Session 6C

Bioterrorism

Identifying the Threats and Preventing Damage

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Protecting natural and agricultural plant systems from bioterrorism and biocrime

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The need for plant biosecurity

Natural and agricultural plant systems are integral to the economy, culture, and standard of living of all nations. Plant systems provide the raw materials for food, fiber, and fuel. Plants are consumed directly as food and they are fed to animals that are used for food. Plants provide fiber for clothing and timber for housing. In certain nations, plants are now being developed as fuels to reduce dependence upon fossil-based fuels. Food security in developing nations is an availability issue while in developed nations it is an economic issue. In both cases, food security is dependent upon healthy plant systems. Consequently, plant biosecurity should be an essential element of a comprehensive national security plan.

There is a long history of the use of disease agents during warfare. Biological weapons were used against animals in the US during World War I. Foreign agents established a laboratory in the US to produce inoculum to cause anthrax and glanders diseases in horses that would be used to transport troops and materials in Europe. Many nations developed biological weapons against humans, animals, and plants over most of the previous century. Although the frequency of use of biological weapons targeting plants and animals in the past and the consequences to humans pale in comparison to armaments, advances in technology and the ready access to technical information raise the prospect for biologically-based weapons to play a more significant role in crime and terrorism of the future.

In addition to bioterrorism and biocrime, plant systems are facing many threats worldwide resulting from globalization, climate change, and population growth. The natural barriers such as oceans and mountain ranges that restricted the rapid and widespread dispersal of pathogens in the past are being circumvented by rapid, mass transportation systems. People and products move around the world at ever increasing rates. Global trade is predicted to increase dramatically over the next few decades, further increasing the spread of pathogens in raw and finished agricultural commodities. Over the next several decades, climate change may well result in the geographic redistribution of pathogens, insect pests, and vectors as well as the emergence of new pathogens and vectors. Population growth will continue to put pressure on certain nations' ability to provide adequate food supplies. To achieve national security and sustainability, every nation must develop a state of preparedness that addresses the natural threats from a changing world and the intentional threats from increased bioterrorism and biocrime. Whether a pathogen or insect pest is introduced naturally or intentionally, the consequences include production decline, economic loss, or ecological damage.

Plant biosecurity infrastructure

The essential elements of a plant biosecurity system include a prevention strategy to restrict the introduction of pathogens and pests, a surveillance strategy to ensure early detection and reporting of outbreaks, a technology strategy that ensures capacity for rapid and accurate diagnostics, a mitigation strategy for effective response, and a recovery strategy to permit effective resolution from outbreaks of introduced pathogens and pests. In the US, prevention is largely the responsibility of the Department of Homeland Security's Customs and Border Protection in collaboration with the US Department of Agriculture's (USDA) Animal and Plant Health Inspection Service. Together they provide port and entry inspections, enact interdiction when necessary, and conduct international disease surveillance through collaboration with trading partners.

Disease surveillance systems have been developed and implemented to provide for passive and active surveillance for introduced pathogens and insect pests. The National Plant Diagnostic Network (NPDN) and the Pest Information Platform for Extension and Education (PIPE) are two interactive systems currently in operation. NPDN is a network of diagnosticians and first detectors in all fifty states and US territories in the Pacific and Caribbean (http://www.npdn.org). Funded by the USDA, NPDN is an effective partnership among universities, state and federal government agencies, and industry. NPDN labs have been enhanced with molecular diagnostics technology and equipment for the safe and secure handling of high consequence pathogens and insects. Web-enabled microscopy has been implemented to facilitate collaborative diagnostics among NPDN labs and USDA expert labs. Hands-on lab-based workshops as well as online learning events are regularly convened to train NPDN diagnosticians in the latest protocols and technology.

A secure communications system links diagnostic labs in Land Grant Universities and State Departments of Agriculture into a national repository of plant diagnostic data. Analyses of the database facilitate the identification and monitoring of outbreaks. In addition, the NPDN database is providing a baseline for the geographic distribution of pathogens in the US. All 50 states have participated in NPDN-managed exercises to establish outbreak communications and response preparedness promoting cooperation at the local, state, and national levels.

The PIPE disease surveillance system was originally developed to track the spread of Asian Soybean Rust (ASR) in the US. Each season sentinel plots are strategically planted through the US. and monitored for disease incidence and severity. NPDN provides diagnostic support for suspect samples collected. A web-based reporting and mapping system (http://www.sbrusa.net/) allows for near real-time tracking of disease development and spread. Epidemiological and meteorological forecasting tools are used to provide for risk estimation and prediction of directional spread of the pathogen. PIPE's success with ASR has led to surveillance projects for additional pathogens and pests. The PIPE system is complementary to NPDN and offers tremendous potential for the detection and tracking of introduced pathogens and insects pests.

International cooperation

The global scope of plant trade coupled with the potential impacts of climate change may cause the geographic redistribution of existing and the emergence of new plant pathogens and insect pests. The added prospect of bioterrorism and biocrime suggest a wide array of threats to plant systems worldwide. The international nature of the threats will require international cooperation to resolve. The barriers to international cooperation are significant including issues of politics and trade. Transnational collaborative diagnostics and research will be essential to achieving plant biosecurity and must involve scientists and policy makers from academia, industry, and government. Food security is every nations' concern and plant biosecurity is essential to food security.

Can insects be bioterrorism agents?

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Advertisements for the classic giant insect movie *Them!* in 1954 certainly argued that insects (at least giant ants) have the capacity to induce terror. But absent radiation clouds, mutating chemicals, and the suspension of the laws of physics necessary for giant arthropods, can insects be legitimate tools for terrorists? We think not, and the reason we hold this view follows from recognizing the intent of terrorism, features of insect biology, and historical examples evolving insects.

In arguing against insects as bioterrorism agents, we must immediately address an apparent contradiction involving the huge impact insects have on human societies. Setting aside damage to agriculture and other human enterprises, insects still have been, and remain, one of the most devastating aspects of the natural environment through their role in disease transmission. However, unless it becomes possible to purposely manipulate insects to cause human disease epidemics, the medical importance of insects does not directly translate to insects being acceptable bioterrorism agents.

Most definitions of terrorism refer to acts designed to create fear in civilians and driven by an ideological agenda. The many specialty terms for terrorism tend to refer the target (e.g., agro-terrorism) or the mechanism of the threat (e.g., bioterrorism), and in most discussions of bioterrorism emphasis is on human and animal pathogens, less frequently plant pathogens, and rarely insects. The need to produce a human disease epidemic, famine through massive crop losses, or similar immediate, broadly influential consequences seems essential for bioterrorism with insects. Of course short-term economic losses, crop quarantines, disruptions in trade, and similar untoward events can occur through insect outbreaks and introductions. But such events do not seem to offer the potential for fear and social disruption necessary to qualify as terrorism.

Biologically, the economic and medical impacts of insects are dependent on insect population densities. A classic example of the role of insect numbers comes from migratory grasshoppers, like the desert locust, *Schistocera gregaria*. Desert locust swarms seem an ideal model for insect-based bioterrorism. Encompassing hundreds of millions of individuals, swarms are objects of terror and for good reason: overnight a swarm can eliminate thousands of hectares of crops and just the flight of a swarm is sufficient to disrupt air and ground transportation. And historically famine follows locust swarms. But how could the purposeful induction of a locust swarm be achieved as an act of terror? Certainly not by rearing locusts or by any simple species introduction or genetic modification. A campaign against locust control efforts might increase the frequency of locust outbreaks, but swarms don't recognize national borders.

While the desert locust example might be taken as unrealistic, the premise that the impact of insects follows from insect numbers is not. Rearing insects on a scale sufficient to cause even modest economic damage would be a Herculean task. Domestication of silkworms and honey bees was the work of centuries, and industrial production of screwworm flies for sterile insect release required millions of dollars and years of research.

The other option for entomological bioterrorism seems to be the purposeful introduction of pest insects to countries or regions where they do not now occur. The history of economic entomology provides dozens, if not hundreds, of examples of devastating consequences of new pest introductions. However, there are at least three fundamental problems with this approach to bioterrorism: First, unless the pest threatens an essential food plant (which is relatively unlikely for developed countries with diversified agricultures and high per capita incomes), the introduction is unlikely to induce fear. Second, there is a delay, often of years, between introduction, discovery, and economic impact. So introductions lack the immediacy of most terrorist acts. And third, how would you know an introduction was an act of terrorism? So many introductions occur through international trade and travel that it would be hard to distinguish bioterrorism introductions from regular introductions. As a vehicle for fear and publicity, pest species introduction does not seem to offer good mileage.

Historically, insect introductions have been cited as examples of bio-warfare, such as claims of the North introducing harlequin bugs to the South in the American Civil War, the Allies introducing Colorado potato beetle to Germany in WWI, and the Germans introducing Colorado potato beetle to Britain in WWII. Even where we have more compelling evidence of the use of insects in war, such as the rearing and release of plague-infested fleas by Japan's Unit 731 in WWII, these have had virtually no military or propaganda value. Perhaps the most famous 'insect' introduction is the oft-told story of the besieging Tartars catapulting plague victims into Kaffa which led (through Genoese merchants fleeing the city) to the Black Death reaching Europe. A more realistic account of the second plague pandemic depends not on catapults and dying sailors, but on European trade with China, the existence of susceptible human hosts, disease vectors in fleas and reservoirs in rats, and socioeconomic conditions favorable for disease transmission. Introduction alone is not enough: introduction of plague to Messina in 1347 leads to conflagration, the introduction of plague to Surat in 1994 leads to a handful of cases.

As a final exercise, what if we look for the ideal insect bioterrorism weapon. An insect whose impact might have devastating economic and humanitarian consequences. We think there is such an insect: *Cochliomyia hominivorax*, the primary screwworm. If primary screwworm was to become established in Africa, for instance, it would devastate economies and would undoubtedly lead to widespread famine and death. It is an insect whose very introduction is to be feared. But notice which societies are at risk: those that are poor, those that are underdeveloped, and those that are dependent on limited agricultural resources. Are these the societies that are mostly likely to be threatened by terrorists? And even in this 'nightmare' scenario, it is worth noting that when primary screwworm was discovered in Libya in 1988, rapid management led to eradication.

From our review, we see little to support the notion that insects would make useful tools for bioterrorism. To us, the risk from insect bioterrorism is minor at most, and the greater risk is from devoting attention and resources away from areas that pose genuine dangers.

Limitations to the use of plant pathogens as agents of bioterrorism

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Terrorism in the larger context has several key criteria, notably violent action against non-combatants, and the intent to cause fear or intimidation to further political goals. As a specific type of terrorism, the US Center for Disease Control defines bioterrorism as "the deliberate release of viruses, bacteria, or other germs (agents) used to cause illness or death in people, animals, or plants." The CDC groups bioterrorism agents based on the ease with which they can be spread and the potential they offer for illness or death. Several features of plant pathogens make them potential bioterrorism agents. Plant pathogens are readily available from nature and inoculum is easily produced in the lab. Also, because plant pathogens rarely cause diseases in humans, they offer little risk to the perpetrators. Moreover, spore-producing pathogens are especially easy to spread because spores are relatively resistant to environmental degradation and can be passively dispersed. Although many pathogens are specific to a particular host species, some pathogens have a more general host range. Additionally, plants are less likely to have resistance to introduced strains of a pathogen that did not previously occur in a region. Finally, there is little security against intentional introduction of new pathogens in local crops. However, bioterrorism through the intentional spread of plant disease is far from inevitable. Both the biology of plant pathogens and the consequences of plant disease epidemics point to limitations in their potential as agents of terror.

Biologically, at least three conditions must coincide for disease to occur. First, the host must be genetically and developmentally susceptible to the pathogen. Plants have many natural defense mechanisms that protect them from pathogens. These can include structural features, chemical defenses, and genetically controlled gene-for-gene interactions between pathogen and host. Second, the pathogen must be virulent to the host and occur in sufficient quantity. Many pathogens can enter plants only through wounds or natural openings. Others rely on insects to introduce them into host tissue. Some pathogens can penetrate directly, but must have the appropriate genetic makeup to do so. Third, the environment must be conducive to disease development. Environment is a broad-based category that includes such variables as temperature, moisture (both in the soil and on the plant), light, soil type and pH, nutritional status of the host, and a myriad of cultural conditions (plant spacing, canopy structure, time of planting, etc.). In addition to these three criteria, there must be sufficient time for the pathogen to cause symptoms and complete its life cycle. If any of these conditions do not occur, the pathogen will have little effect on the crop.

Beyond these biological limitations, for plant disease to be of concern it must occur to a degree to cause significant loss of plant yield or quality. In the context of bioterrorism, 'significant loss' must lead to fear: through huge economic losses, starvation, or some similar social disruption. Many devastating plant disease epidemics have occurred through history, and looking at a few of these epidemics can illustrate both the factors involved in crop loss and societal consequences.

In the late 1850s the Irish Potato Famine led to the deaths of 1.5 million Irish. The pathogen responsible for the disease, late blight of potato, (*Phytophthora infestans*) was a highly virulent, newly introduced pathogen, and potato was a susceptible host. The weather conditions, cool and wet, were highly conducive for the spread of the disease. However, although the epidemic was a biological one, the famine was artificial. The immense loss of life was due as much to the overwhelming poverty of the Irish, their sole reliance on potato for their nutritional needs, and the political climate (which offered little or no famine relief) as it was to the disease. Given modern circumstances, a similar famine would be unlikely.

In 1970, 80-85% of corn grown in the Midwest United States was of a uniform genotype, Texas cytoplasmic male sterile (Tcms) corn. Tcms corn is susceptible to race T of *Bipolaris (Helminthosporim) maydis*. In 1970, a combination of wet, conducive weather, a susceptible host, and a virulent pathogen lead to an epidemic outbreak of Southern Corn Leaf Blight. Losses were 50-100% in some areas, and economic losses totalled $1 billion. This epidemic illustrates the risk of growing genetically uniform crops, a condition that is, to more or less degree, widely practiced. However, despite the economic damages and losses, there was no famine and adequate corn seed was available in 1971.

There is little a terrorist could do to increase environmental conduciveness or the susceptibility of the host. To increase pathogen virulence through genetic manipulation would require specialized expertise and extensive resources of the type that would most likely only be provided by a state or institution. That leaves the terrorist with the sole option of selecting a naturally virulent pathogen, perhaps one that would be a new introduction to the crop area and therefore more likely to escape natural defenses.

Because pathogens tend to be specific to a single plant species or to a narrow range of species, and because Western societies are not reliant on a single food source as the Irish were in the 1800s, it is unlikely that release of a pathogen would cause widespread food losses. Given the stringent conditions that are required for epidemics to develop, it is unlikely that plant pathogens would make efficient bioterrorism agents if the goal is extensive loss of crop yield.

The more likely risk is to export markets, perhaps a form of economic terrorism. Countries ban the import of crops that may contain previously un-introduced pathogens. Consequently, the introduction and establishment of a new disease could limit the exportability of that crop. To prevent loss of exports, it is important to prevent the establishment of a pathogen. As is illustrated by the surveillance for soybean rust, this is achieved by early detection and control. In their white paper document, the American Phytopathogical Society (APS) encourages preparedness in the defense against bioterrorism. The APS document points out the limitations of increased security in limiting bioterrorism. Focusing on rapid detection, diagnosis, and recovery would provide a more responsible and effective strategy. An additional benefit of this approach is that these strategies would provide both protection from economic terrorism and a sensible approach to limiting natural spread of plant disease.

Bioterrorism: past, present and preparedness in plant protection

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Agroterrorism has been defined as a subset of terrorism and bioterrorism. There is a new, potential concern that a disease-causing pathogen or insect purposely introduced into a crop plant would devastate the yields or contaminate the food supply. Agriculture and the economy of any country, as a whole would hurt. An attack may concern each link of the nutritional chain from the field and down to the table. The countries most vulnerable to such an economic attack on the agricultural sector are those that have high density plantings and large monocultures of specific or narrow genotype plantings.

Historically, the evidence that nations or groups have deliberately introduced biological agents and invasive species targeted against plants are limited. Reportedly, during the sixth century, B.C., Assyrians poisoned enemy wells with rye ergot and in 1952 the Mau Mau killed cattle at a Kenyan mission station using a local toxic plant known as African milk bush. However, these examples were not targeted at plants. Determining whether an insect or plant pathogen is an accidental or intentional release is extremely hard to document. Globally, most countries have a weak plant epidemiological or diagnostic infrastructure.

The characteristics of insects or plant pathogens that render them with special features for an attack on the agriculture sector are that they are completely harmless to man. In most cases they are relatively simple to produce, are widely available, more widely available than chemical or nuclear weapons and in most cases would use low technology to produce. A covert program would be easy to conceal and in fact a maximum effect may not be needed to cause a serious disruption of international trade. Even a rumoured outbreak or infestation can have a tremendous economic impact. Providing the goal is disruption of international trade, it would be near impossible to distinguish between a natural introduction versus an intentional release because of the high background of naturally-occurring diseases and/or insects; it is possible that a deliberately instigated outbreak could be mistaken for a natural one. A point source introduction would mimic a natural point-source outbreak. Such a release has the potential for large impact, especially in areas where the organism does not exist. Further, the low security of vulnerable plant targets, large and isolated plantings of farms complicates detection, especially at low levels.

Over the years, multiple countries have experimented with the use of insects and or plant diseases as biological warfare agents. The following examples can be found in the literature: potato beetle experiments were conducted by both Germany and France in the late 1930s and early l940s. Japan explored the effects of fungi, bacteria, and nematodes on many grains and vegetables. Further, they had some success in dissemination of infected grains of wheat, millet and contaminated cotton. The former Soviet Union conducted work on wheat and barley mosaic streak viruses, potato virus, tobacco mosaic virus, brown grass mosaic to be used against barley, maize and thornapple, plus they worked on various wheat fungi and brown leaf rust.

The United States made significant progress in their development of anti-plant agents when they developed and standardized wheat stem rust as an agent. More recently, Iraq experimented with wheat stem rust as a biological agent. Hence, the work of Germany, France, Britain, Japan, the United States, the Soviet Union and Iraq all illustrate the potential for agricultural biological warfare agents.

The American Phytopathological Society and the Entomological Society of America have dedicated symposia and sessions on agricultural bioterrorism. These two societies represent broad representation of national and international scientific leadership and expertise in protecting agriculture crops against disease and insects. These societies addressed the many issues and implications of pathogens and insects as agents of bioterrorism. The consensus recommendations were the need for international cooperation and education with emphasis on a network to facilitate diagnosis, communication and training. Prevention and preparedness are the two terms that captures the focus of the broader objective of plant protection.

Prevention is currently being used at international borders both for individuals and for trade. Prevention is focused on security and protection, while preparedness places an emphasis on early detection, fast diagnosis, response strategies, education, research and training. Open forum discussions have lifted up the need to globally increase preparedness through investments in infrastructure, diagnostic centers, education and training of first responders. Preparedness is critically dependent on early detection and subsequent communication or reporting of any outbreak. Prevention and preparedness are both dependent on research. An investment in basic research is needed for the development of durable mechanisms of disease and insect-defense within crop plants. Plant pathologists and subsequently entomologists have a very credible history of reducing plant threats through the use of host plant resistance. Clearly, there is a need for plant protection scientists to better understand virulence mechanisms and new approaches to plant protection and control. The discovery of new genes, molecules, or sequences and the use of more molecular diagnostic tools as well as genomic analysis of plant insects and pathogens would help manage plant pests.

Genomic technologies will be fundamental to the development of new diagnostic tools, and new genetic varieties. However, agriculture is very vulnerable to genotype-specific attacks. Currently, four global biotechnology firms are responsible for the bulk of hectares with plant protection traits. In many developed countries the high density planting of these crops over large areas results in essentially genetically identical cultivars, with reduced genetic variability and creates circumstances that facilitate disease and insect spread. Genomics offer information and new understanding of the vulnerabilities of agriculture, both natural and intentional, and make a huge contribution to prevention and preparedness.

New software to manage pest information for phytosanitary and safeguarding programmes

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Modern changes in international trade, travel, and communication patterns have transformed the world. Natural and national borders that previously provided some measure of protection from unwanted diseases, organisms and materials are of themselves no longer sufficient to maintain a reasonable level of bio-security. As a consequence, the global community has developed a series of contracting agreements to govern the rules by which the international economy can thrive while simultaneously ensuring acceptable levels of risk. The World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS agreement) recognizes three intergovernmental standard-setting bodies to protect food safety (Codex Alimentarius), animal health (OIE), and plant health (IPPC).

The International Plant Protection Convention (IPPC) mandates that contracting parties provide information regarding pest status to trading partners. East African countries stand to gain much by increasing trade capacity, but this is often problematic given insufficient infrastructures or resources required to provide such information reliably and transparently. As the Internet becomes more widespread and available, however, it functions as an equalizer for the developing world. Through web-enabled pest databases, countries are able to access reliable information locally for domestic programs as well as share critical information that satisfies international obligations (e.g. the International Phytosanitary Portal of the IPPC). On a regional basis, web-enabled databases empower National Plant Protection Organizations (NPPOs) to combine resources and strategies for pest management and exclusion.

Working with numerous partners, the NSF Centre for IPM has developed and begun to put in place a web-based information system describing pests of significance to agricultural and natural resources. The system is built in a modular fashion to provide different search and access capabilities, while providing for future tailored enhancements by individual partners. Additional planned modules will allow dynamic sharing of pest information electronically within a regional information system and with the IPPC.

Current participants include the respective agricultural ministries of Serbia, Uganda, Kenya, Tanzania, and Zambia, together with COMESA, African Union, USDA, USAID and the NSF Centre for IPM. The software, the Pest Information Management System (PIMS), is now installed in Serbia and Uganda, with Tanzania and Zambia scheduled to follow prior to this Congress. It is expected that the same software will be used by the Caribbean Region as time and funding allow. All activities and priorities for continued software development are determined by partner representatives at periodic country/regional meetings. Within this program, USAID and CIPM have to date provided 3 in-country servers and temporary data entry/webserver access for partners currently without such facilities. USAID and CIPM have also provided in-country and in-US training for partners.

PIMS includes a number of key elements to both protect information and enhance appropriate access globally. The system uses freeware solutions including MySQL, Java, Tomcat application server and Apache web server, in addition to Mapserver to render GIS information. The use of Asynchronous Javascript and XML (AJAX) allows the application to feel more responsive by reading and loading data from the server behind the scenes and then displaying only the information that has changed or been requested without having to reload the entire web page each time a request is made. This serves to increase the web page's interactivity, speed, functionality, and usability. These factors are serious problems in countries/cities with limited internet connectivity. For the user, all that is needed is a web browser and internet connection, whether the user is a Ministry of Agriculture official entering data or a biodiversity expert comparing invasive species' distributions.

The development of this system is not meant to compete with other programs (e.g., the International Phytosanitary Portal), but to help meet the phytosanitary and pest management priorities and responsibilities of developing countries, while at the same time providing dynamic data access among other regional and international programs and systems. Individual country ministries maintain full control of their information, including access to incomplete or not yet validated pest information and internal or sensitive documentation.

The system will be capable of dynamic reporting from individual countries to regional servers and to the IPPC. On-going discussions with individuals responsible for the International Phytosanitary Portal have assured us that the use of this approach is both feasible and desirable. These reports will contain links back to the in-country server that provide details not available in the IPPC report itself, such as dynamic maps of on-going surveys, in-country distributions with pest-free and managed areas indicated. Information such as pest surveys can be entered directly into the mapserver database or dynamic links to separate survey databases can be established. Dynamically connected regional servers will provide a geographically broader picture of invasive and emerging pests and diseases.

The core of the system is a fully vetted taxonomy down to genus that provides 'select lists' rather than 'typed text' to avoid common typographical errors and mis-spellings. Internal modules allow linking pests with commodities, and dynamic mapping of in-country distributions. In addition, individual ministries can define 'Document Types' such as Pest Risk Assessments, Import/Export Regulations, Inspection Protocols and Identification Guides, and upload or link individual documents to specific pests and commodities. This provides a flexible method for incorporating multiple types and levels of information.

In order to avoid costly and time-consuming collection and database storage of already available pest information, PIMS searches Google dynamically for pest graphics, general information, and news, displaying the information within PIMS. We have had initial discussions with Ecoport about developing an enhanced information system that relies on the large Ecoport information base, but with the ability for individual Ministries of Agriculture to approve key information as accurate for their use and inclusion. PIMS will also be integrated with diagnostic information from the International Plant Diagnostic Network (IPDN), a part of the USAID IPM Collaborative Research Support Program. Results from distance diagnoses will dynamically feed into the individual country PIMS through a module to be developed in cooperation with the University of Florida and the Ohio State University.