportunities abound for parallel research on many additional agriculturally important plant diseases.

Problem Statement 2A: Fundamental Pathogen Biology

Pathogens range from the relatively simple viruses to very complex organisms, such as fungi and nematodes. In recent years, the genomes of many agriculturally relevant pathogens of all types have been partially or fully sequenced. These genomic sequences have been valuable in illuminating aspects of pathogen biology that have eluded science in the past. For example, genomic sequences of the new race of stripe rust of wheat (Ug99), the causal agent of sudden oak death, *Phytophthora ramorum*, and the bacteria associated with citrus greening resulted in the identification of pathogenicity genes and provided leads for the development of eradication strategies or resistance in host plants. Genomic sequences of more plant pathogens, including those with large and complex genomes, are needed to extend the power of genomics to other agriculturally-important plant pathogens. A major challenge for the future is to develop and apply tools needed to fully exploit these genomic sequence data to advance knowledge of pathogen biology. Meeting this challenge will require bioinformatic resources and interdisciplinary systems approaches involving computational biology coupled with laboratory methods for high-throughput functional genomics and genetics, proteomics, and metabolomics.

In addition, the fundamental biology of individual pathogens must be developed as a stepping stone to systems biology involving all the various players in the disease. ARS research will make significant contributions to understanding the fundamental biology of plant pathogens of economic and regulatory significance to U.S. agriculture, which in turn can be translated to novel disease management strategies that disrupt a pathogen's ability to cause disease or its ability to overcome plant defense responses. Research in fundamental biology of plant pathogens is expected to provide model systems that can be used in animal pathogenesis, systems for production of animal proteins such as vaccines.

Research Needs

ARS will sequence genomes of important and emerging pathogens of major and specialty crops. Bioinformatics coupled with laboratory and field studies will define pathogen gene/protein/metabolite expression and function in pathogen invasion, infection, virulence, transmission, and other phenotypic traits. These studies will build on the phylogenetic and diagnostic information, and provide fundamental information on the genome and functional genomics of important and emerging pathogens of major and specialty crops.

Anticipated Products

- Description of pathogen genomes, development of pathogen libraries, and maintained pathogen collections.
- Linking phenotype to genotype of pathogens and pathogen populations.
- Reliable bio-markers for important phenotypic traits.
- Level of diversity established for key biological traits of pathogen populations.
- Increased knowledge of pathogen biology and life cycles.
- New technologies for evaluating the role of pathogen genes and gene products in pathogenicity and transmission.

Potential Benefits

- Information on the role of pathogen genes in disease development and the identification of targets for disease management that will aid development of novel disease management strategies.
- Identification of gene flow between pathogen species that may aid in detection of new pathogens.
- Measurements of pathogen load would be applied to assessing the likelihood of a serious disease problem developing with resultant economic losses in specific field locations and years.
- New technologies based upon the high replication capacity of plant viruses to express desirable proteins in plants for the prevention and treatment of veterinary diseases, thereby impacting animal health and benefitting producers and processors.

Problem Statement 2B: Systems Approaches to Pathogenesis

Disease development is a complex process that involves a network of interactions between the pathogen and host plant, and in many cases a specific vector. The majority of plant viruses, mollicutes, and fastidious bacteria are disseminated by arthropod, nematode, or fungal/protist vectors. For a multitude of pathosystems, additional organisms may be involved in mitigating or exacerbating disease. Gene discovery within single organisms has been a standard approach to understanding pathogenesis in recent times and these studies have clearly shown that most biological pathways have significant redundancy; therefore, manipulation of single genes in such redundant systems has little effect. Furthermore, gene regulation, expression, and the multitude of downstream processes are far more complex than initially thought. Understanding all the mechanisms that result in disease requires knowledge of communication and interactions between and among organisms. ARS will conduct coordinated and collaborative research that develops a systems approach to understanding all the components of a disease and understanding all the factors that each component contributes to the process and how they interact. The results from these studies will enable the development of new control methods that target specific mechanisms of pathogenesis. For example, the potato cyst nematode injects proteins into the host plant that mimic plant hormones and cause the plant to modify its cell structure and metabolism to benefit the nematode. Understanding nematode-plant interactions allowed the development of a novel form of resistance that targets the nematode proteins and prevents the plant from creating a feeding site for the nematode.

Research Needs

A fundamental understanding will be developed for how pathogens cause disease, trigger and suppress host defenses, survive, reproduce, and disperse, and coexist with vectors to move between hosts.

Anticipated Products

- Novel disease control strategies that can be developed based on specific molecular targets identified in these studies.
- Compounds that can prevent the efficient transmission of pathogens by vectors.
- Discovery of the underlying pathogenic mechanisms essential for the initiation, establishment, and spread of plant disease.

Potential Benefits

- Improved knowledge of pathogen vectoring which can lead to new management tools and strategies.
- Identified genes or pathways that provide targets to interrupt pathogen-host or pathogen-vector interactions.
- Innovative disease management strategies that are deployed in the field based on new molecular targets identified.

Problem Statement 2C: Ecology and Epidemiology of Plant Diseases

Plant disease epidemics result from timely combinations of susceptible host plants, virulent pathogens, and favorable environmental conditions. For some diseases, the interactions may also include efficient pathogen vectors. An understanding of these interactions is essential for disease forecasting and management. In addition, determining the modes of spatiotemporal spread and community ecology of the pathogen and associated vectors will aid in predicting their ability to cause an epidemic. Knowledge of the ecology and life cycle of a pathogen, including its survival and reproduction, is needed as a basis for epidemiological models and disease strategies. ARS research will explore pathogen, host, vector, and environmental factors that result in pathogen transmission and dispersal, and the development of epidemics. This knowledge will be used to design better methods for monitoring pathogen and vector populations to facilitate the development of expert systems for disease forecasting and provide the basis for alternative approaches to disease management and control.

Research Needs

Methods for determining the genetic diversity and population dynamics of pathogens in the field will be developed. Monitoring emerging and transitioning diseases is necessary for sampling to determine pathogen load and inoculum dispersal patterns (global and local). Development of robust statistical methods to quantify relationships between disease levels and economic loss will be addressed to provide better methods for yield loss assessments. Plant disease, and when appropriate pathogen vector, forecasts will determine optimum periods to use or apply management options to reduce crop inputs without increasing risk of crop loss.

Anticipated Products

- Robust statistical models to quantify relationships between disease levels and economic loss, and analyzing impact of disease.
- Mathematical models for disease forecasting/epidemic development of diseases with a user interface for growers.
- Better sampling methods for pathogen dispersal.
- Increased knowledge of pathogen life cycles, which can identify vulnerabilities to be targeted for disease management.

Potential Benefits

The research will provide a scientific basis to growers for allocating resources for increased crop productivity, targeted application of chemical treatments, and targeted deployment of pathogen race-resistant germplasm, resulting in a reduction of input costs and prevention of yield losses.

Component 2 Resources:

Twenty three ARS projects in NP 303 address the research problems identified under Component 2 and the scientists assigned to these projects are located at:

- Beltsville, Maryland;
- Corvallis, Oregon;
- Fargo, North Dakota;
- Fort Detrick, Maryland;
- Fort Pierce, Florida;
- Ithaca, New York;
- Jackson, Tennessee;
- Lincoln, Nebraska;
- Madison, Wisconsin;
- Parlier, California;
- St. Paul, Minnesota;
- West Lafayette, Indiana;
- Wooster, Ohio.

<u>Component 3: Plant Disease Management</u>

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 of these diseases are not managed adequately by methods available today, and others controlled by chemicals that may be unavailable in the future due to regulatory actions prompted by environmental or safety concerns. To manage the full spectrum of plant diseases caused by endemic and exotic pathogens, new tactics must be developed, optimized, and integrated into disease management systems. These tactics will include durable plant host resistance, as well as effective and reliable biological and cultural controls. Integration of non-chemical management tactics can also be used to delay and manage pesticide resistance in pathogen populations and reduce the overall dependence of pesticides for the control of many plant diseases. Development and optimization of these disease management tactics requires a fundamental knowledge of host-pathogen-vector-environmental interactions. Deployment and integration of this knowledge into disease management systems will rely on cross-cutting, interdisciplinary programs.

Problem Statement 3A: Development and Deployment of Host Resistance

Host resistance is a direct and environmentally benign method to control plant diseases. Resistance is most often directed at the pathogen, but resistance to pathogen vectors can also be effective in management of some plant diseases. Unfortunately, durable and effective host resistance is not available for most plant pathogens in most crops. Even in cases where resistance genes are identified, the generation of disease-resistant cultivars 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 protein, and new tools have been developed to integrate genomic and genetic data for crop improvement. Resistance gene marker-assisted selection and the identification of quantitative resistance loci (QRLs) facilitate the selection of disease-resistant genotypes early in the breeding process. Due to the pathogens' genetic diversity and ability to mutate quickly, 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. Recent 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" technologies may alleviate many of the concerns associated with transgenic plants expressing foreign genes. Research on pathogen-host interactions aided by bioinformatics will identify candidate genes from the host that are appropriate for the development of intragenic disease resistant plants.

Research Needs

A more in-depth understanding of crop resistance mechanisms and defense responses is necessary to identify plant genes best suited for the development of resistant plants either through conventional breeding or transgenic/intragenic approaches. General disease mechanisms will be better understood, as well as details of specific plant disease mechanisms. Knowledge of genetic diversity and shifts in the virulence profiles of pathogen populations will help scientists anticipate emerging vulnerabilities for U.S. crops to initiate breeding for crops resistant to emerging pathogens. Collections of pathogens will be developed and maintained especially with regard to pathogen race-, pathovar-, or species-differentiating host plants.

Anticipated Products

- Expanded genetic and genomic resources for crops, their pathogens, and other microbes needed to develop new strategies to protect crops from disease.
- Expanded disease-resistance mechanisms that are deployed to benefit crop production.
- Characterized plant and pathogen germplasm collections to identify new genes for disease resistance.
- Molecular markers that facilitate plant breeding for disease resistance.
- Efficient methods for incorporating disease resistance genes into crop plants.

Potential benefits

- Enhanced availability of new genetic and genomic information for crops and crop pathogens accelerates plant breeding, resulting in disease-resistant crops that lower input costs while reducing economic losses due to plant diseases.
- More effective disease resistance protection for crops based on knowledge of pathogen attributes essential for maximum pathogen virulence and disease development.
- Better understanding of the genetic control and physiological basis for plant defense mechanisms to pathogens will enhance breeding for disease-resistant crops.
- More accurate and timely assessment of rapidly changing genetic profiles of pathogen populations and emerging vulnerabilities in U.S. crops.
- More effective strategies for deploying host-plant resistance genes to combat emerging diseases.

Problem statement 3B: Biologically-Based and Integrated Disease Management

Multiple disease control tactics are necessary to manage the diverse array of pathogens that can simultaneously or sequentially diminish crop productivity or the health of plants in managed or natural landscapes. These tactics include cultural control methods, such as sanitation, crop rotation, and other agronomic practices that have been mainstays for the management of plant disease. Some cultural control methods function by promoting natural processes of biological control, such as populations of plant- or soil-inhabiting microorganisms that suppress plant disease. Individual strains of microorganisms that suppress plant disease have been developed as biological control agents, which are used today in commercial agriculture for the management of a limited number of plant diseases. New cultural practices and biological control agents are needed to combat diseases caused by emerging and exotic pathogens. Used alone, many biologically based control tactics suppress disease to a degree, but their efficacy and reliability can be enhanced when combined with other tactics. There is a critical need for research integrating host-plant resistance, biological, cultural, and chemical control tactics into plant management systems that optimize plant health in commercial agriculture. Enhanced methods for pathogen detection and monitoring and knowledge of pathogen biology, ecology, and epidemiology are key elements of integrated disease management systems, enabling the tactics to be employed most effectively and efficiently.

Research Needs

Field research is needed to evaluate the integration of multiple control tactics (including host resistance, biological control agents, suppressive soils, management and cropping practices, natural products, organic amendments, reduced levels of pesticides, and physical and chemical treatments) into disease management systems. New biocontrol agents and cultural practices (e.g., cropping practices, organic amendments, and physical treatments) must be discovered, characterized, and tested in the field to identify those providing the greatest level of disease suppression. Methods for large-scale production, formulation, and application of biocontrol agents and natural products must be developed to optimize the efficacy and reliability of these products in the field. Because the widespread use of biological control in agriculture is impeded by unexplained variations in the efficacy of biocontrol organisms, research is needed to understand the biological and physical factors that influence the establishment of these organisms and their expression of key biocontrol traits on plant surfaces. Biological control is based on a complex network of interactions among the pathogen, plant, antagonist, and environment, and the nature of these interactions must be elucidated so that more reliable and efficacious biologically-based disease management tactics can be developed.

An understanding of natural processes of biological control, such as suppressive soils, is needed to fully exploit and build upon these processes for the benefit of agriculture. Microbial communities associated with disease-suppression and the mechanisms by which they suppress disease remain largely uncharacterized, but powerful methods now exist for characterization of these communities and mechanisms. This knowledge will lead to fundamental concepts of plant disease suppression that can be applied broadly for the development of more efficacious and reliable cultural practices for plant disease management. An expanded set of reliable and efficacious cultural and biological controls are required for widespread deployment of these tactics in the ecologically-based disease management systems of the future.

Anticipated Products

- Selection criteria for biological control agents based upon knowledge of key biological control traits and genes.
- Tools and methods for analyzing system-specific plant-microbe-environment interactions and evaluating the success of biological and cultural control tactics.
- Knowledge of the microbial communities in disease-suppressive soils obtained through altered cropping practices, the use of organic amendments, or other approaches that can be used to develop farming recommendations.
- Production, formulation, and application technologies that enhance the efficacy of biocontrol agents and natural products.
- Integration of control measures (plant resistance and cultural, biological, and/or chemical control) into effective, economical, and sustainable disease management systems.

Potential benefits

- Mechanisms of biological control gained from characterization of the plant-pathogen-antagonist-environment interactions will facilitate screening and deployment of new biocontrol agents and increase effectiveness of existing ones for plant disease management.
- Effective cultural control methods, including the use of cover crops, soil amendments, and recommended cropping practices.

- Newly developed tools for studying system-specific interactions will advance understanding and application of disease management in previously understudied systems, thus enhancing the use of this technology and safeguarding U.S. agriculture.
- Effective disease management strategies, based on host resistance, cultural, biological and/or chemical controls that are benign to human health and the environment, and economically and ecologically sustainable.

Component 3 Resources:
Twenty-seven ARS projects in NP 303 address the research problems identified under Component 3 and the scientists assigned to these projects are located at:

- Beltsville, Maryland;
- Byron, Georgia;
- Canal Point, Florida;
- Charleston, South Carolina;
- College Station, Texas;
- Corvallis, Oregon;
- Davis, California;
- Dawson, Georgia;
- Houma, Louisiana;
- Jackson, Tennessee;
- Kearneysville, West Virginia;
- Peoria, Illinois;
- Pullman, Washington;
- Salinas, California;
- Stoneville, Mississippi;
- Tifton, Georgia;
- Urbana, Illinois;
- Wenatchee, Washington;
- West Lafayette, Indiana;
- Wooster, Ohio.

Component 4: Alternatives to Preplant Methyl Bromide Soil Fumigation

For more than half a century, the primary means of controlling most soilborne plant pathogens was application of soil fumigants, particularly methyl bromide, prior to planting. With the identification of methyl bromide as an ozone depleting substance in the Montreal Protocol (1992), the international phase-out of methyl bromide began along with the search for alternatives to methyl bromide and other soil fumigants. In developed countries, the complete phase-out of manufacturing and importation of methyl bromide occurred on January 1, 2005, except for quarantine/pre-shipment (QPS) uses and Critical Use Exemptions (CUEs). CUEs are granted on a case-by-case yearly basis by an international committee. The non-quarantine use of methyl bromide in the United States has been reduced by approximately 96 percent compared to 1991 baseline levels. Research is needed to address the remaining 4 percent of use, which consists of recalcitrant problems and new problems that have emerged as alternatives to methyl bromide have been implemented. For 2014, the United States requested CUEs for soil fumigation with methyl bromide for strawberry fruit production, and supplemental requests are being prepared for additional crops. Viable alternatives are needed for these remaining uses of methyl bromide as well as optimization of alternatives already in use. Currently registered, chemically-based alternative systems face existing and potential problems associated with township use limitations, emission control, and buffer zone restrictions.

Problem Statement 4A: Develop New Technologies for Commercial Crop Production Systems Currently Dependent on Soil Fumigation

Soil fumigation is used in the production of a variety of plants including: plasticulture annual fruit and vegetable crops; annual and perennial ornamental crops; perennial crops, such as fruit and nut trees; and nursery crops. Alternatives to fumigation must take into account the dynamic economic thresholds and different pest complexes found in the various cropping systems. Currently available chemical fumigants have varying degrees of potential for deleterious environmental impacts related to worker exposure, air and water quality, and long-term exposure of surrounding populations. Potential negative impacts have already limited the use of some chemicals through buffer zone requirements and township cap regulations which have resulted in the loss of chemicals through withdrawal from the market by the manufacturer or cancellation of registration by regulatory agencies. In addition, chemicals adopted as alternatives to methyl bromide are limited in the spectrum of pests and weeds that they control.

New approaches are needed to supplement the currently-registered products as well as to provide alternative tools for the future. New chemistries and new application technologies to optimize efficacy of new and currently available chemicals need to be evaluated. Development of new biological control agents and improvement in the efficacy and applicability of existing biological agents are needed. A greater understanding of the mechanisms of activity and the genetic basis of control will enhance the usefulness of biological control agents. Cultural practices can also be a useful component in an integrated management production system where economics allow.

Performance of alternatives needs to be evaluated in two ways: 1) Under controlled laboratory or small plot conditions where relationships among treatments, exposure time, environmental conditions, pest species, and crop growth stage need to be determined; and 2) In the field, where factors such as treatment distribution, pest population density and distribution, pest interactions, and environmental and soil conditions influence efficacy. In the case of chemical alternatives, knowledge on emission characteristics and efforts to control emissions through fumigant application technology need to be expanded.

Research Needs

Data regarding efficacy, spectrum of activity, and feasibility of use are needed for new chemicals. Further development of resistant rootstocks and grafting onto resistant rootstocks is needed to make better use of these alternatives. Research is needed to enhance the selection of desirable traits among existing biological control agents to improve efficacy and commercial acceptability. New populations of biological agents should be investigated and screened for suitability for use in integrated systems, either as individual isolates or as beneficial populations arising from whole-farm management practices. Cultural management tools, such as cover crops, soil amendments, crop rotations, and alternative mulches, should be evaluated for their potential contributions to multi-component alternative production systems. A better understanding of the effects of biological, physical and chemical factors on the performance of anaerobic soil disinfestations (ASD) is needed to make better use of ASD. Knowledge of each alternative's efficacy against target pests, ease of implementation, and required modifications to existing practices is necessary to determine the optimal role in the overall pest and pathogen management system.

Anticipated Products

- Improved fumigant application methods to reduce emissions and enhance efficacy with less potential for negative environmental impacts.
- New chemicals or more efficacious use of current chemicals in controlling targeted pests.
- Additional commercially viable biological control agents.

- Anaerobic soil disinfestations and similar soil treatments with consistent efficacy for managing weeds and plant pathogens.
- Disease-resistant rootstocks and grafted plants.

Potential Benefits

- Reduction in the number of methyl bromide Critical Use Nominations (CUN) proposed by the U.S. or the total amount of methyl bromide requested.
- Growers remain competitive in the global market.
- Reduced use of soil fumigants, due to reduced application rates resulting from implementation of emission-reducing technologies and approaches.

Problem Statement 4B: Develop Integrated Pest Management Systems to Replace Preplant Use of Methyl Bromide

Overall pest and disease management systems that integrate newly-developed and existing alternatives with other components of production systems are needed to optimize disease and pest control, and to optimize production efficiency. Factors impacting performance of alternatives across crops, rotations, pests, regions, soil types, and soil water content are often poorly characterized, resulting in inconsistent performance that reduces the likelihood of their adoption. In addition, although a substantial amount of work has been done with many alternative fumigants, new materials that are nearing registration have not been adequately tested in all crops and regions and over multiple cropping cycles.

Research Needs

Each of the single tactics developed can be improved through the integration of multiple compatible approaches into long-term, sustainable systems. All new management strategies need to be evaluated under commercial field conditions with significant pest and pathogen pressure over multiple cropping cycles to determine whether they constitute technically and economically feasible alternatives to methyl bromide. The impact of alternative systems on beneficial and detrimental soilborne communities needs to be assessed. Increased knowledge of soil biology, particularly in pest and disease-suppressive soils, is required. In addition, non-chemical management strategies need to be developed and evaluated within the framework of existing commercial production systems. Integration of nematode- and pathogen-resistant germplasm into commercially acceptable varieties for all sectors, as well as grafting desirable scions onto pest and pathogen resistant rootstocks, would increase the potential for pest and pathogen control. A more holistic understanding of healthy and suppressive soils is needed in order to create and maintain soils that are inherently disease and pest resistant.

Anticipated Products

- Commercially acceptable (effective, feasible, affordable) pest and pathogen management systems.
- Characterization of healthy soils and use of this knowledge to develop methods to create and maintain healthy soils.

Potential Benefits

- An integrated approach will allow for the continued profitable production of the high-value crops currently dependent on soil fumigation.

- An over-all reduced need for pre-plant fumigation via implementation of IPM-based systems.
- Multi-component management systems that address current and emerging pest problems to keep productions systems viable and avoid the potential for future dependence on any single chemical pesticide.
- Fewer deleterious environmental impacts than current systems.
- Integration of new chemicals, efficacy of biocontrol agents, and appropriate cultural management tools will minimize adverse environmental effects associated with the use of methyl bromide and other soil fumigants.

Problem statement 4C: Identification and Mitigation of Problems Emerging Following Transition from Soil Fumigants

As growers have moved away from traditional methyl bromide:chloropicrin or other chemical soil fumigation treatments, shifts in soil biological communities have occurred. In some cases this has led to emerging or re-emerging pest and pathogen problems. Often these problems emerge slowly over several years. The implications of shifts in pest and disease populations and emergence of new pest and disease problems needs to be anticipated, identified, and evaluated quickly. The potential impact of existing and emerging pests, diseases, and weeds on crop production will need to be quantified for crops in production systems using rotations, cover crops, double crop strategies, and pesticides with a narrower spectrum of activity than methyl bromide. Pest population thresholds that impact crop production will need to be quantified. Rapid identification of emerging pest and pathogen problems will allow for modifications in component pest management system development.

Research Needs

As new alternatives are used, the biotic and abiotic factors in the soil environment can change resulting in soil conditions that favor the emergence of new pests and pathogens or the re-emergence of those previously controlled. Accurate, affordable methods for the timely detection and identification of current and emerging pests and pathogens need to be developed. Improved methods for detecting pests and pathogens, and knowledge of how pest and pathogen populations are related to economic thresholds, are needed.

Anticipated Products

- New diagnostic and detection tools.
- Timely identification of emerging pest problems.
- Quantification of pest impacts on crop production.

Potential Benefits

- Accurate detection and diagnostic tools for current and emerging pests will foster optimal management decisions.
- Quantification of pest impacts will allow for more cost-effective crop management decision-making.
- Profitable continuation of high-value cropping systems in the face of emerging pests without dependence on methyl bromide.

Component 4 Resources:
Six ARS projects in NP 303 address the research problems identified under Component 4, and the scientists assigned to these projects are located at:

- Beltsville, Maryland;
- Fort Pierce, Florida;
- Parlier, California;
- Salinas, California;
- Washington, DC; and
- Wenatchee, Washington.