The National Plant Diagnostic Network

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The need for biosecurity in our natural and agricultural plant systems can be ascertained by understanding the threats and risks to those systems. Assessments made over the last 10 years have concluded that the threats are real and the risk is moderately high for unintentional introductions of pathogens and pests (6,7,13,15). Risk assessments include an evaluation of the vulnerability of our plant systems, the probability of introductions, and the severity of consequences resulting from those introductions (8,12,15). Continuing globalization of trade and the large-scale movement of people and goods have greatly increased opportunities for the introduction of pathogens and pests. Current movement of agricultural products is over greater distances in shorter periods of time than at any point in U.S. history. With those products come pests and pathogens. The probability of unintentionally introducing a new pest or pathogen increases with the increasing magnitude of this international transport of agricultural products. For logistic reasons, only small percentages of these products can be inspected before importation.

Natural introductions of invasive plant pathogens and insect pests have had, and continue to have, an enormous effect on the agricultural and natural plant systems in the United States (7,9,10). Worldwide, the damage from invasive plant, insect, and pathogen species is more than $100 billion annually (10). The geographic distribution of certain pathogen and pest species influences agricultural trade regulations and affects the international movement of agricultural products (9). There are many historical examples of introductions of invasive species that resulted in high-impact epidemics causing massive economic damage and sociological upheaval (1,4,5).

The threat of intentional introductions of pathogens and pests is significant, but difficult to quantify (8). In general, it is difficult for man to initiate a pest or disease epidemic in nature. For a disease to develop, many interacting factors must occur in a coordinated manner; for an epidemic to result, those conditions must be sustained over time and space. The ability to regulate those factors to a degree that would promote an epidemic is lacking. In some plant systems, however, it is conceivable that a pathogen could be intentionally introduced that would result in at least a limited outbreak. Of equal concern is the introduction of a pest or pathogen of quarantine significance that would significantly impact trade, whether or not an epidemic ensued (14). The end result would be significant economic impact on some segment of the agricultural industry (3,7). Declassification of official documents has revealed that many countries have had anti-crop weapons programs with varying degrees of sophistication (11). Although most countries discontinued their biological weapons programs by 1980, the threats to U.S. agriculture persist. A few countries continued their programs at least through the 1990s, and state-independent terrorist organizations may pose a continuing threat.

Introductions of new pathogens and pests are not the only threats to our agricultural and natural plant systems. Equally important is the evolution of new races and biotypes of indigenous pathogens and pests. As the genotypes of varieties and hybrids change, susceptibility to pathogens and pests may change. Landscape modification resulting from urban and rural development and potential pressures of climate change may well result in population changes in pathogens and pests. The importance of detection and diagnosis is no less for these threats than from the threat of intentional, unintentional, and accidental introductions.

To prevent the establishment and dispersal of pests and pathogens after introductions and to minimize subsequent impact, a plant biosecurity system will require the capability for early detection, accurate diagnosis, and rapid response (2,7). Success will depend upon effective communications and cooperation among plant health professionals in state and federal government, industry, academia, and public arenas. The National Plant Diagnostic Network (NPDN; see the sidebar Definitions of Acronyms) was established as one component of a national system to achieve those goals; the specific objectives include: (i) establish a national communications

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system linking plant diagnostic laboratories of land grant universities (LGU) and state departments of agriculture, state and federal agencies, and national expert laboratories; (ii) upgrade the diagnostic infrastructure in state diagnostic labs; (iii) provide advanced training to diagnosticians; (iv) provide training to "first detectors" to facilitate the rapid reporting of outbreaks of pests and pathogens; and (v) develop data capture and analysis capabilities for the rapid identification of outbreaks (Fig. 1).

Mission and Structure of NPDN

The mission of NPDN. In 2002, the U.S. Secretary of Agriculture established the Animal and Plant Disease and Pest Surveillance and Detection Network within the Cooperative States Research, Education, and Extension Service (CSREES). The mandate was to develop a network linking plant and animal disease diagnostic facilities across the country. The NPDN (http://www.npdn.org) will focus on the plant disease and pest aspects of the program. The network is a collective of plant disease and pest diagnostic facilities at LGU from all 50 states, Puerto Rico, and the U.S. territories in the Pacific: American Samoa, Guam, Marshall Islands, Northern Mariana Islands, Rota, Pohnpei, Saipan, and Palau. The National Animal Health Laboratory Network was established with similar objectives to those of the NPDN, namely early detection and accurate diagnosis of outbreaks of animal diseases. It has five regional diagnostic centers and a series of support satellite laboratories.

The mission of the NPDN is to enhance national agricultural security by quickly detecting outbreaks of pests and pathogens. To achieve this mission, a nationwide network of public agricultural institutions that functions as a cohesive system to quickly detect and diagnose high-consequence biological pests and pathogens in our agricultural and natural ecosystems was developed. The network provides the means for rapid diagnosis and has established protocols for immediate reporting of outbreaks to responders and decision makers. It allows LGU diagnosticians and faculty, state regulatory personnel, and first detectors to efficiently communicate information, images, and methods of detection throughout the system in a timely manner. The network ensures that all participating diagnostic facilities are alerted to possible outbreaks and are technologically equipped to rapidly detect and identify high-risk pests and pathogens. It established an effective communication network, developed standardized diagnostic and reporting protocols, and is cataloging pest and disease occurrence in a national database.

The structure of NPDN. The NPDN is divided operationally into five geographic regions and consists of five regional diagnostic networks: the Great Plains, North Central, Northeast, Southern, and Western (Fig. 2). Each regional diagnostic network is a consortium of land grant institutions and state departments of agriculture that provide services for plant disease diagnosis, plant identification, and insect/pest identification. The regional diagnostic center labs are: UC Davis, coordinating the Western Plant Diagnostic Network (WPDN); Kansas State University, coordinating the Great Plains Diagnostic Network (GPDN); Michigan State University, coordinating the North Central Diagnostic Network (NCPDN); Cornell University, coordinating the North Eastern Network (NEPDN); and Florida State University, coordinating the Southern Network (SPDN). In addition, an NPDN repository for data collection and analysis has been established at Purdue University within the National Agricultural Pest Information System (NAPIS). For information concerning state members of each regional network, please see www.npdn.org and look at the web links for regional networks.

NPDN is coordinated by three levels of operations committees: a national commit-

Definitions of Acronyms

APHIS	Animal and Plant Health Inspection Service
CCA	Certified Crop Advisor
CERIS	Center for Environmental and Regulatory Information Systems
CSREES	Cooperative States Research, Education, and Extension Service
EDEN	Extension Disaster Education Network
FD	First Detector
GIS	Geographic Information System
GPDN	Great Plains Diagnostic Network
IPM	Integrated Pest Management
LCMS	Learning Content Management System
LGU	Land Grant Universities
NAPIS	National Agricultural Pest Information System
NCPDN	North Central Plant Diagnostic Network
NEPDN	Northeast Plant Diagnostic Network
NPB	National Plant Board
NPDN	National Plant Diagnostic Network
PCA	Pest Crop Advisor
PCR	Polymerase Chain Reaction
PDIS	Plant Diagnostic Information System
PPQ	Plant and Pest Quarantine
SDA	State Department of Agriculture
SOP	Standard Operating Procedure
SPDN	Southern Plant Diagnostic Network
SPHD	State Plant Health Director
SPRO	State Plant Regulatory Officer
WPDN	Western Plant Diagnostic Network

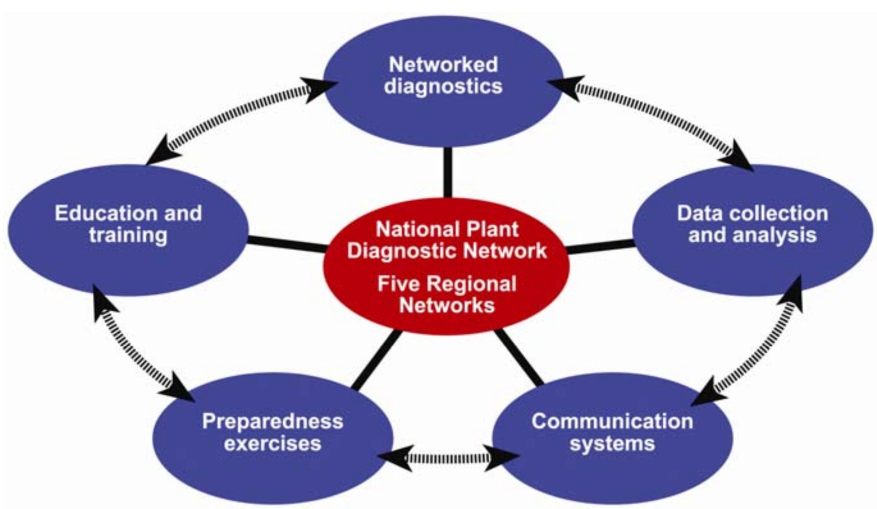

Fig. 1. The National Plant Diagnostic Network (NPDN) was established as one component of a national plant biosecurity system. NPDN goals include: (i) establish a national communications system linking all plant diagnostic laboratories, (ii) upgrade the diagnostic infrastructure in state diagnostic labs, (iii) provide advanced training to diagnosticians, (iv) provide training to "first detectors" to facilitate the early detection and reporting of outbreaks, and (v) develop data capture and analysis capabilities for the rapid identification of outbreaks.

tee, a regional committee, and programmatic committees. The national operations committee (chaired by the CSREES National Program Leader, plant pathology) comprises one regional director and assistant director from each regional lab and CERIS, one representative of the National Plant Board, one representative of the National Disaster Extension Network (EDEN), one member of the National Animal Health Laboratory Network, one representative of a private Crop Consultants Association (CCA), one representative from the Regional IPM Centers, members from CSREES, and members of APHIS. The national operations committee convenes semiannual meetings and biweekly conference calls to develop objectives and assess the progress and needs for the national network.

Subcommittees within the national operations committee promote and implement the objectives of NPDN. These programmatic operations committees are chaired by the regional lab director or assistant director and focus on the following topic areas: education and training, diagnostics, epidemiology, communications and IT, and public relations. Each of these committees comprises private and public sector experts from around the country. The programmatic operations committees convene annual meetings and conference calls as needed.

Regional networks are coordinated by regional directors and managed by regional operations committees comprising representatives of each member state LGU, SDA, and relevant industries. Regional meetings are held annually, and conference calls to discuss diagnostics and other network activities are conducted as needed. Some regions use video conferences to facilitate operations.

Parallel Networked Diagnostics

To succeed, NPDN needs a highly effective LGU diagnostic system. Enhancing the diagnostic capacity and infrastructure at the LGU laboratories is a high priority, and a plan to accomplish that objective is underway. Training materials for diagnostics are being developed, diagnostics expertise is being catalogued across the country, and lists of high-priority pests and pathogens are being developed.

Over the past two decades, there has been a significant erosion of the plant diagnostic capabilities at most LGU, relative to veterinary and human diagnostic facilities. Plant diagnostic laboratories have been impacted by shrinking state support, department mergers, and changes in university priorities. Many labs are expected to support all, or most, of their activities from diagnostic fees; this has been difficult since in many cases, the implementation of fees for diagnoses resulted in a reduction in the number of samples submitted to the lab. Over the last 10 years, DNA and protein-based technologies have become increasingly useful in identification of microbial pathogens, but diagnosticians have found it difficult to obtain the training and equipment needed to implement these new technologies.

The availability of scientists with expertise in the identification of specific pathogens and pests at LGU has also decreased with retirements, increased teaching demands, and reduced effort in applied research and extension. This has left diagnosticians with little backup for identification of rare or exotic pests and pathogens. Although the internet can be a useful source of images and diagnostic information, internet resources differ in

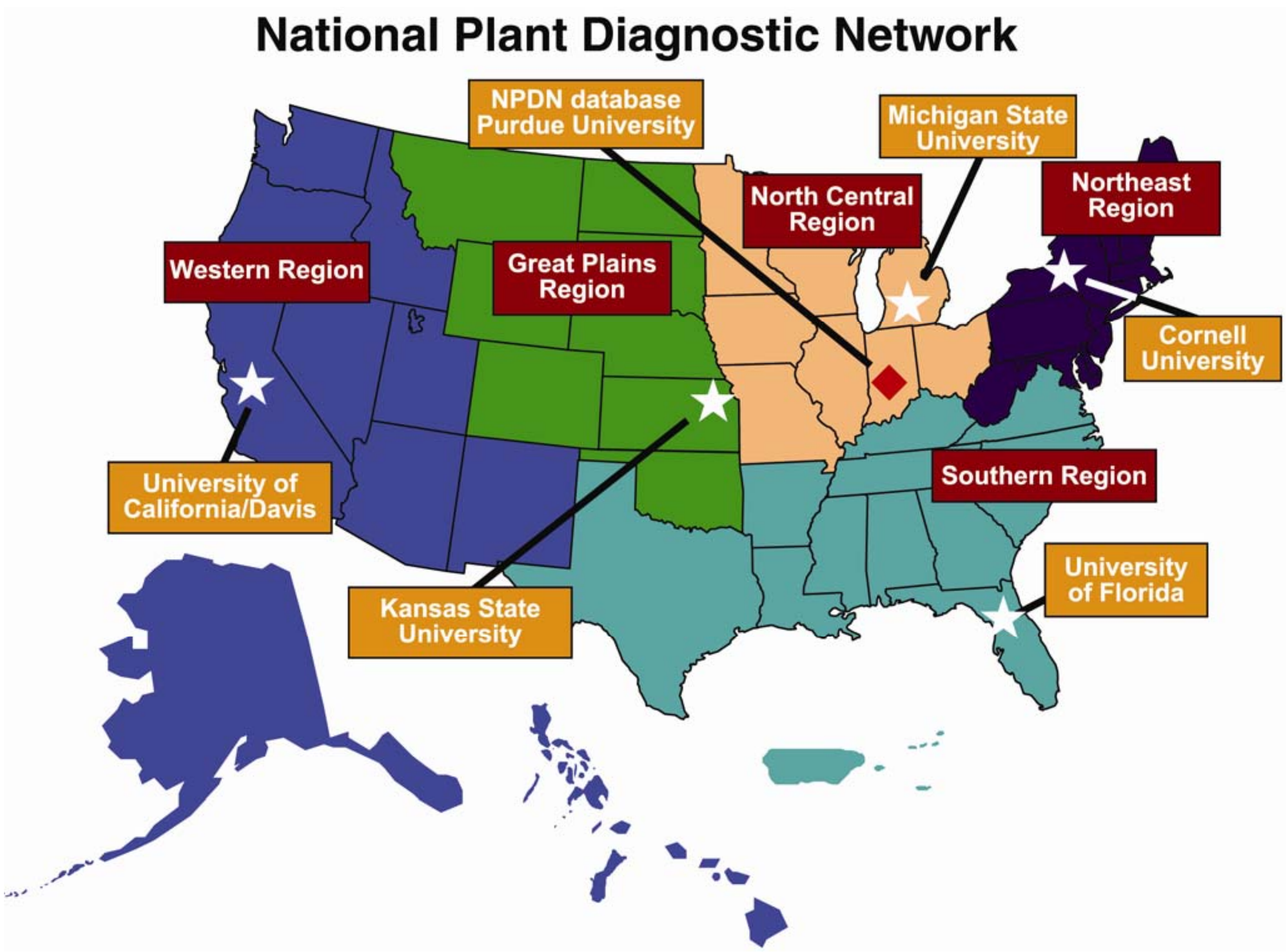

Fig. 2. The National Plant Diagnostic Network is a consortium of five regional diagnostic networks. Five regional diagnostic centers serve as hubs for communications and coordination for a network of 54 land grant university and state department of agriculture laboratories, as well as a national data repository at Purdue University in West Lafayette, IN.

quality, can be difficult to locate, and are not comprehensive. In most cases, there is no way to validate scientific information posted to websites.

Just as resources for plant diagnostics at most LGU have reached an all-time low, the need for coordinated, highly efficient, and accurate diagnoses has emerged as a national priority. The nature of the threat to American agriculture requires responsive, accurate diagnosis of exotic and regulated organisms. As a network, LGU diagnostic labs possess the capacity to respond to multiple regional disease outbreaks. Legal responsibility for identification of regulated pathogens lies with APHIS Plant and Pest Quarantine (PPQ). Official diagnostic tests for regulated organisms are developed, evaluated, and subsequently approved by APHIS scientists. Therefore, if the capacity of LGU plant diagnostic laboratories is to be utilized in a national effort to protect agriculture from introduced pathogens, a close, collaborative relationship between LGU diagnosticians and APHIS scientists is required. Also, LGU labs must be equipped and diagnosticians must be trained to carry out APHIS-approved diagnostic tests. Finally, distance diagnosis technology needs to be developed to provide access to pathogen and pest diagnostic expertise.

The NPDN is striving to enhance plant diagnostic resources at LGU and network the laboratories to enhance collaborative diagnostic activities. The NPDN has provided funding to upgrade laboratory equipment and procure supplies needed to increase diagnostic capabilities at LGU laboratories. New microscopes, digital cameras, computers, and reagents for new diagnostic technologies are now in place. NPDN funds support the participation of diagnosticians in scientific meetings and workshops to enhance their diagnostic expertise. NPDN has provided professional development opportunities for diagnosticians, including molecular diagnostics workshops (Fig. 3A).

A committee of NPDN diagnosticians collaborates with APHIS scientists to produce standard operating procedures (SOP) for diagnosis of high-priority diseases, including those on the select agent list. These SOPs specify sample shipping, handling, isolation media and procedures, and notification procedures for putative positives. Symptoms, pathogen characteristics, and other useful diagnostic information are incorporated in accompanying documentation. These SOPs are working documents; implementation in multiple labs often reveals issues that require clarification or modification. Some NPDN diagnosticians participate in APHIS-sponsored workshops to provide experience with exotic pathogens and new diagnostic protocols.

In some NPDN regions, software is available that allows distance diagnosis in real time, as well as access to comprehensive image libraries and other diagnostic information. The Plant Diagnostic Information System (PDIS) is a web-based software package that is being collaboratively developed and implemented in the Great Plains, North Central, and Northeast regions. The package has many modules, including those that allow real-time viewing of diagnostic images by multiple parties in separate locations. An image library and ready access to other diagnostic resources are available to the entire NPDN through PDIS.

Communications System

Communication among network laboratories is a critical activity of NPDN. Thousands of first detectors, diagnosticians, state regulatory officials, and federal regulatory officials need rapid, reliable, and secure communications during plant disease and pest outbreaks. Many small independent communications systems developed by LGU labs and state and federal regulatory labs have been linked with new communications systems developed to facilitate NPDN objectives; together they make up the NPDN communications network.

The NPDN communications system is deployed at the state diagnostic labs and the regional centers and is interconnected at the national level. This integrated network facilitates communications from field to lab, and between state departments of agriculture, APHIS, CSREES, and the national NPDN database. An interface to facilitate exchange of data among the different systems within the NPDN network was developed. The Extensible Markup Language (XML) standard for data exchange is being used to standardize data definition, formatting, and communications for plant diagnostics data.

The model for data movement from laboratories to the national database can involve state, regional center, and APHIS expert diagnostic labs; e.g., a diagnosis at a state laboratory can be submitted to the regional center and then relayed to the national database. This model provides a framework that in the future will allow laboratory diagnosticians and extension specialists to view plant health and pest status at the state, regional, and national levels with epidemiological analysis tools.

Most of the NPDN systems use the Internet2 Abilene network for communications between university labs. The Internet2 backbone runs at 10 gigabits per second and connects to 44 primary connectors, 228 universities, and 101 spon-

Fig. 3. A, The National Plant Diagnostic Network (NPDN) provides professional development opportunities, including hands-on workshops to facilitate the adoption of molecular diagnostics technology. B, The NPDN training and education program provides first detectors with the necessary skills and knowledge to enhance early detection. To date, NPDN has trained over 2,500 first detectors in the United States.

sored sites. A goal of the Abilene network is to provide 100 megabits of bandwidth between every connected desktop. Use of the Abilene network allows NPDN to successfully deploy and utilize high-bandwidth technologies such as digital microscopy and video conferencing.

The primary functions of the network communications system currently used include diagnostic sample submission, diagnosis reporting, laboratory record keeping, digital microscopy, image archiving, encrypted communications, an alert system, exercise and scenario management, video conferencing, and training. Additional applications being developed for the NPDN network include pathogen and pest population-dynamics models and outbreak event notification. By combining databases of pest information with weather and climate data, along with GIS maps of soil and land use, it will be possible to assemble and deploy existing models for pest outbreak prediction and to establish a baseline population database. These can be used to help decide if reported observations are normal and to be expected for a given time and location, or are unusual and require closer attention. A rule-based notification system can assist in automatically alerting appropriate persons and organizations in the event of a specific pattern of pathogen or pest outbreaks. Rules distributed over the national network can be used to implement SOPs and assist in carrying out those procedures. Efforts are currently underway in several states to develop pathogen or pest population-dynamics studies and rule-based outbreak event-notification procedures.

Data Collection and Analysis

The purpose of the data-collection and analysis program is to improve our ability for early detection of potential biosecurity threats to agricultural and natural plant ecosystems. NPDN is collecting diagnostic records from designated laboratories at LGU and state departments of agriculture. The collection will eventually include records from private diagnostic laboratories that choose to participate. This will create an extraordinary opportunity for the sharing and analysis of diagnostic information on an unprecedented scale. By employing complex pattern analysis of diagnostic information to detect anomalies, the NPDN data system will enable recognition of new outbreaks much earlier than is currently possible. This system will link with other existing databases on a real-time basis. The analysis tool envisioned will be used to help determine if new pests and diseases were intentionally introduced, accidentally introduced, or newly emerged from native populations.

Data from the participating diagnostic laboratories are collected at local, regional, and national levels; current data fields collected include the name of the host plant; the name of the disease, insect, or weed of concern; the county of sample collection; and the date of collection. In the future, data fields will include symptoms, host parts affected, host history and cultural practices, and additional site-specific information on sample collection.

The NPDN data system began receiving records during April 2004. Development of the system is the result of a coordinated effort among the five NPDN regional centers and CERIS. Each state has chosen its database format from a selection of available record-management systems. A unified format has been developed at the regional and national levels. The data system is activated when a sample is brought into the lab, where it is uniquely identified and labeled. Diagnostic information is entered into the system; authorized personnel trained in the analysis procedures can then automatically or manually query the database. After entry at the regional level, the sample information is uploaded to the NPDN national database and analyzed for a regional and national perspective. The database is not public information, and confidentiality is maintained by allowing access only to authorized personnel. Online dynamic maps and reports can be generated by using the analysis engines and enhanced Geographic Information Systems (GIS). The goal is a system that integrates diagnostic data with other data layers, such as climate, land use, soils, topography, and transportation routes. Subsets of layers represented as maps will facilitate rapid anomaly detection and rapid notification and response. The NPDN GIS system will provide a convenient user interface with easy-to-use analytical tools for data visualization and anomaly detection.

Education and Training for Preparedness

As already discussed, early detection of outbreaks is essential to minimize negative impact. This requires skilled first detectors (FDs) who can identify unusual occurrences that may be high consequence pathogens and pests. First detectors consist of a wide array of agricultural professionals including county agricultural agents, certified crop advisors/consultants (CCA), Pest Control Advisors (PCA), and agricultural industry professionals; for some outbreaks it may also include Master Gardeners and the general public.

A major objective of NPDN is to develop the educational resources and implement training programs to provide FDs with the necessary skills and knowledge to enhance early detection. At the heart of the NPDN education and training program is an evolving curriculum. Following the events of 11 September 2001, a sense of urgency prevailed to quickly develop and deploy training materials relevant to the select agent list of 10 high-consequence pathogens that could be used as weapons against U.S. agriculture. To raise awareness of the newly developing NPDN, prepare FDs to identify potential select agent introductions, and instruct on methods for proper sample submission, educational materials that could be delivered rapidly with existing technology (e.g., Microsoft PowerPoint) were developed. To ensure ease of adoption, it was necessary to use teaching methods with which most county faculty and consultants are familiar.

This phase I curriculum contained six modules: (i) NPDN mission, biosecurity, and response (core module); (ii) monitoring for high-risk and unknown pests (core module); (iii) quality and secure sample submission (core module); (iv) art and science of diagnosis; (v) exercises for target pests and pathogens; and (vi) digitally assisted diagnosis. These training modules are available (under password protection) for use by trained FDs on the SPDN website (http://spdn.ifas.ufl.edu/modules/modules.html). Training events included traditional classroom and field (Fig. 3B) extension programming, specialized workshops, and video conferences. Using this curriculum and delivery strategy, the NPDN goal of training 2,500 FD prior to the 2004 cropping season in the United States was met.

The NPDN curriculum was developed by the training and education subcommittee that consists of representatives from all five NPDN regions, as well as two representatives from EDEN and one from the American Phytopathological Society. Departments of plant pathology, entomology, nematology, agronomy, agricultural engineering, and educational design are represented.

The NPDN curriculum was designed to be complementary to the EDEN agricultural biosecurity curriculum. The emphasis of the EDEN curriculum is disaster education emphasizing the four phases of emergency management: (i) preparation, (ii) response, (iii) recovery, and (iv) mitigation. The program is designed for extension advisers, agents, and specialists who teach plant biosecurity management to agricultural producers, workers, and other individuals involved in the U.S. agricultural sector. The EDEN curriculum is available online (http://www.agctr.lsu.edu/eden/; click on Plant and Crop Security).

There are three levels in the training and educational program: I. awareness of the mission and structure of NPDN and of the importance of crop biosecurity; II. first detector educator training (i.e., "train the trainer"); and III. certified first detector training. Since 2002, over 100 NPDN mission and plant biosecurity presentations (level I) have been delivered across the United States. First detector educator training (level II) requires completion of the three core modules and at least two additional modules. Certification as a "First

Detector Educator" allows the trainee to train others with support from state specialists. Certified First Detector training (level III) requires completion of the three core modules that provide the basic information for an increased awareness of biosecurity, monitoring skills, and submission procedures for high-risk plant samples. The first three modules provide a consistent message for the entire United States. Modules 3 through 6 allow for inclusion of region-specific information with respect to local cropping systems and environmental conditions.

Participants of first detector or first detector educator training often complete a pre- and posttraining test to determine knowledge gained and to track progress of the training program. Questions are based on key concepts from the NPDN curriculum. Test results are entered into an NPDN database providing accountability to USDA-CSREES and the data with which to develop a national registry of first detectors. In the event of an outbreak involving a select agent, the registry can serve as resource to access local assistance.

Curriculum development. The scope of NPDN has broadened beyond the select agents to incorporate all threats to plant biosecurity, whether intentional, accidental, or natural. Consequently, additional education and training materials are being developed to address a broader range of high-consequence pathogens and insect pests. The NPDN curriculum will remain dynamic to facilitate the development of educational materials and training programs to address newly emerging problems. Although no insects are listed as select agents, exotic insect introductions continually threaten U.S. agricultural and natural areas. Consequently, entomology-related topics are included in the modules where appropriate. The NPDN first detector training program will continue to include material to enhance the early detection of exotic arthropods. For example, intensive workshops have been conducted on identification of key arthropod pests in the Homopteran group, the Pink Hibiscus mealybug, and insect vectors of plant pathogens.

Training of first detectors will remain an NPDN priority. In partnership with the IPM Centers and EDEN, the NPDN teaching and education committee is developing fact sheets, pest alerts, and computer presentations for a broader audience. SPDN and the IPM Center conducted a joint Soybean Rust Workshop in 2004 that will serve as a prototype for the entire network.

New learning technologies applied to crop biosecurity for first detectors. A large segment of the target audience of FDs consists of crop consultants and county agents, estimated to be more than 25,000 nationwide. E-learning technology offers added opportunity to deliver educational programs to this diverse group. A National Research Initiative–funded multistate project to develop a comprehensive crop biosecurity training program in collaboration with NPDN will develop standardized training materials using a learning content management system (LCMS). An LCMS is a combination of a learning management system that tracks student learning, administers assessments in real-time, and provides remedial assistance and a content management system that consists of a database to store all content materials, including text, images, video, and appropriate citations. Using LCMS, materials can be retrieved easily by the educator and used to quickly develop materials in a variety of formats, (e.g., articles, fact sheets, computer presentations). Currently used by the military and large corporations, these technologies are being developed for e-Extension programs for the future. This new learning system has many advantages and will be used to supplement the traditional methods of information transfer. Our current modules and related materials will be incorporated into the new LCMS for crop biosecurity.

Preparedness Requires Practice

A fundamental tenet for outbreak management is that early detection and rapid response are necessary to minimize impact. To accomplish this requires not only early detection and accurate diagnosis, but also rapid and secure communication of information and samples. Outbreak management involves many individuals representing several institutions and agencies, including LGU, private industry, USDA APHIS, state departments of agriculture, and communications media. Efficient management of outbreaks will require the cooperation of all these individuals; they will need to perform as a team. It is important that everyone involved understand their roles and responsibilities during the outbreak and its subsequent management (Fig. 4). An NPDN exercise committee has developed a national exercise program to help each state attain and maintain a level of preparedness. The exercise program includes different types of scenarios to reflect the different aspects of outbreak management. The NPDN exercise scenario committee includes representatives of NPDN, APHIS, and the National Plant Board.

Each exercise is managed by a national and regional coordinator. A script for each exercise, developed by the exercise committee, is presented to the participants in advance. It is understood that a real outbreak may vary in some aspects from the practice exercise. The goal of the exercise program is to establish communications networks and working relationships that will be necessary to effectively manage a plant disease or pest outbreak. Included in the script is a flow diagram illustrating the proper flow of samples and information during an outbreak (Fig. 5). During the exercise, each step of the process is entered into a secure website developed for the program. This allows monitoring during the exercise, as well as follow-up analysis. To date, more than 40 states have conducted exercises.

The exercise begins with submission of a suspect sample to a state diagnostic lab. This triggers an array of actions, including communications to the state plant regulatory officer, the state plant health director,

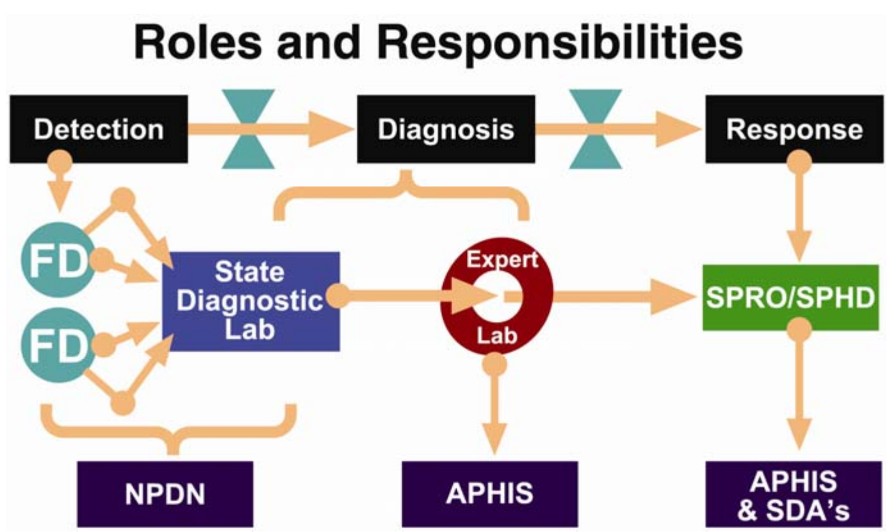

Fig. 4. The National Plant Diagnostic Network serves as a system of networked diagnostic laboratories to provide surge diagnostic capacity during an outbreak. Detection, diagnosis, and management of outbreaks involve local, state, and federal institutions as well as the public and private sectors. It is imperative that everyone involved understands their roles and responsibilities during a disease or pest outbreak. The National Plant Diagnostic Network contributes to the detection and diagnosis phases during an outbreak. (FD = first detector; NPDN = National Plant Diagnostic Network; APHIS = Animal and Plant Health Inspection Service; SPRO = State Plant Regulatory Officer; SPHD = State Plant Health Director; SDA = State Department of Agriculture)

NPDN personnel, and an APHIS expert lab. The sample is transferred by an approved and secure protocol to an APHIS expert lab and/or an NPDN regional lab. A diagnosis is derived and confirmed by using an approved protocol; in many cases a combination of traditional and molecular (e.g., PCR) techniques is used in a confirmatory diagnosis. The results are then communicated to those who need that information, including the person who originally submitted the sample. The average time to complete an exercise, from sample submission to communicating the results, is 48 hours.

The national exercise program plan is to conduct exercises in each state at least once every 3 years for each scenario type. This will account for the turnover in positions and the need to be updated on protocol amendments. NPDN scenarios will fully integrate with incident command system protocols recently adopted by federal agencies for emergency management.

Future: Clarifying and Expanding the Vision

Although much has been accomplished, there remains much to do. In various stages of discussion and planning are the following issues: accreditation and certification for NPDN laboratories, real-time mapping of plant health using Geographic Information Systems (GIS) technology, stronger connectivity and collaboration with industry, and establishing international cooperation for collaborative diagnostics.

Lab accreditation and certification. State diagnostic labs differ with respect to capabilities and support. This has challenged our objectives to improve the diagnostic and communications infrastructure of all NPDN labs. One program under consideration is the establishment of a lab accreditation and certification program. Accreditation standards will indicate basic levels of capability for NPDN laboratories and diagnosticians. Under this program, all NPDN labs would be given the resources and training necessary to achieve the accreditation standards for an NPDN diagnostic laboratory. Individual labs and diagnosticians could then pursue certification for specific agent protocols established by APHIS. A national committee is exploring the development of this program.

This program will have important ramifications for future outbreak management. A common consequence of an outbreak is the submission of very large numbers of samples to state triage labs. If a regulated pathogen or pest is suspected, then all of the samples are submitted to the APHIS expert lab (a lab with legal authority for diagnosing pathogens and pests of regulatory significance), creating the issue of surge capacity (i.e., the inability of the existing infrastructure to process a large number of samples in a short period of time). It is extremely important to rapidly identify positives to facilitate mitigation and to rapidly clear the negatives to avoid impacting commerce. One goal of the accreditation and certification process is to create a network of expert labs to provide for surge capacity during large-scale outbreaks. This will be accomplished in partnership with, and under the guidance of, APHIS. The end result will be a national plant diagnostics system that will better serve our agricultural and natural plant systems.

Real-time mapping of plant health. The quest for real-time plant health monitoring faces many challenges, including technology, information security, and funding, but has been identified as an important component of a security network (13). One effort underway involves the development of GIS applications that will allow real-time mapping of disease incidence and severity at different geographic and temporal scales. Included in this effort are projects to address the issues of scale, the employment of reliable detection technol-

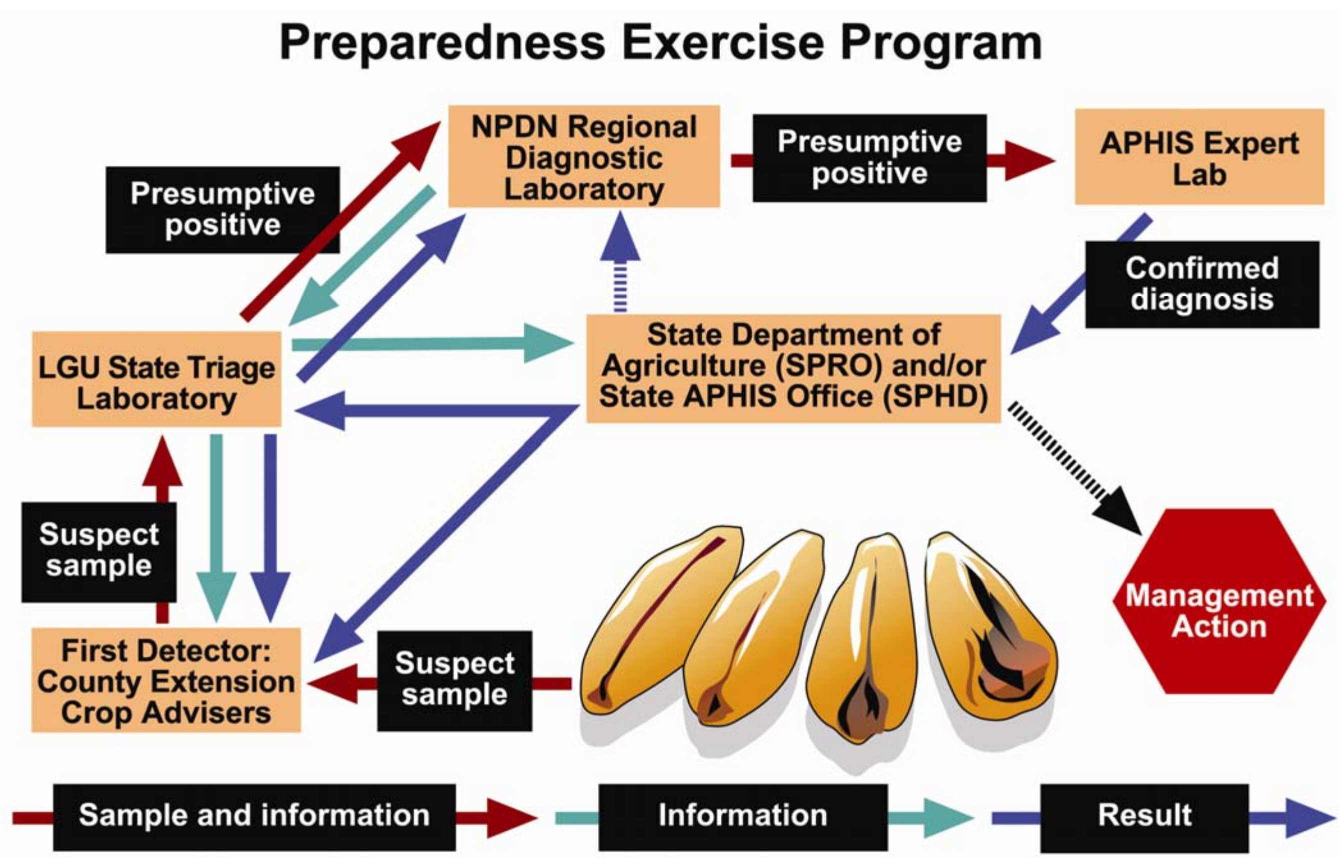

Fig. 5. The successful management of plant disease outbreaks requires the collaboration and coordination of local, state, and federal institutions in order to minimize the ultimate impact. The National Plant Diagnostic Network has developed and implemented an exercise program to assist each state in developing preparedness plans. Each exercise is based on a scenario to ensure the timely and secure communication of information and samples that will result in a rapid and accurate diagnosis and a rapid and appropriate response. (APHIS = Animal and Plant Health Inspection Service; LGU = Land Grant University)

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Kitty F. Cardwell received a B.A. degree in botany at the University of Texas in Austin, and a Ph.D. in plant pathology at Texas A&M University. She did a 4-year stint as a plant pathologist-Peace Corps volunteer in Nicaragua and Colombia, and then farmed 500 hectares of upland rice in the Llanos Orientales of Colombia for 6 years. Dr. Cardwell spent 12 years working as a research plant pathologist and project manager in sub-Saharan Africa, and in 2003, she won the APS International Service Award for that work. She is now the national program leader of plant pathology at CSREES, USDA, and the founding coordinator and national director of the National Plant Diagnostic Network.

Ray Hammerschmidt is professor and chairperson of the Department of Plant Pathology at Michigan State University. He also serves as the coordinator of diagnostic services at MSU and director of the North Central Plant Diagnostic Network. He received his B.S. and M.S. degrees in biochemistry and plant pathology, respectively, from Purdue University and his Ph.D. in plant pathology from the University of Kentucky. Dr. Hammerschmidt joined the faculty at MSU in 1980, where his research has focused on physiology and biochemistry of resistance and induced resistance.

Janet Byrne received her B.S. degree in plant science from Cornell University and M.S. and Ph.D. degrees in plant pathology from Michigan State University. She is currently the plant pathologist in the MSU diagnostic services laboratory, a multidisciplinary laboratory that serves commercial growers as well as the general public. Her interests include expanding diagnostic capabilities by incorporating technologies that offer efficient and cost-effective diagnostic methods pertinent to Michigan's diverse agricultural community. Dr. Byrne is a member of the NPDN operations and diagnostic committees.

R. Loria is a professor and former chair of the Department of Plant Pathology at Cornell University. She is a member of the Graduate Fields of Plant Pathology and Microbiology and has an active research program in the molecular genetics and genomics of *Streptomyces* species that cause diseases of plants. Dr. Loria is a co-editor of the *Compendium of Potato Diseases*. She received her Ph.D. in the Department of Botany and Plant Pathology at Michigan State University.

Karen L. Snover-Clift has been the director of the Plant Disease Diagnostic Clinic of the Department of Plant Pathology at Cornell University since July 1998 and the associate director of the Northeast Plant Diagnostic Network (NEPDN) since November 2002. She received her B.S. degree from Cornell in floriculture and ornamental horticulture and her Masters of Professional Studies degree in the Department of Plant Pathology. As associate director of the NEPDN, she supports the overall mission of providing detection of a possible bioterrorist attack of the nation's natural and agriculture systems and is responsible for ensuring the NEPDN Regional Center is prepared to quickly and accurately process suspect samples. Karen is currently pursuing her Ph.D., conducting research in the area of *Phytophthora* species identification techniques.

Will Baldwin has been involved in information technology since 1989. He was first employed in the Engineering Computer Center working with Harris 800 mainframes for the College of Engineering, Kansas State University. He then served as Information Systems Analyst for the College of Architecture at KSU. In 1994, he began serving as a systems engineer and software engineering coordinator for K-State Research and Extension. While there, he led the team that designed and developed the Plant Diagnostic Information System. PDIS provides essential communication infrastructure between plant diagnostics laboratories at 34 universities and USDA CPHST. Mr. Baldwin also serves as the associate director of information technology for the Great Plains Diagnostic Network with regional headquarters at KSU.

Gail Wisler received her B.S. in biology at the College of William and Mary in 1976. She spent 12 years as a biological scientist in the plant disease clinic for the Florida Department of Agriculture in Gainesville. She completed her M.S. degree in plant virology at the University of Florida in 1981. She managed a monoclonal antibody lab from 1986 to 1988 in the UF plant pathology department, and in 1992, completed her Ph.D. in plant virology. She was a postdoctoral associate at the USDA-ARS in Salinas, CA from 1992 to 1994, then became a research scientist with ARS, and eventually assumed leadership of the pathology group in Salinas, working on soilborne and whitefly-transmitted viruses of sugar beet and vegetables. In 2000, she became chair of the Department of Plant Pathology at the University of Florida, where she is responsible for a statewide pathology program consisting of 34 pathologists at nine locations.

Howard Beck is a professor in the Agricultural and Biological Engineering Department at the University of Florida. He specializes in agricultural decision support systems, information retrieval systems, databases, and artificial intelligence. He developed several Web-based information systems including EDIS (Extension Digital Information Source), DISC (Decision Information Systems for Citrus), SPDN (Southern Plant Diagnostics Networks), NUMAPS (Nutrient Management Plan Support), and research systems involving object databases, ontologies, expert systems, and computer simulation of agroecosystems.

Richard Bostock is a professor and former department chair (1999 to 2005) in the Department of Plant Pathology at the University of California, Davis. Dr. Bostock received his B.S. degree in biology from Rhodes College in 1974 and a Ph.D. in plant pathology at the University of Kentucky in 1981. He was appointed to the faculty in plant pathology at UC Davis in 1981. His research and teaching interests are the biochemistry and molecular biology of plant-microbe interactions. He and his colleagues have studied programmed cell death in response to pathogens, toxins, and elicitors, systemic signaling in resistance and susceptibility, and the influence of diverse stressors on these processes. In addition, he leads an applied research program on fungal diseases of orchard crops, with a current emphasis on brown rot of stone fruits caused by *Monilinia fructicola*. In 2002 he was appointed as the founding director of the Western Plant Diagnostic Network.

Carla Thomas is deputy director of the Western Region Plant Diagnostic Network, located at University of California, Davis. She has an M.S. from Michigan State University. She worked for 10 years at the University of California, Davis, developing weather-based plant disease risk models and providing diagnostic services for the department, and she worked for 5 years with Adcon Telemetry and Western Farm Service, to implement crop risk warning systems in the United States and nine other countries. In 2002, she returned to the University of California, Davis to join the NPDN effort. She is chairman of the NPDN epidemiology workgroup and of the NPDN exercise committee and participates in several national infectious disease advisory groups. She has served as exercise coordinator for biosecurity exercises conducted in over 40 states.

Eileen Luke is the director of the Center for Environmental and Regulatory Information Systems at Purdue University. For over 10 years, she has managed and led information technology (IT) development for the National Pesticide Information Retrieval System, Export Certification Project, and the National Agricultural Pest Information System database systems that cover pesticide registrations, export summaries, and plant pest surveys, respectively. She received her B.S. (1979) in mathematics from the University of California, Davis and her M.S. (1982) in statistics from Purdue University. As chairman of the NPDN IT Committee, she has worked collaboratively with the regional centers to develop a cohesive and secure distributed computing system and network.

ogy, and the coupling of validated epidemiological models for predictive capability.

Industry connectivity and collaboration. The U.S. agricultural industry is composed of many companies with tremendous domestic and international experience and capability. Their continued existence is dependent upon an in-depth understanding of agricultural biosecurity issues as well as an ability to manage the risks. They develop germ plasm, they grow seed, and they move plant products globally; they understand these issues. To date, industry has been a largely untapped resource for NPDN. Discussions have been renewed to develop mechanisms for collaboration in the areas of detection, diagnostics, and training.

International cooperation. Agriculture is international in scope, and the threats are transnational in nature. There are many areas for potential cooperation and collaboration with our trading partners and with nations where high-risk pathogens and pests are indigenous. Collaborative research in detection and diagnostics could be very rewarding for all nations by making international agriculture more secure against natural and intentional threats. The challenges to cooperation and collaboration are significant with respect to trade-sensitive information and national security, but the benefits with respect to protecting the world's food supply could be greater.

Summary

The Animal and Plant Disease and Pest Surveillance and Detection Network was establish in 2002 by the U.S. Secretary of Agriculture to develop a network linking plant and animal disease diagnostic facilities across the country. The NPDN is a consortium of LGU plant disease and pest diagnostic facilities established to enhance national agricultural security by facilitating rapid detection and accurate diagnosis of high-consequence pathogens and pests. This is being accomplished through the development and delivery of education and training programs for first detectors and diagnosticians, enhancing the diagnostic infrastructure at network laboratories, and establishing strong working relationships with all agencies involved in managing plant disease and pest outbreaks.

Although significant investments have been made in technology to accomplish NPDN objectives, the most valuable network resource is people. Through the significant efforts of many people in several institutions, much has been accomplished since 2002. To achieve and maintain agricultural security will require the continued efforts of many to identify the threats, reduce our vulnerabilities, and strengthen our detection and diagnostics capability. New training programs and diagnostic protocols will be needed as new threats emerge and as personnel turnover in key positions occurs. NPDN is an important component to our national agricultural security system.

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