NC STATE UNIVERSITY

PREDICTING THE NEXT PLANT DISEASE PANDEMIC SYMPOSIUM

April 5-6, 2023

Organized by Jean Ristaino, Director,
Emerging Plant Disease and Global
Food Security Cluster,
North Carolina State University
Sponsored by National Science Foundation Grant Number 2200038, Predictive Intelligence for Pandemic Preparedness Program

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GRIP4PSI, Game-Changing Research for Plant Science
Emerging Plant Disease and Global Food Security Cluster
Global One Health Academy

USDA United States Department of Agriculture Food Safety and Inspection Service
APHIS

Symposium Overview

The Predicting the Next Plant Disease Pandemic Symposium was held at North Carolina State University on April 5th and 6th, 2023. Dr. Jean Ristaino', Dr Jason Delborne and the co-PI's of the NSF Grant Predictive Intelligence for Pandemic Preparedness, Award number 200038, organized the symposium and workshop.

Plant disease outbreaks are increasing and threaten food security for the vulnerable in many areas of the world and in the US. Recently, a global human pandemic threatened the health of millions on our planet. A stable, nutritious food supply is needed to both lift people out of poverty and improve health outcomes. Plant diseases, both endemic and recently emerging, are spreading and exacerbated by climate change, transmission with global food trade networks, pathogen spillover and evolution of new pathogen genetic lineages.

Prediction of plant disease pandemics is unreliable due to the lack of real-time detection, surveillance, and data analytics to inform decision-making and prevent spread. This is the grand challenge that the Predictive Intelligence for Pandemic Prevention (PIPP) Phase 1 planning grant aims to address. As part of this work, a symposium and workshop were held at North Carolina State University (sponsored by the NSF PIPP program) to discuss new tools for pandemic prediction and the social and political implications of implementing them for monitoring and managing plant disease pandemics. The symposium featured a global panel of speakers, a poster session, and was followed by an invitation-only workshop to further discuss and assess current tools and brainstorm strategies for predicting future plant disease pandemics.

This report summarizes the speaker presentations, posters, workshop and demonstrations, and discussion among participants throughout the Symposium.

Contents

Summary of Day One Presentations

Presentation Title	Speaker	Key Takeaways
The Persistent Threat of Emerging Plant Disease to Global Food Security	*Dr. Jean Ristaino, William Neal Reynolds Distinguished Professor of Plant Pathology, Director, Emerging Plant Disease and Global Food Security Cluster, Department of Entomology and Plant Pathology NC State University*	• Emerging plant diseases pose a growing threat to global food security. • Surveillance, early detection, and timely information delivery are vital for effective disease control. • Innovative tools and technologies, such as geospatial analytics, remote sensing, and pathogen risk modeling, enhance disease detection and diagnostics.
Climate and Potential Yield Losses to Fungal Plant Pathogens	*Dr. Dan Bebber, Professor, Biosciences, University of Exeter, Exeter, UK*	• Climate change affects pathogen pressure and leads to yield losses in agricultural fields. • Paired trials offer valuable insights into disease pressure and should be further analyzed to understand disease impacts on crops. • Predictive models have potential for driving agronomic practices, but their accuracy and timing challenges must be considered.
R2M Rapid Risk Assessment to Support Mitigation of Plant Disease: A Toolbox for National Programs	*Dr. Karen Garrett, Preeminent Professor, Department of Plant Pathology, University of Florida, Gainesville, FL.*	• The toolbox presented uses Expert knowledge elicitation, Crop line connectivity analysis, and Scenario analysis to help national programs address disease risks. • Tools should be accessible and user-friendly, promoting collaboration and data sharing among national plant protection organizations and graduate students.
A View from the Ground and Above: A Crops Consultant's Experience with Mapping Farms, Pests, and Pathogens	*Mr. Stan Winslow, President, Tidewater Agronomics, Inc., Camden Co, NC*	• Targeted scouting is essential in crop consulting, focusing on specific areas prone to problems based on crop characteristics, potential pests, and diseases. • Remote sensing and imagery are utilized, but current technology has limitations in early-stage detection of diseases and pests. • Relationships and trust with farmers are critical for managing plant disease outbreaks.
An Area Agent's Perspective on Pest and Pathogen Emergencies	*Ms. Erin Eure, Area Specialized Agent, NC Extension, Gates Co. NC*	• Extension agents play a crucial role in supporting growers by diagnosing crop issues and providing timely and accurate recommendations. • Timeliness, accuracy, and unbiased information are key factors for extension agents to effectively serve growers, helping them manage crop problems, minimize losses, and maintain trust and confidentiality.

Summary of Day One Presentations

The Plant Pathogen Confirmatory Diagnostics Laboratory: Safeguarding US Agriculture and Natural Resources	*Dr. John Bienapfl, Molecular Biologist, USDA Science and Technology Lab, USDA APHIS, Beltsville, MD*	• The PPCDL focuses on developing and implementing advanced biochemical and molecular methods for detecting plant pathogens, and it is the only Federal Plant Pathology ISO/IEC 17025:2017 accredited laboratory that conducts diagnostics for plant pathogens of regulatory concern. • PPCDL's work on the pathogen *Phytophthora ramorum* involved the development and implementation of diagnostic tests, ongoing training of diagnosticians, and improving proficiency testing for this pathogen. • Collaboration and knowledge sharing, both nationally and internationally, are crucial in addressing the challenges of detecting select agents and exotic plant pathogens.
The National Plant Diagnostic Network	*Dr. Neil McRoberts, Director, National Plant Diagnostic Networks, Department of Plant Pathology, University of California, Davis;* *Dr. Jim Stack, Director, Great Plains Diagnostic Networks, Department of Plant Pathology, Kansas State University*	• It is critical to involve policy scholars in addressing complex problems like pandemic response. • The NPDN relies on Congressional funding that is not stable from year to year, jeopardizing its effectiveness. • The regional structure of the NPDN, its activities in regulatory, research, and extension areas, and the significance of its National Data Repository containing millions of diagnostic records were discussed, highlighting the interrelated nature of these functions and the extensive coverage of samples from U.S. counties in the repository.
The North American and Global Perspective on Understanding and Mitigating the Threats of the Next Plant Health Pandemic	*Dr. Stephanie Bloem, Executive Director, North American Plant Health Organization (NAPPO), Raleigh NC*	• The International Plant Protection Convention (IPPC) is a global multilateral treaty that aims to develop and implement plant health standards worldwide, ratified by 184 countries forming the Commission on Phytosanitary Measures. • International plant health standards play a crucial role in creating a level playing field for nations dealing with plant health issues, covering areas such as pest risk analysis, surveillance, and diagnostics, with 47 published standards available in multiple languages. • The IPPC's 10-year strategic framework for 2020-2030 focuses on objectives like protecting the environment from the impact of plant pests and includes development programs such as strengthening outbreak alert systems, managing e-commerce pathways, and establishing a global diagnostic laboratory network.

Summary of Day One Presentations		
Experiences and Insights for Developing and Delivery Plant Disease Risk Information to Small Stakeholder Farmers in Kenya	*Dr. Bryony Taylor, Digital Development Coordinator, Modeling and Data Science, CABI Bioscience, Oxford, UK*	• Challenges faced in lower middle income countries include smallholder farming systems, limited resources, poor infrastructure, and lack of data and equipment. • The Plantwise program trains local extension officers as "plant doctors" to manage crop pests and diseases, setting up plant clinics, collecting data, and reaching millions of farmers. • Case studies highlight surveillance and preparedness efforts, such as the control of the coffee berry borer pest in Papua New Guinea and the Pest Risk Information Service utilizing weather-driven models and field data in sub-Saharan Africa for optimal intervention against pests.
How Might Spatially Explicit Landscape Scale Models Be Improved?	*Dr. Nik Cunniffe, Head of Theoretical & Computational Epidemiology Group, Cambridge University, Cambridge, UK*	• Landscape-scale models are valuable for retrospective analysis of epidemics, considering factors like spatial distribution of hosts, pathogen responses to the environment, and pathogen dispersal. • Missing features in these models include stakeholder behavior, such as individual actions and responses to the epidemic, and genetics, particularly the polygenic basis of pathogen resistance. • Models can be used to design effective control strategies by incorporating optimal control theory and applying techniques like model predictive control to find the most effective treatment profiles over time.
Slowing the Spread of Sudden Oak Death in Oregon Forests: An Overview of a Landscape Scale Disease Management Program	*Ms. Sarah Navarro, Regional Forest Pathologist, US Forest Service, Portland Oregon*	• Oregon's comprehensive approach to managing sudden oak death involves surveying, detection, and treatment, with a focus on managing the disease in tanoak trees, the primary host species. • The program has demonstrated a significant cost benefit, preventing potential losses in timber exports, jobs, timber harvest, and property values. Increased funding and support have been secured, enabling the implementation of new survey tools, faster diagnostics, and expanding the quarantine boundary. • Since its discovery, an interagency team has been working to eradicate and slow the spread of sudden oak death through measures like state quarantine, early detection, surveying, monitoring, and destruction of infected and nearby host plants. Collaboration among stakeholders has been facilitated through the establishment of a Sudden Oak Death Task Force and the development of a strategic action plan.

Summary of Day One Presentations

Effectiveness of Management Program for Sudden Oak Death in Oregon	*Dr. Chris Jones, Research Scholar, Center for Geospatial Analytics, NC State University. Raleigh, NC*	• The presentation focused on iterative forecasting and disease modeling, specifically for Sudden Oak Death. • Collaboration with the Oregon Department of Forestry was highlighted, and an analysis was conducted to assess the effectiveness of previous treatments in preventing the spread of Sudden Oak Death. • The PoPS (Pest or Pathogen Spread) modeling framework was used to simulate the spread of the NA1 and EU1 strains of Sudden Oak Death, incorporating factors like reproduction, dispersal, and establishment of the disease. The simulations showed that treatment efforts effectively prevented infection on a significant scale.
MARPLE Diagnostics: A Pioneering Step in Wheat Rust Management	*Dr. Diane Saunders,* Group Leader, *John Innes Research Institute, Norwich, UK*	• The MARPLE Diagnostics project develops a mobile and real-time plant disease diagnostics system using advanced sequencing technologies to tackle fungal pathogens like wheat rust. • The project aims to provide a simple genotyping platform for rapid and accurate strain identification, reducing the need for distant lab analysis. • Successfully implemented in Ethiopia and expanded to Nepal and Kenya, the MARPLE Diagnostics platform offers portability, accessibility, and integration with disease risk forecasting models, emphasizing knowledge sharing and capacity building through workshops and freely accessible resources.
T-BAS: A Tool for Real-Time Tracking of Biodiversity Across the Tree of Life	*Dr. Ignazio Carbone, Department of Entomology and Plant Pathology, NC State University*	• The Tree-Based Alignment Selector (T-BAS) toolkit integrates complex microbial biodiversity data and metadata, providing insights into the web of biotic and abiotic interactions in plant performance. • T-BAS facilitates population genetics analysis, multi-locus phylogenetic reconstruction, and metadata visualization, promoting standardization of data and enhancing our understanding of taxonomic relationships and attributes.
RIGEL: A Genomic-Based Biosurveillance Approach	*Dr. Willy A. Valdivia-Granda, Orion Integrated Biosciences, Inc., Manhattan Kansas*	• There is a need for effective biosurveillance due to the emergence and persistence of infectious diseases, and their risks to global security. • The incorporation of genomic information and other data types in assessing risks within the agricultural supply chain is discussed, with RIGEL being presented as a system that assesses risk levels associated with different countries and their commodities entering the United States, leveraging artificial intelligence and genomic analysis.

Summary of Day One Presentations		
Preventing and Managing Plant Diseases	*Dr. Wendy Jin, Associate Deputy Administrator, Science, Technology, Plant Protection and Quarantine, USDA, APHIS, Raleigh, NC*	• The U.S. Department of Agriculture's APHIS-PPQ is dedicated to safeguarding U.S. agriculture and natural resources from harmful pests while facilitating safe agricultural trade through the use of advanced science and technology. • PPQ conducts risk analyses, collaborates with researchers, and utilizes surveillance programs and predictive modeling to understand pest risks associated with imported agricultural commodities, anticipate the impact of pests due to climate change, and develop proactive guidelines and decision-making tools. • Collaboration with domestic and international partners is a key component of PPQ's efforts to protect U.S. agriculture and mitigate pest risks.
Mitigating Biothreat Risk at the Border	*Dr. Romelito Lapitan, Agrobioterrorism Countermeasures, Department of Homeland Security, Custom and Border Control, Washington DC*	• CBP works with partner government agencies to enforce import requirements, including those related to animals, plant commodities, organisms, vectors, and biological and biotechnology products. • CBP intercepts significant plant pests, prohibited animal and plant products, and non-compliant biological agents through advanced screening techniques, physical inspections, K-9 units, and the use of technology.
Assessing the Risk of Cucurbit Downy Mildew Outbreaks in the Eastern United States	*Dr. Peter Ojiambo, Department of Entomology and Plant Pathology, NC State University, Raleigh, NC*	• Downy mildew, caused by *Pseudoperonospora cubensis*, is a widespread disease affecting crops like cucumbers, squash, and cantaloupes, and prediction of disease outbreaks is crucial for effective management. • Risk maps were generated to identify high-risk areas for downy mildew across the United States, aiding in disease monitoring and control efforts, while the extension of the model to incorporate epidemic duration provided additional insights for disease control strategies.

The Persistent Threat of Emerging Plant Disease to Global Food Security

Dr. Jean Ristaino
William Neal Reynolds Distinguished Professor of Plant Pathology
Director, Emerging Plant Disease and Global Food Security Cluster
North Carolina State University

Dr. Ristaino's presentation focused on the increasing threat of emerging plant diseases to global food security. She highlighted the global trends and challenges that shaped the future of agriculture, particularly the need to prevent the spread of pests and pathogens that could cause outbreaks in crops. Dr. Ristaino emphasized the characteristics of emerging plant diseases, such as increased incidence, changes in pathogenesis, and newly evolved or discovered pathogens.

She provided examples of recent plant disease outbreaks, including coffee rust in Central America, olive tree diseases in Italy, stem rust in Europe, and Panama disease in Africa and Colombia. These outbreaks posed significant threats to food crops and food security worldwide. Dr. Ristaino emphasized the importance of surveillance and early detection of plant diseases using various tools such as geospatial analytics, remote sensing, and pathogen risk modeling. She highlighted the need to deliver timely information for effective disease control.

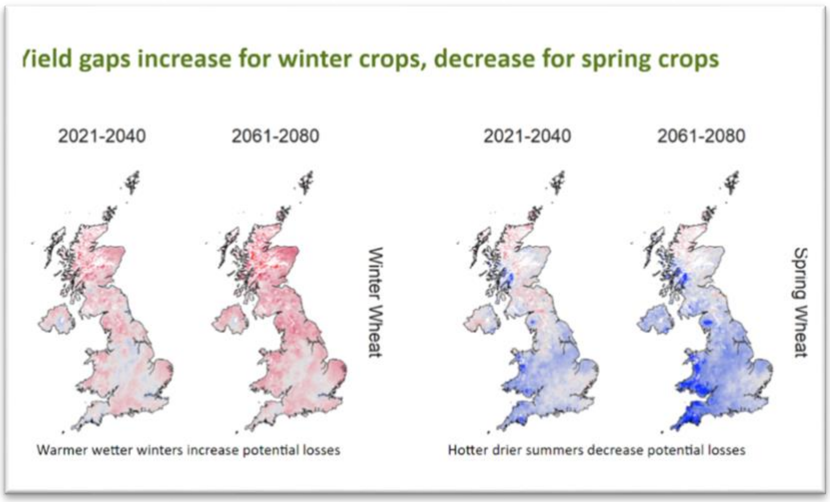
Dr. Ristaino mentioned her research on *Phytophthora infestans*, the pathogen responsible for the Irish famine, and the ongoing threat it posed to smallholder farmers. She discussed the use of genotyping and genomic surveillance to track changes in lineages and understand the evolutionary history of plant pathogens. Through these studies, her team traced the movement of pathogens through historic samples and identified different lineages in various regions.

The presentation also showcased innovative tools and technologies for disease detection and diagnostics. Dr. Ristaino introduced a tool that provided a living phylogeny of *Phytophthora* species, allowing for real-time updates as new species were discovered. She also discussed diagnostics using smartphone sensors and field-compatible molecular assays for rapid detection of pathogens. Furthermore, she highlighted the development of a web application and image analysis using artificial intelligence for data interpretation and analysis.Finally, Dr. Ristaino emphasized the importance of integrating different data streams, including sensor data, geospatial analytics, and DNA analysis, into a centralized database for early detection of plant diseases. This comprehensive approach aims to work in the pre-epidemic event space and prevent full-blown outbreaks, ultimately safeguarding global food security.

Climate and Potential Yield Losses to Fungal Plant Pathogens

Dr. Dan Bebber
Professor
University of Exeter

Dr. Dan Bebber, a professor at the University of Exeter, delivered a presentation on climate change and potential yield losses to fungal plant pathogens. The talk focused on the impact of climate change on pathogen pressure and the resulting yield losses in agricultural fields. Dr. Bebber discussed the utilization of data collected by the Agriculture and Horticultural Development Board (AHDB) in the UK over the past 20 years. These data encompassed trials of different crop varieties, such as winter wheat, spring wheat, winter barley, spring barley, and oats.



By comparing treated fields with untreated fields, it was possible to determine the potential impact of pathogens on crop yield. Dr. Bebber highlighted that climate change can influence disease pressure, which depends on factors like genetic resistance of crop varieties and weather conditions. Warmer winters were found to increase yield losses for winter varieties, while summer relative humidity was more influential for both winter and spring varieties. Dr. Bebber discussed the implications of these findings for crop productivity and the choice of crop varieties in the face of changing climate conditions. The effects of climate change on disease levels and the use of fungicides were also addressed.

The presentation emphasized the importance of paired trials as an underexplored resource for understanding disease pressure in agriculture. Dr. Bebber encouraged further analysis of such trials, which provide valuable insights into the potential impacts of diseases on crops. The talk concluded by discussing the potential application of predictive models in driving agronomic practices. However, the accuracy of predictions and the challenge of timing actions based on these predictions were acknowledged.

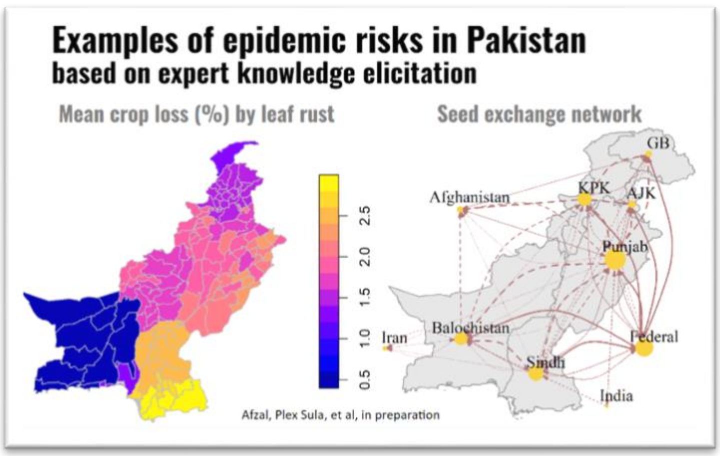
Overall, Dr. Dan Bebber's presentation highlighted the complex relationship between climate change, fungal pathogens, and crop yield losses. The research aimed to provide valuable insights for farmers and decision-makers in choosing crop varieties and implementing agronomic practices in the face of changing climate conditions.

R2M Rapid Risk Assessment to Support Mitigation of Plant Disease: A Toolbox for National Programs

Dr. Karen Garrett
Preeminent Professor
University of Florida

Dr. Karen Garrett's presentation focused on a toolbox that can be used by national programs to address current and future disease risks, especially under climate change scenarios. The toolbox aims to make the most of existing data and knowledge while incorporating new information as it becomes available.

One key aspect of the toolbox is expert knowledge elicitation, which involves gathering information from plant pathologists and experts in the field. This can help fill in geographic details and provide insights that may be costly to collect through formal means. The expert knowledge elicitation process generates curated sets of questions, which are used to create survey instruments for data collection.



Another tool discussed in the presentation is crop line connectivity analysis. By evaluating the landscape structure and considering factors like host plant density and field network connectivity, it becomes possible to assess disease risks and prioritize locations for management efforts. This analysis involves examining the spread of pests or pathogens within a network and determining the potential impact on the overall system.

Scenario analysis is another important tool in the toolbox. By using frameworks like impact network analysis, researchers can explore different management scenarios and evaluate their implications. Questions related to location prioritization, system benefits, policy influences, and monitoring of system dynamics can guide decision making and provide valuable insights into disease management strategies.

Dr. Garrett emphasized the importance of making these tools accessible and user-friendly for national plant protection organizations and graduate students. Additionally, the presentation highlighted the need for developing shared databases and an open-source ecosystem to promote collaboration, data sharing, and model validation.

A View from the Ground and Above: A Crops Consultant's Experience with Mapping Farms, Pests, and Pathogens

Mr. Stan Winslow
President, Tidewater Agronomics, Inc.

Mr. Stan Winslow shared his experiences and insights on crop consulting and mapping farms, as well as managing diseases and pests, gained through his years of experience at Tidewater Agronomics. Tidewater Agronomics operates in six North Carolina and six Virginia counties, serving around 100 growers. They provide a range of services, including fertility management, scouting, and crop advising, without selling any agricultural products.

Mr. Winslow's presentation emphasized the importance of targeted scouting rather than random sampling. His company focuses on specific areas where problems are likely to occur, such as low-lying areas, shady wood lines, or wet spots, based on the characteristics of each crop and the potential pests or diseases they may face. They also consider the differences in insect and disease infestations based on crop varieties and planting dates.

The use of remote sensing and imagery is a part of their work, although current technology has limitations in early-stage detection of diseases and pests. They utilize tools like Google Earth for mapping soil types and satellite imagery for creating soil sample zones. They also use drones equipped with high-resolution multi-spectral cameras to capture images for research trials, allowing for more objective data collection.

Mr. Winslow mentioned the potential future advancements in remote sensing technology, where plants may emit different light spectra when infected with diseases or pests. However, the current detection levels and data are not sufficient for preventive or predictive measures. While technology continues to improve, it is not yet able to replace the need for physically walking through fields and visually inspecting crops.

In addition to discussing the technical aspects of crop consulting and mapping, Mr. Winslow highlighted the importance of relationships and trust with farmers in dealing with plant disease outbreaks. Building strong connections with farmers and effectively communicating information about potential threats helps prevent unnecessary treatments and fosters a collaborative approach to managing agricultural challenges.

Overall, Mr. Winslow's presentation showcased the expertise and practical knowledge gained through his years of experience in crop consulting, emphasizing the value of targeted scouting, the limitations of current remote sensing technology, and the significance of trust and relationships in agricultural management.

An Area Agent’s Perspective on Pest and Pathogen Emergencies

Ms. Erin Eure
Area Specialized Agent

Ms. Erin Eure presented on her role as an area specialized agent for the Cooperative Extension Service in North Carolina and experiences working with growers in the state. As a specialized agent, she bridges the gap between county-level agents and specialists on campus or at research stations. Her region covers the far northeast of North Carolina, which requires extensive travel and collaboration with county agents to effectively serve growers.

Ms. Eure emphasized the importance of being in the field and building relationships with growers. She often responds to problem calls where growers request her expertise in diagnosing crop issues or providing guidance on how to address them. Some problems can be diagnosed in the field, especially with proper training and observable symptoms, allowing for quick management recommendations and potential yield preservation. However, more complex diagnoses may require further analysis in the office or laboratory, which can be time-consuming and may involve sending samples to distant labs at considerable cost.

The effectiveness of extension agents like Ms. Eure hinges on three factors: timeliness, accuracy, and unbiased information. Getting timely diagnoses to growers is crucial for effective management and minimizing losses. Accuracy is essential to avoid providing incorrect recommendations that could harm crops or erode trust with growers. Being part of the land grant university system allows extension agents to offer research-based, unbiased information, unlike private companies driven by product sales. Maintaining confidentiality is also critical in preserving relationships and market access, particularly in the fresh fruits and vegetables industry, where even minor issues can lead to rejected loads.

Ms. Eure also mentioned the challenges associated with managing emerging diseases like strawberry *Neopestalotiopsis* and the importance of confidentiality in tracing and addressing these issues. Additionally, she highlighted the impact of guava root-knot nematode on sweet potato production in North Carolina and the difficulties in conducting research and finding cooperators due to growers' reluctance to disclose their disease status to protect their market position.

In summary, Ms. Erin Eure's presentation focused on the role of extension agents in supporting growers through field visits, diagnosing crop issues, and providing research-based recommendations. The presentation highlighted the importance of timeliness, accuracy, unbiased information, and confidentiality in maintaining effective relationships and addressing pest and pathogen emergencies.

The Plant Pathogen Confirmatory Diagnostics Laboratory: Safeguarding US Agriculture and Natural Resources

Dr. John Bienapfl
USDA APHIS

Dr. John Bienapfl discussed the work done at the USDA APHIS PPQ Science and Technology (S&T) Plant Pathogen Confirmatory Diagnostics Laboratory (PPCDL), which develops, adapts, validates, and utilizes diagnostic methods for the detection of regulated plant pathogens. The PPCDL is committed to quality in confirmatory molecular diagnostics and is the only Federal Plant Pathology ISO/IEC 17025:2017 accredited laboratory that conducts diagnostics for plant pathogens of regulatory concern. The laboratory uses cutting-edge technologies for accurate and rapid diagnosis of high-consequence plant pathogens, including select agent and exotic pathogens, and conducts molecular confirmation/identification of other plant pathogens of regulatory significance.

Dr. Bienapfl highlighted the PPCDL's work on the *Phytophthora ramorum* pathogen, also known as Sudden Oak Death, which was initially a new and unknown threat. They developed and implemented diagnostic tests, starting with culture-based methods and later incorporating PCR-based methods. Even after 20 years, they continue to train diagnosticians and improve their efficiency testing for this pathogen, developing four real-time PCR tests that can yield rapid identification and thereby hasten response time.

The presentation also mentioned the challenges faced in detecting select agents. International collaborations play a critical role in sharing knowledge, developing protocols, conducting inter-laboratory validations, and harmonizing processes and methods. An example of international collaboration was shared, where the USDA lab collaborated with the Canadian Food Inspection Agency and attended an international potato work meeting to develop diagnostic protocols for a soilborne fungus called *Synchytrium endobioticum*.

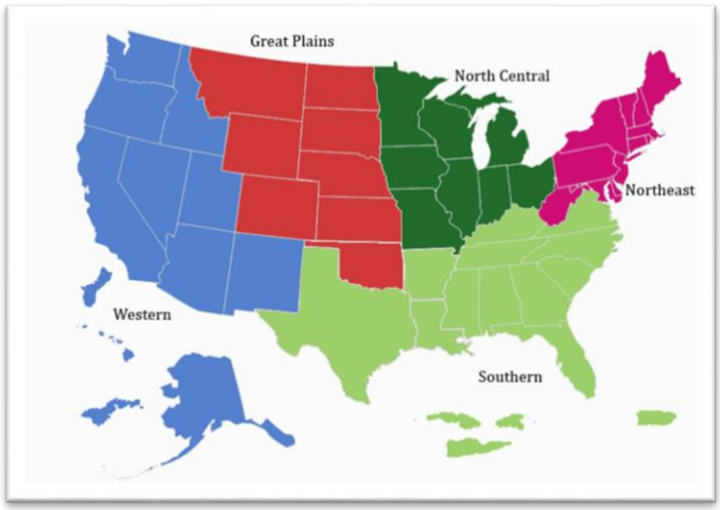
Overall, Dr. Bienapfl emphasized the importance of collaboration, knowledge sharing, and continuous improvement in diagnostic methods to effectively detect and manage plant pathogens.

The National Plant Diagnostic Network

Dr. Neil McRoberts
Director, National Plant Diagnostic Networks, University of California, Davis
Dr. Jim Stack
Director, Great Plains Diagnostic Networks, Kansas State University

Dr. McRoberts briefly discussed the history of the National Plant Diagnostic Networks (NPDN), which was established in 2002 as a response to the events of 9/11. He highlighted the funding challenges faced by the network, as its budget is not guaranteed and can be zeroed out during times of financial restraint. Despite this, NPDN adds considerable value to plant diagnostic activities in every US state and several US territories in the Pacific and Caribbean.

NPDN consists of 5 regional networks of diagnostic labs and the National Data Repository, which is hosted by the Center for Environmental and Regulatory Information Services at Purdue University in Indiana. NPDN works closely with state and federal regulatory agencies to provide US agriculture and other plant-based socio-ecological systems with robust, high-quality diagnostic capability. In the context of the future of the PIPP program, NPDN's 20-year existence may be viewed either as a glittering success story or a dire warning about institutional development and policy implementation in the biosecurity arena.



Dr. McRoberts emphasized the need to involve policy scholars in addressing complex problems like pandemic response. Dr. McRoberts emphasized that not all solutions to problems like plant health diagnostics are solely scientific and mentioned the importance of indemnification and financial support for individuals reporting problems in the public health arena.

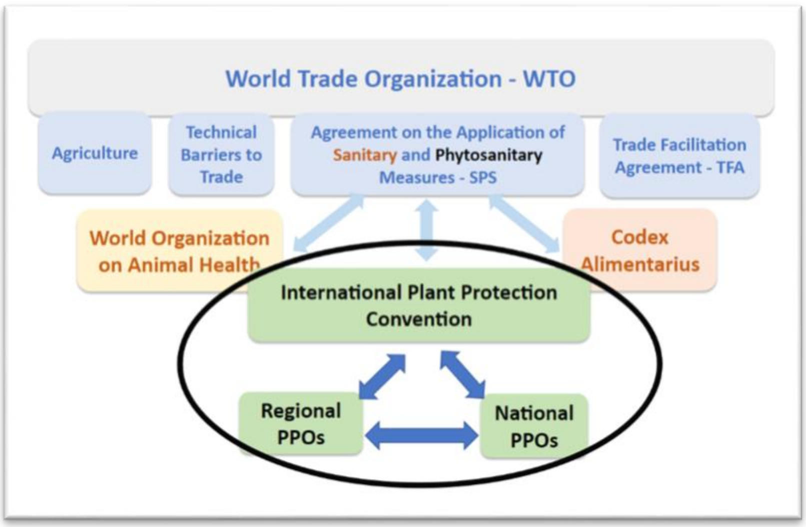
The network funds diagnostic labs and builds relationships with various stakeholders, including regulatory officials, university labs, and extension programs. He highlighted the three main areas of activity: regulatory, research, and extension, and the interrelated nature of these functions.

Dr. McRoberts concluded by mentioning that the NPDN primarily relies on passive surveillance, as they don't have the capacity for active surveillance programs. Despite this limitation, they have samples from over 90% of U.S. counties in their data repository, which represents a wealth of diagnostic data.

The North American and Global Perspective on Understanding and Mitigating the Threats of the Next Plant Health Pandemic

Dr. Stephanie Bloem
Executive Director, NAPPO

Dr. Stephanie Bloem gave a presentation on the international regulatory framework for plant health and initiatives related to predicting and understanding the next plant health pandemic. She highlighted the International Plant Protection Convention (IPPC) as a key component of the global structure for plant health. The IPPC is an international multilateral treaty that aims to develop, adopt, and implement plant health standards worldwide. It has been ratified by 184 countries, which form the Commission on Phytosanitary Measures, the governing body of the IPPC.



Dr. Bloem emphasized the importance of international plant health standards in leveling the playing field for nations dealing with plant health issues. These standards cover various aspects such as pest risk analysis, surveillance, and diagnostics. The IPPC has published 47 standards, including a glossary, surveillance protocols, and phytosanitary treatments. These standards are available in the six official languages of the Food and Agriculture Organization (FAO).

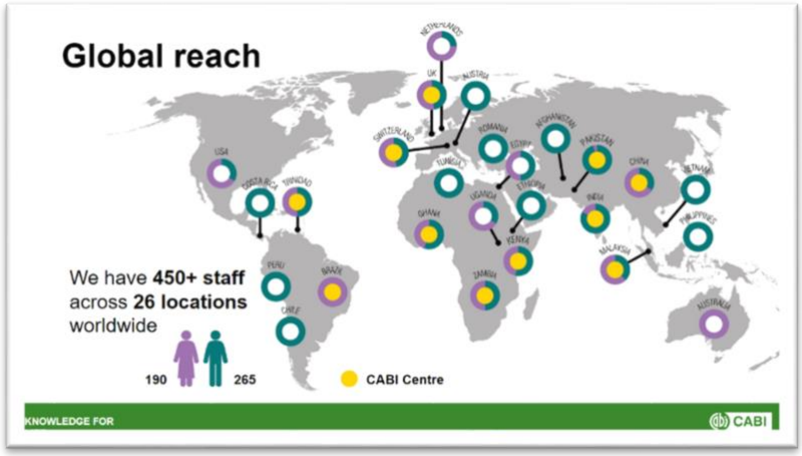
She discussed the IPPC's recently approved 10-year strategic framework for 2020-2030, which has three overarching objectives. One of the objectives is to protect the environment from the impact of plant pests, which is of particular relevance to this symposium. The framework also includes eight development programs, including initiatives like strengthening pest outbreak alert and response systems, managing e-commerce and courier pathways, and establishing a global diagnostic laboratory network.

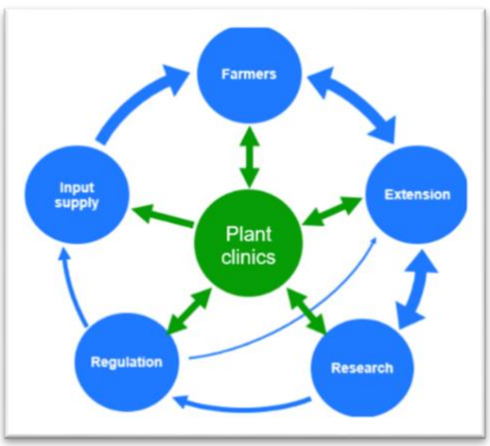
Dr. Bloem highlighted the significance of collaboration and encouraged attendees to engage with these initiatives. She concluded by emphasizing the importance of collaboration at both the regional and global levels.

Experiences and Insights for Developing and Delivery Plant Disease Risk Information to Small Stakeholder Farmers in Kenya

Dr. Bryony Taylor
Digital Development Coordinator
CABI Bioscience, UK

Dr. Bryony Taylor is the coordinator for modeling and data science at CABI, an intergovernmental international organization that focuses on sustainable livelihoods and agricultural development in lower-middle income countries. She highlighted the challenges faced in these countries, such as disparate smallholder farming systems, limited resources, poor infrastructure, and lack of data and equipment.





Dr. Taylor discusses the Plantwise program, which trains local extension officers as "plant doctors" to identify and manage crop pests and diseases. The program has been successful in setting up plant clinics and collecting data, reaching millions of farmers and detecting new and emerging diseases.

She shared a case study from Papua New Guinea where they worked on surveillance and preparedness for the introduction of the coffee berry borer pest. Plantwise set up a surveillance network, identified the pest in certain areas, and collaborated with local organizations successfully to control its spread.

Dr. Taylor mentions the Pest Risk Information Service, a project focused on insect pests in sub-Saharan Africa. They use weather-driven models and field data to determine the optimal time for intervention against pests, providing alerts and risk maps to farmers through existing dissemination channels.

CABI conducted a survey on controlling angular leaf spot disease and found that some farmers lacked resources for spraying. They aim to develop a disease alert service alongside the insect service, considering the limitations and working with existing extension systems.

In conclusion, Dr. Taylor emphasized the importance of planning and delivering information in resource-limited countries, considering local constraints, and finding innovative solutions.

How Might Spatially Explicit Landscape-Scale Models Be Improved?

Dr. Nik Cunniffe
Head of Theoretical and Computational Epidemiology Group
Cambridge, UK

Dr. Nik Cunniffe gave a presentation on spatially explicit landscape-scale models and their applications in understanding and managing epidemics. Dr. Cunniffe began by discussing the use of landscape-scale models in retrospective analysis of epidemics. These models take into account the spatial distribution of hosts, pathogen responses to the environment, and pathogen dispersal. He presented an example of an epidemic spread model for Sudden Oak Death in California, showing the impact of control measures on reducing the size of the epidemic. He highlighted the importance of considering the optimal radius for control, balancing effectiveness with resource limitations.

Next, Dr. Cunniffe discussed the missing features in landscape-scale models. One such feature is stakeholder behavior, where individual actions and responses to the epidemic can significantly impact its spread. He mentioned studies on face mask usage during the COVID-19 pandemic and changes in people's responsiveness to disease over time. Incorporating such behavior into models can provide valuable insights into control strategies.

Another missing feature is genetics, specifically in the context of pathogen resistance. Dr. Cunniffe emphasized the importance of considering the polygenic basis of resistance in models, rather than assuming a monogenic trait. He presented examples of models exploring fungicide resistance and its polygenic basis, highlighting the need to include this aspect in landscape-scale models.

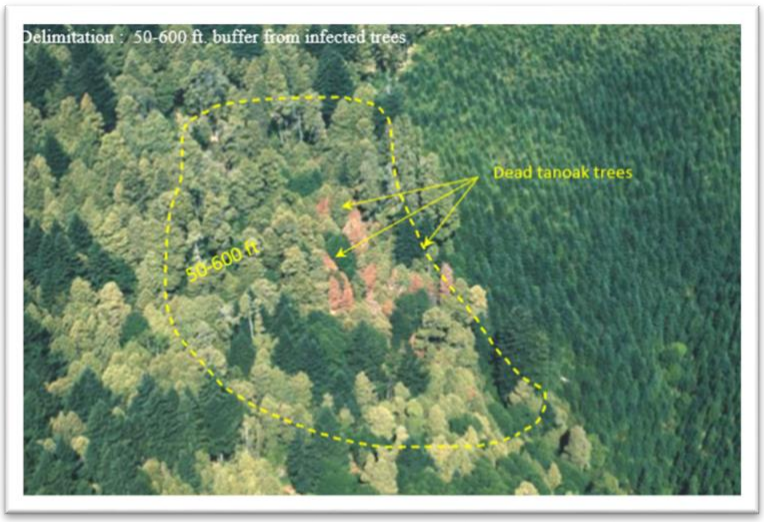
Dr. Cunniffe also discussed the use of models for designing effective control strategies. He acknowledged the computational limitations of scanning over all possible control scenarios and presented optimal control theory as a mathematical technique to identify the most effective strategies. He mentioned the application of model predictive control, which approximates the simulation model and repeatedly recalibrates it to find optimal treatment profiles over time.

In conclusion, Dr. Cunniffe highlighted the importance of incorporating missing features such as stakeholder behavior and genetics into landscape-scale models. He emphasized the potential of using these models to design effective control strategies and mentioned ongoing research in his lab, including the application of optimal control theory and the exploration of machine learning techniques.

Slowing the Spread of Sudden Oak Death in Oregon Forests: An Overview of a Landscape-Scale Disease Management Program

Ms. Sarah Navarro
Regional Forest Pathologist
US Forest Service

Dr. Sarah Navarro discussed Oregon's collaborative efforts to manage Sudden Oak Death. The disease, caused by the pathogen *Phytophthora ramorum*, has been introduced to Oregon forests multiple times through infected plant nursery stock. To combat the spread, Oregon focuses on managing the disease in tanoak trees, which serve as the primary host species. Rain events and turbulent transfer contribute to widespread infection, necessitating comprehensive measures.



Since the discovery of sudden oak death in coastal southwestern Oregon forests in 2001, an interagency team has been working to eradicate and slow the spread of the disease. Their efforts include a state quarantine, early detection, surveying, monitoring, and destruction of infected and nearby host plants. Ground, aerial, and stream bait surveys are conducted throughout the year to detect and delimit the disease. Aerial surveys cover a large, forested area, while ground surveys focus on specific sites. Although eradication treatments have been successful on many infested sites, the disease continues to spread gradually, mainly in a northward direction.

In 2017, a Sudden Oak Death Task Force was established, bringing together various stakeholders to develop a strategic action plan. This plan aimed to secure resources, apply the best available science, and contain the NA1 strain of *Phytophthora ramorum* while eradicating the EU1 strain in Curry County, Oregon. Over the past 20 years, Oregon has made significant progress in treatments, funding, and stakeholder involvement.

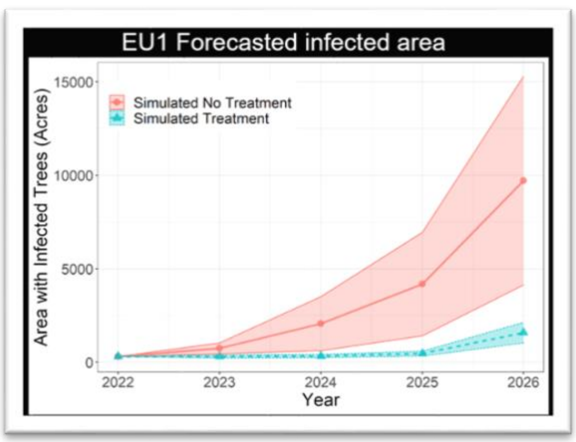
Oregon's program not only creates employment opportunities but also prevents potential losses in timber exports, jobs, timber harvest, and property values. The cultural impact of the disease, especially among tribal members, is also a significant concern. In response to these challenges, Oregon has secured increased legislative support, including federal, state funding. The state is implementing new survey tools, faster diagnostics, and expanding its quarantine boundary to effectively address the ongoing threat of Sudden Oak Death.

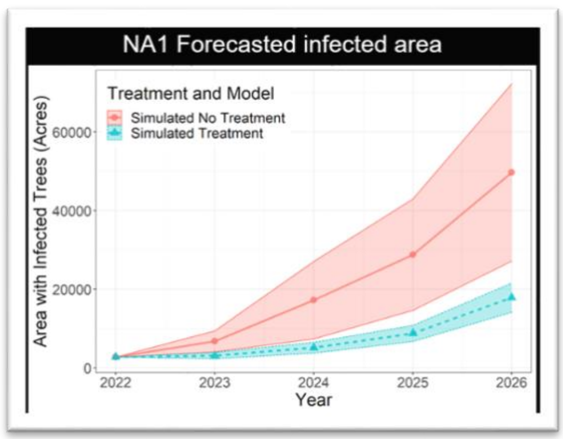
Effectiveness of Management Programs for Sudden Oak Death in Oregon

Dr. Chris Jones
Center for Geospatial Analytics
North Carolina State University

Dr. Chris Jones presented on iterative forecasting and disease modeling, with a focus on Sudden Oak Death (SOD). He mentioned the Center for Geospatial Analytics' collaboration with stakeholders, including the Oregon Department of Forestry (ODF), and highlighted their analysis of the effectiveness of previous treatments in preventing the spread of *Phytophthora ramorum*, the causal agent of SOD. The analysis utilized data from 2015 to 2022 for the EU1 strain and from 2002 to 2022 for the NA1 strain.

Using the PoPS (Pest or Pathogen Spread) modeling framework, they simulated the spread of both NA1 and EU1 strains of *Phytophthora ramorum* in Oregon. The model incorporated factors such as reproduction, dispersal, and establishment of the disease over space and time, based on current infections and environmental data. To ensure accuracy, the NA1 model was calibrated from 2002 to 2015 and validated from 2016 to 2022. The EU1 model, on the other hand, was calibrated from 2015 to 2020 and validated with data from 2021 to 2022.





The simulations included two scenarios: one using the actual treatments that were applied and another with no treatment interventions at all. The goal was to compare the total infected area with the management interventions to what was observed in the field, as well as to the simulation without any treatments. This allowed them to quantify the potential prevention of infection based on the treatments implemented by ODF and the Forest Service. The results demonstrated that the treatment efforts had effectively prevented the infection of thousands of acres, surpassing the area that was directly treated.

In summary, Dr. Jones's presentation provided valuable insights into the effectiveness of treatment strategies in mitigating the spread of Sudden Oak Death. The collaboration with the Oregon Department of Forestry and the use of the PoPS modeling framework contributed to a better understanding of disease dynamics and informed decision making for managing the disease.

MARPLE Diagnostics: A Pioneering Step in Wheat Rust Management

Dr. Diane Saunders
John Innes Research Centre, UK

Dr. Diane Saunders gave a presentation on the MARPLE Diagnostics project. The project focuses on developing a mobile and real-time plant disease diagnostics system using gene sequencing technologies. Specifically, it aims to address the challenges of fungal pathogens, particularly wheat rust pathogens, which cause significant economic losses globally.

MARPLE DIAGNOSTICS

The presentation highlighted the impact of wheat rust diseases, such as yellow rust, which caused a devastating epidemic in Ethiopia in 2010, leading to substantial economic losses. In response, the Wheat Rust Early Warning System was established to prevent future epidemics. However, one missing component was the ability to identify the precise strain present in a farmer's field, which was crucial for assessing the threat and implementing appropriate measures.

To address this gap, the MARPLE Diagnostics program was established to develop a simple genotyping platform for complex fungal pathogens, specifically targeting yellow rust. The platform enables rapid and accurate strain identification, providing results within two days. This eliminates the need for sending samples to distant labs and significantly reduces the time and cost required for analysis.

The MARPLE Diagnostics platform has been successfully implemented in Ethiopia, and expansion efforts have extended to Nepal and Kenya. The system's portability and accessibility make it suitable for resource-poor regions, where laboratory infrastructure and expertise may be limited. The platform's near-real-time data allows for integration with disease risk forecasting models, facilitating early detection and response to new strains and potential fungicide resistance.

Furthermore, the MARPLE Diagnostics project emphasizes knowledge sharing and capacity building through workshops and freely accessible resources. The project website provides training guides, protocols, and equipment information for interested users worldwide.

T-BAS: A Tool for Real-time Tracking of Biodiversity Across the Tree of Life

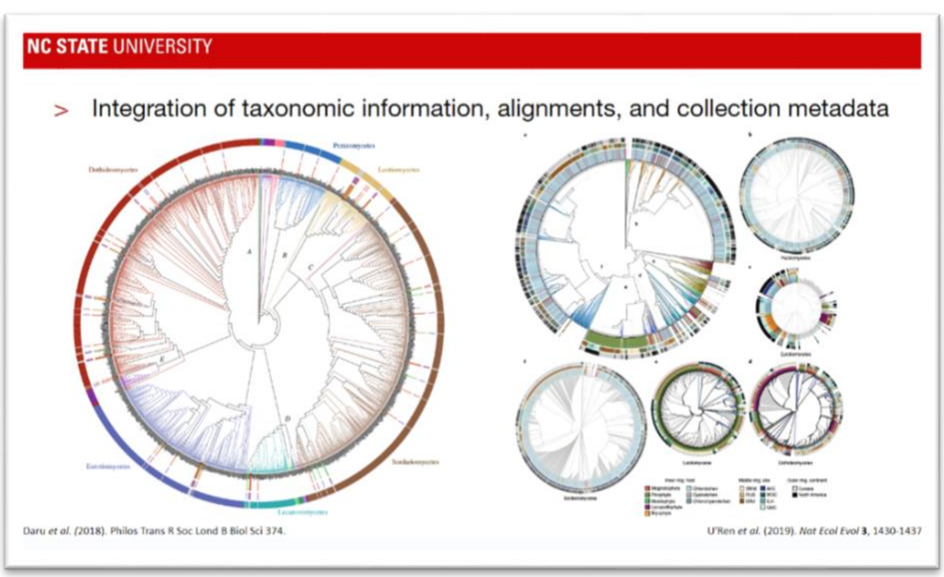
Dr. Ignazio Carbone
North Carolina State University

Dr. Carbone presented the Tree-Based Alignment Selector (T-BAS) toolkit, which is a powerful tool for real-time tracking of biodiversity across the tree of life. The presentation emphasized the importance of taxonomy reflecting phylogeny, where names used in biological classifications should correspond to branches in the tree of life. Existing tree of life initiatives, such as the NCBI Taxonomy Browser, the Open Tree of Life, and the QA Tree Explorer, provide static representations of phylogenetic relationships but lack sequence alignments and comprehensive specimen metadata.

The T-BAS toolkit aims to address these limitations by integrating unknown sequences with reference trees, alignments, and metadata from cultured specimens. It allows the creation of new reference trees with alignments, metadata, and critical components required for building on phylogenies. The toolkit scales the taxonomy from domain to species, enabling the placement of unknown sequences at various taxonomic ranks. This scalability is essential for understanding emerging species and uncovering the vast unclassified and uncultured microbial diversity known as microbial dark matter.

Population genetics and genomics play a crucial role in T-BAS, providing insights into the processes driving the emergence of new species. The toolkit allows for multi-locus phylogenetic reconstruction, which becomes especially important at the species level. By placing sequences on established reference trees and utilizing population-level data, researchers can explore mutation, recombination, and population dynamics. The visualization of metadata on trees, including radial views and the ability to zoom in and out, enhances the understanding of taxonomic relationships and associated attributes.

Overall, T-BAS is a dynamic and open tree of life toolkit that integrates phylogenetic databases, taxonomy, metadata validation, and real-time tracking of biodiversity across taxonomic ranks. It supports population genetics analysis, aids in cataloging microbial diversity, and provides a valuable resource for researchers.



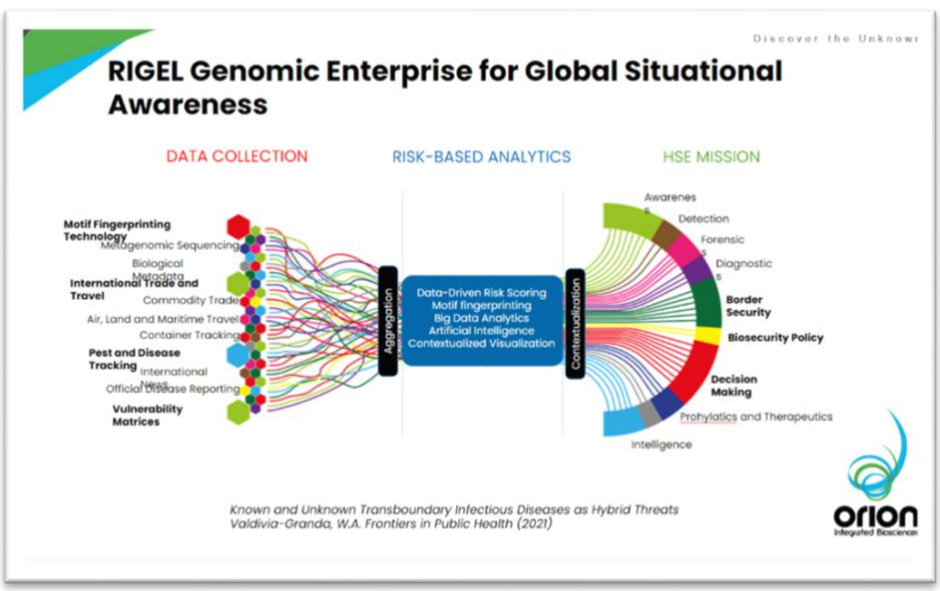
RIGEL: A Genomic-Based Biosurveillance Approach

Dr. Willy A. Valdivia-Granda
Orion Integrated Biosciences Inc.

Dr. Valdivia-Granda focused on the emergence and persistence of infectious diseases, the risks they pose to global security, and the need for effective biosurveillance. The introduction of RIGEL, a data mining and artificial intelligence system, was highlighted as a solution for estimating the risks associated with specific pathogens in various commodities. RIGEL collects and analyzes diverse data from biological facilities, scientific literature, patents, disease outbreaks, news feeds, and trade information to provide a comprehensive understanding of the pandemic potential of pathogens.

Dr. Valdivia-Granda presented RIGEL as a system that collects various parameters, such as socioeconomic indicators, disease information, facility data, and genomic samples, to assess the risk levels associated with different countries and their commodities entering the United States. The system combines dynamic and static parameters to score the risk level of countries and their incoming cargo. It leverages artificial intelligence methods to analyze container contents, read and analyze news reports, extract relevant information like location and disease-related keywords, and map them to the genomic database. RIGEL enables real-time assessment of risk levels, visualization of risk scores, and identification of potential threats in cargo shipments.

RIGEL also has significant potential in countermeasure development, and Dr. Valdivia-Granda showcased prototype insecticides and fungicides with high efficiency against specific pathogens. He emphasized the challenge of accurately identifying pathogens due to morphological similarities and presented RIGEL's advantage in discriminating and differentiating strains using genomic analysis.



Overall, the integration of data mining, artificial intelligence, and genomic-based biosurveillance through RIGEL provides a comprehensive approach to assess and mitigate risks associated with infectious diseases in the agricultural supply chain, contributing to global biosecurity efforts.

Preventing and Managing Plant Diseases

Dr. Wendy Jin
USDA APHIS

Dr. Wendy Jin spoke on the U.S. Department of Agriculture's Animal and Plant Health Inspection Service's (APHIS) Plant Protection and Quarantine's (PPQ) commitment to safeguarding U.S. agriculture and natural resources from harmful pests while facilitating safe agricultural trade. Using advanced science and technology, PPQ analyzes global data to identify pests that could harm U.S. agriculture and develop measures to keep them out. The Safeguarding Continuum, which spans from overseas to U.S. ports of entry and throughout the nation, ensures comprehensive protection.

PPQ collaborates with State Departments of Agriculture and other stakeholders to quickly detect and respond to new pests and diseases, aiming to prevent large-scale damage to farms and forests. When foreign pests establish in the United States, PPQ works closely with federal, state, tribal, and industry partners to control and eliminate them. The agency emphasizes science-based policy-making in its regulatory program and ensures it has the best tools for pest detection, surveillance, and mitigation.

PPQ conducts risk analyses to understand potential pests associated with imported agricultural commodities and collaborates with university researchers and the Center for Integrated Pest Management (CIPM) to develop proactive guidelines and decision-making tools. Pathway analyses identify potential entry routes for pests, and surveillance programs like the Cooperative Agricultural Pest Survey (CAPS) monitor pests nationwide. Predictive modeling using climate data helps assess pest risks, and PPQ develops climate suitability maps to anticipate the impact of pests due to climate change.

Collaboration is essential to PPQ's success, as they work with domestic stakeholders such as the National Plant Board and sister agencies, as well as international partners like the International Plant Protection Convention (IPPC) and the Agricultural Quarantine and Inspection (AQI) Program. By leveraging these partnerships and focusing on method development, diagnostics, and treatment measures, PPQ aims to protect U.S. agriculture and mitigate the risks posed by pests.

Mitigating Biothreat Risk at the Border

Dr. Romelito Lapitan
Agrobioterrorism Countermeasures
DHS

Dr. Romlito Lapitan discussed the role of the U.S. Customs and Border Protection (CBP) in mitigating risks to American agriculture and public health at the border. CBP, formed as a unified border agency in 2003, has over 27,000 officers and 2,700 agriculture specialists stationed at 328 ports of entry, covering various pathways such as cargo, passenger, and mail. Their mission is to enforce over 400 laws on behalf of 40 partner government agencies to safeguard American agriculture and public health.

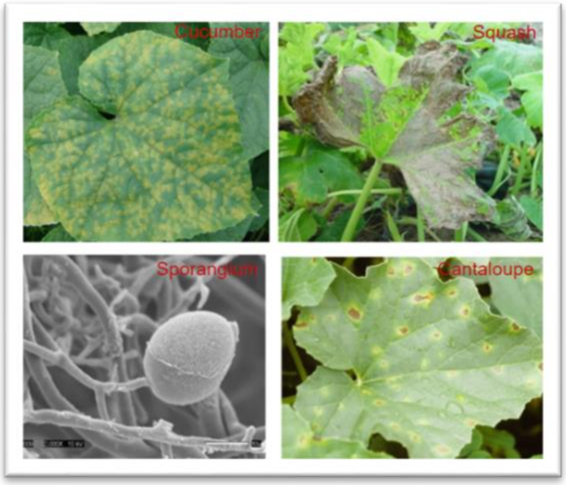
CBP agriculture specialists work with the Animal and Plant Health Inspection Service (APHIS) to enforce compliance with agricultural and biological import regulations. They inspect not only animals and plant commodities but also materials covered under organisms and vectors, as well as the virus serum toxin act. CBP also assists other agencies like the FDA, EPA, and Fish and Wildlife Services in enforcing import requirements. On the export side, CBP ensures that biological and biotechnology products are properly flagged and referred to the Bureau of Industry and Security for clearance.

CBP uses advanced screening techniques for cargo, such as filing of entry in advance and flagging high-risk shipments. Physical inspections are conducted on carriers, import commodities, and passenger luggage. CBP looks for pests, diseases, wood packing materials, contraband, and regulated garbage that could pose risks to agriculture and public health. They also employ K-9 units, distribute informational materials, and use technology like the CBP One mobile referral system to facilitate entry and enhance their operations.

CBP plays a crucial role in protecting American agriculture and public health by inspecting and mitigating risks at the border. They continue to enhance their capabilities through interagency coordination, risk-based screening tools, and the adoption of new technologies.

Assessing the Risk of Cucurbit Downy Mildew Outbreaks in the Eastern United States

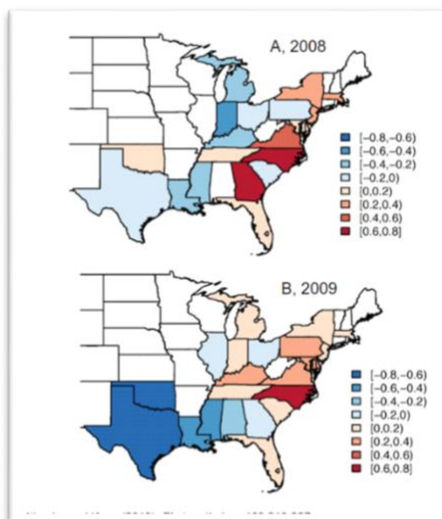
Dr. Peter Ojiambo
North Carolina State University



Dr. Ojiambo gave a presentation on his work related to understanding the risk of a disease called cucurbit downy mildew, caused by the pathogen *Pseudoperonospora cubensis*. The disease has a wide distribution and affects various cucurbit crops such as cucumbers, squash, and cantaloupes. The focus of the research was to investigate the long-distance movement and spread of the disease.

The disease has been a significant problem in the eastern part of the United States, but it has also been observed in California. Control options for the disease are limited, relying heavily on fungicides. Therefore, prediction and forecasting of disease outbreaks become crucial for effective disease management.

Dr. Ojiambo presented a Bayesian hierarchical modeling approach to estimate the risk of disease onset and duration. The analysis incorporated survivor analysis, spatial analysis, and Bayesian approaches to account for spatial structure and uncertainty. The modeling included random effects at the state level to capture the spatial variability of disease occurrence.



The results of the modeling showed maps indicating the risk of cucurbit downy mildew across the United States for different years. Higher-risk areas were identified in states along the mid-Atlantic region, such as New York, Pennsylvania, and North Carolina. Lower-risk areas were observed in Texas, Mississippi, and Louisiana. These risk maps can be used to guide disease monitoring and control efforts, especially in high-risk areas, to optimize resource allocation.

Dr. Ojiambo also discussed the extension of the Bayesian model to incorporate epidemic duration. The duration of infection plays a crucial role in understanding disease risk. The model utilized a truncated Poisson distribution to describe the epidemic duration and incorporated random effects to capture spatial variability. The results provided insights into both disease onset and epidemic duration, helping to identify areas of higher risk and informing disease control strategies

Summary of Poster Sessions		
Poster Title	Authors	Key Takeaways
Monitoring Emerging *Phytophthora ramorum* and *P. kernoviae* in Rhododendron	*Amanda Mainello, Amanda Saville, Jyotsna Acharya, Rajesh Paul, Qingshan Wei, Jean Ristaino*	This study evaluates and develops loop-mediated isothermal amplification (LAMP) assays for detecting *Phytophthora* pathogens, *specifically Phytophthora ramorum* and *P. kernoviae*, aiming to utilize these assays to detect and monitor the spread of Phytophthora species in forest and nursery settings, highlighting the significance of rapid, field-deployable assays for preventing pathogen transmission.
An Open-Access T-BAS Phylogeny for Emerging *Phytophthora* Species	*Allison Coomber, Amanda Saville, Ignazio Carbone, and Jean Beagle Ristaino*	This poster details the development of the Tree-Based Alignment Selector Toolkit (T-BAS), a phylogenetic tool that centralizes sequence data and metadata for over 190 species of Phytophthora, providing a comprehensive resource for research, identification, and data sharing within the global *Phytophthora* research community.
Distribution and Diversity of Abaca Bunchy Top Virus and Banana Bunchy Top Virus Causing Bunchy Top of Abaca in Caraga, Philippines	*Mark Paul Selda Rivarez, Jezmeir Porras, Cristal Mae Magadan, Arnaldo Gagula, Rezel Borines, Elizabeth Parac*	This poster discusses the generation of a distribution map for the incidence of abaca bunchy top disease (BTD) in the Caraga region of the Philippines using mapping tools and molecular diagnostics, providing valuable insights into the distribution and diversity of abaca bunchy top virus (ABTV) and banana bunchy top virus (BBTV) and advancing the understanding of the disease's epidemiology.
Economics of Plant Diseases and Disease Management with Application to Field Tomatoes	*Daemyung Lee, Kelly Zering*	Linked models predict outcomes and assess new technology's value, identifying needed adaptations in markets and policy based on disease effects, management practices, and external factors.
Global Surveillance and Detection of Novel Cereal Rust Virulence	*Douglas Luster, Melissa Carter, Pablo Olivera, Yue Jin*	Global surveillance of cereal rust diseases is crucial for timely control measures, and the FDWSRU plays a critical role by receiving, analyzing, and monitoring highly virulent rust samples to identify new sources of resistance and enhance crop protection.
Identification of Southern Leaf Blight Infected Corn for Remote Sensing Field Imager	*Grace Vincent, Cranos Williams, Michael Kudenov, Peter Balint-Kurti*	This research aims to develop efficient detection and classification models using machine learning and hyper-spectral imagery to identify and analyze crop diseases, with the potential to enhance crop disease management and reduce crop loss, benefiting food security and sustainability.

Summary of Poster Sessions		
Near Real-time Decision Making Under Uncertainty for Disease Mapping, Monitoring, and Prediction	*Raju Vatsavai, Ezio Mei*	Integrating diverse datasets, including remote sensing data, into machine learning models offers opportunities for more accurate and timely disease mapping, prediction, and management, which provides actionable knowledge for farmers to make informed decisions under uncertainty and optimize resource allocation.
Development of a LAMP/Cas12a Assay to Specifically Detect the California Strain of Resistance Breaking (RB) - Tomato Spotted Wilt Virus (TSWV) in Tomato	*Tatsiana Shymanovich, Amanda Saville, Noor Mohammad, Qingshan Wei, Dorith Rotenberg, Anna E. Whitfield, Jean Beagle Ristaino*	Detecting and differentiating strains of plant-pathogenic viruses, particularly the RB-TSWV strain in tomato plants with and without the Sw-5 gene, was investigated using disease progress comparison, microneedle RNA extractions, LAMP, and a rapid LAMP/Cas12a assay, demonstrating the potential for accurate and rapid field detection of RB-TSWV.
The Advanced Plant Phenotyping Laboratory: A Phenomics Platform for Dissecting Genomics of Plant Performance and Health	*Larry M. York, Stan Martin, Mac McLennan, Wellington Muchero, Dave Weston*	The Advanced Plant Phenotyping Laboratory (APPL) integrates various imaging modalities and automated systems to measure plant properties, enabling the generation of plant "health fingerprints" through machine learning and AI, with applications in genome-wide association studies, heat-stress tolerance monitoring, drought tolerance assessment, and potential implications for plant disease epidemics.
Automating Severity Assessment of Southern Leaf Blight in Corn Leaves Using Machine Learning	*Chanae Ottley, Cranos Williams*	This work aims to develop an efficient computational pipeline using machine learning and computer vision to estimate disease severity caused by Southern Leaf Blight in field-grown maize plants, with the potential to enable early detection, monitor epidemics, and optimize resource allocation for plant stress management.
Revolutionizing Plant Pathogen Detection and Monitoring: Portable VOC Fingerprinting and Continuous Monitoring in Agriculture	*Oindrila Hossain, Zheng Li, Giwon Lee, Sina Jamalzadegan, Yuxuan Liu, Rajesh Paul, Amanda C. Saville, Tatsiana Shymanovitch, Dorith Rotenberg, Anna E. Whitfield, Jean B. Ristaino, Yong Zhu, Qingshan Wei*	To overcome the limitations of conventional plant pathogen detection methods, cost-effective and miniature volatile organic compound (VOC) sensor platforms were developed, including a smartphone-based device and a wearable sensor, enabling non-invasive and real-time diagnosis of plant diseases such as late blight and tomato spotted wilt virus (TSWV) in the field.
Tailoring Named Entity Recognition (NER) to Extract Pest Event Data from Online News and Tweets	*Ariel Saffer, Laura Tateosian, Makiko Shukunobe, Chelsey Walden- Schreiner*	The use of web media data as a supplementary source for pest observation and distribution information shows promise in addressing the limitations of traditional data sources, such as latency and sparseness, and can enhance predictive models and control programs, as demonstrated by case studies on Spotted

Summary of Poster Sessions

		Lanternfly and *Tuta absoluta*, utilizing text analysis and Natural Language Processing techniques.
Prediction of Leaf Wetness Duration and *Botrytis*, and Validation in Strawberry Fields with Multi-Sensor Arrays	*Ashley N. Philbrick, Joshua C. Larsen, Michael W. Kudenov, Tika B. Adhikari, and Roger D. Magarey*	An ongoing experiment aims to evaluate the accuracy of leaf wetness and Botrytis prediction models using field-deployed sensors, comparing predictions from in-field weather sources and local weather stations to improve management decisions for Botrytis cinerea infection in strawberry production.
Pest or Pathogen Spread Model Case Study with Late Blight	*John Polo, Chris Jones, Jean Ristaino, Amanda C. Saville, Inga Meadows, Ella Reeves*	The Pest or Pathogen Spread model (PoPS) was developed as a flexible and species-agnostic model for forecasting diseases like Late Blight caused by *Phytophthora infestans*, using weather and environmental conditions to simulate the spread of the disease, and it was validated using data from a field study in Western North Carolina.

Monitoring Emerging *Phytophthora ramorum* and *P. kernoviae* in Rhododendron

Amanda Mainello[1] Amanda Saville[1] Jyotsna Acharya[1] Rajesh Paul[2] Qingshan Wei[2] Jean Ristaino[1,3]

1. Department of Entomology and Plant Pathology, NC State University; 2. Department of Chemical and Biomolecular Engineering, NC State University; 3. Emerging Plant Disease and Global Food Security Cluster, NC State University

Rapid, field-deployable assays such as loop-mediated isothermal amplification (LAMP) are critical for detecting nursery and forest pathogens like *Phytophthora ramorum* and *P.kernoviae* to prevent pathogen spread. We evaluated the specificity and sensitivity of previously published *P. ramorum* and *P. kernoviae* LAMP assays and developed a new LAMP assay for genus-level detection of Phytophthora spp. using DNA extracts and infected Rhododendron leaf samples. Sensitivity was measured for each assay by running serial dilutions of target DNA of the pathogen in the thermocycler and real-time LAMP. Products were visualized using colorimetric dyes, gel electrophoresis, on a microfluidic chip on a smartphone device, and as fluorescence curves. All methods can reliably detect 10-1pg/µl of target DNA. Real-time LAMP is being used to measure the target DNA concentration in infected leaf samples over time. The *P. ramorum* LAMP assay accurately detected 14 of 15 inoculated leaves after two days post inoculation. The specificity of the three LAMP reactions is under evaluation using DNA from other Phytophthora spp. found on hosts of *P. ramorum* and *P. kernoviae*. Our goal is to run the three LAMP assays together on one microfluidic chip to detect and monitor spread of these important *Phytophthora* species in forest and nursery settings.

An Open-Access T-BAS Phylogeny for Emerging Phytophthora Species

Allison Coomber[1,2] Amanda Saville[1] Ignazio Carbone[1,4] Jean Beagle Ristaino[1,3]

1. Department of Entomology and Plant Pathology, NC State University; 2. Functional Genomics Program, NC State University; 3. Emerging Plant Disease and Global Food Security Cluster, NC State University; 4. Center for Integrated Fungal Research, NC State University

Phytophthora species cause severe diseases on food, forest, and ornamental crops. Since the genus was described in 1876, it has expanded to comprise over 190 formally described species. There is a need for an open access phylogenetic tool that centralizes diverse streams of sequence data and metadata to facilitate research and identification of Phytophthora species. We used the Tree-Based Alignment Selector Toolkit (T-BAS) to develop a phylogeny of 192 formally described species and 33 informal taxa in the genus *Phytophthora* using sequences of eight nuclear genes. The phylogenetic tree was inferred using the RAxML maximum likelihood program. A search engine was also developed to identify microsatellite genotypes of *P. infestans* based on genetic distance to known lineages. The T-BAS tool provides a visualization framework allowing users to place unknown isolates on a curated phylogeny of all *Phytophthora* species. Critically, the tree can be updated in real-time as new species are described. The tool contains metadata including clade, host species, substrate, sexual characteristics, distribution, and reference literature, which can be visualized on the tree and downloaded for other uses. This phylogenetic resource will allow data sharing among research groups and the database will enable the global *Phytophthora* community to upload sequences and determine the phylogenetic placement of an isolate within the larger phylogeny and to download sequence data and metadata. The database will be curated by a community of *Phytophthora* researchers and housed on the T-BAS web portal in the Center for Integrated Fungal Research at NC State. The T-BAS web tool can be leveraged to create similar metadata enhanced phylogenies for other Oomycete, bacterial, or fungal pathogens.

Distribution and Diversity of Abaca Bunchy Top Virus and Banana Bunchy Top Virus Causing Bunchy Top of Abaca in Caraga, Philippines

Mark Paul Selda Rivarez[1,2] Jezmeir Porras[1] Cristal Mae Magadan[1] Arnaldo Gagula[3] Rezel Borines[1] Elizabeth Parac[1]

1. Department of Agricultural Sciences, College of Agriculture and Agri-industries, Caraga State University, Ampayon, Butuan City, Agusan del Norte 8600, Philippines. 2. Department of Entomology and Plant Pathology, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, NC 27607, USA. 3. Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University, Ampayon, Butuan City, Agusan del Norte 8600, Philippines.

The Philippines contributes more than 80% to the world production of abaca (*Musa textilis*) fiber or 'Manila hemp' that is used in various industrial products. However, abaca industry growth is significantly hampered by the bunchy top disease (BTD) caused by abaca bunchy top virus (ABTV) and banana bunchy top virus (BBTV). In this study, we surveyed major abaca plantations in Caraga region of the Philippines using mapping tools complemented with molecular diagnostics, to generate a distribution map for the incidence of abaca BTD. We showed that BTD is present in all Caraga provinces where a total of 395 samples were collected. A subset (n=120) was tested for ABTV/BBTV using duplex PCR tests where 84 samples were positive for BBTV and 66 samples for ABTV. Interestingly, there is a high rate of ABTV/BBTV co-infection, where 4 samples (41%) tested positive for both viruses. Diversity analyses revealed moderate levels of nucleotide diversity for both viruses with evidence of recombination and phylogenetic lineages showed correspondence with the geographic origin of the global isolates. Furthermore, data from PCR tests were used for the MaxEnt analyses that provided predictive insights on the possible spread of the disease in the region. Overall, we contributed novel information on the distribution and diversity of ABTV and BBTV. By using predictive analyses, we advanced the understanding of the epidemiology of abaca bunchy top disease in a major growing region of the Philippines.

Economics of Plant Diseases and Disease Management with Application to Field Tomatoes

Daemyung Lee, Kelly Zering

Department of Agricultural and Resource Economics, NC State University

Linked models are integrated to represent field production, pathogen transmission between fields, effects of disease, and effects of disease management practices. External stochastic factors affect crop production and yield quantity and quality along with revenues, costs, and profit. The models are used to predict probabilistic outcomes for current production practices as well as to predict effects of alternative practices. Predicted value of new technology and practices are derived at the field level, regionally, nationally, and internationally. Needed adaptations in markets and policy can be identified.

Global Surveillance and Detection of Novel Cereal Rust Virulence

Douglas Luster[1] Melissa Carter[1] Pablo Olivera[2] Yue Jin[3]

1. USDA-ARS, Foreign Disease-Weed Science Research Unit, Ft. Detrick MD; 2. University of Minnesota, Dept. of Plant Pathology, St. Paul MN; 3. USDA-ARS, Cereal Disease Lab, St. Paul MN

Rust diseases, caused by Puccinia spp., are among the most important causes of yield loss of cereal crops in the US and worldwide. Global surveillance of cereal rusts is an important mitigation strategy to ensure the timely deployment of control measures in vulnerable cereal production areas. The FDWSRU plays a critical role in such efforts, receiving samples of exotic cereal rusts collected by cooperators at institutes in East and North Africa, Europe, and South and Central Asia. Viable rust samples are received, recovered, increased, and archived in the FDWSRU BL-3 facility. A preliminary race analysis is also performed by testing on selected differential lines. Increased rust cultures are shipped to the CDL in St Paul, MN for in-depth phenotypic and genotypic analyses. Analyses derived from these rust cultures have enabled us to monitor the evolution and spread of highly virulent races of the wheat stem rust pathogen, and to identify hot spots around the world where diverse virulence combinations are generated and sustained through sexual cycles of the pathogen. Establishment of sentinel plots will enable us to identify new and highly virulent races promptly as they emerge, providing early warning for potential vulnerability. The new virulent races are being used to identify new sources of resistance for development of durable resistance in cereal crops.

Identification of Southern Leaf Blight Infected Corn for Remote-Sensing Field Imagery

Grace Vincent[1,2] Cranos Williams[1,2] Michael Kudenov[1,2] Peter Balint- Kurti[3]*

1. NC Plant Sciences Initiative; 2. Department of Electrical and Computer Engineering; 3. Department of Entomology and Plant Pathology
**gmvincen@ncsu.edu*

The conventional method of crop disease detection, relying on visible symptoms, is time consuming and often results in the loss of yield. The ability to detect the effects of these stressors early enables growers to mitigate these losses. This research proposes utilizing machine learning algorithms to develop efficient detection and classification models that recognize patterns in infected and noninfected plants from hyper-spectral bands. This research will use hyper-spectral imagery with corresponding plot-wise disease severity scores assigned by an expert breeder based on visual inspection from a single growing season. For the initial processing, we implement unsupervised clustering to extract pixels and features that correspond to the crops, grass, and background and manually segment plot maps. These components are used to determine the correlation between the visual inspection scores to specific features and plots. Preliminary experiments have shown that the crop-focused segmented data has a strong relationship with the ability to detect the disease. Supplementary statistical tests will be run to provide additional understanding of these relationships. We will then use elastic net regression models to identify specific spectral bands that serve as essential features for distinguishing disease severity. Moreover, we will study the change in intensity of the hyperspectral wavelengths at different disease severity levels to identify influential frequencies. These results will contribute to the advancement of crop disease management and reducing crop loss. Furthermore, the development of a model that uses hyper-spectral field imagery and machine learning can be applied to other crops and stressors, improving food security and sustainability.

Near Real-Time Decision Making Under Uncertainty for Disease Mapping, Monitoring, and Prediction

Raju Vatsavai, Ezio Mei

Department of Computer Sciences, NC State University

Disease mapping, prediction, and management are based on the appropriate data. Farmers are under tremendous pressure to adapt their decision-making to not only changing climate but also due to resource scarcity (e.g., water), reducing arable lands, and crop diseases. Traditional forecasting systems are based on assumptions about pathogens' interactions with the host and the environment. On the other hand, Remote sensing data plays an important role in mapping crop health over time and provides an opportunity to build machine learning-based forecasting systems. By integrating diverse datasets such as weather, local sensor measurements, and on-demand remote sensing data (e.g., UAVs), one could hope for more accurate and timely predictions for farmers with actionable spatial and temporal knowledge (where, when, and by how much) about water, fertilizers, and pesticides. We present ongoing work on incorporating in-situ and remotely sensed measurements into machine learning models, in particular models for making decisions under uncertainty. We will discuss opportunities for integrating this framework with farm equipment (tractors and UAVs) to generate near-real-time actionable knowledge for farmers.

Development of a LAMP/Cas12a Assay to Specifically Detect the California Strain of Resistance Breaking (RB) - Tomato Spotted Wilt Virus (TSWV) in Tomato

Tatsiana Shymanovich[1] Amanda Saville[1] Noor Mohammad[2] Qingshan Wei[2] Dorith Rotenberg[1,3] Anna E. Whitfield[1,3] Jean Beagle Ristaino[1,3]

1. Department of Entomology and Plant Pathology, NC State University; 2. Department of Chemical and Biomolecular Engineering, NC State University; 3. Emerging Plant Disease and Global Food Security Cluster, NC State University

Rapid and accurate detection of strains of plant-pathogenic viruses is critical for disease outbreak surveillance. In California (CA), the widespread use of tomato cultivars with the Sw-5 tospovirus resistance gene has led to the occurrence and spread of an RB-TSWV strain. The objectives of our study were to 1) compare disease progress and impact on plant growth of the RB to a wild type (non-RB) strain on tomato with (cv. ‘Mountain Merit’) and without (cv. ‘Mountain Fresh Plus’) the Sw-5 gene; 2) determine incidence of detection of RB and non-RB TSWV using microneedle RNA extractions and LAMP; and 3) develop a rapid LAMP/Cas12a assay for detection of the TSWV NSm mutation in the RB strain. Susceptible plants showed 15% - 25% stunting when inoculated with either strain compared to non-infected controls. Sw-5 plants had little disease when inoculated with non-RB but exhibited severe stunting (>50%) when inoculated with RB. The detection of positive LAMP reactions from susceptible tomatoes was higher in non-RB than RB over time. The RB strain remained detectable in susceptible tomato over the 14 days, while non-RB was undetectable by LAMP tests in resistant tomato. We developed a two-step LAMP/Cas12a protocol that differentiates the two strains within one hour that includes colorimetric LAMP followed by Cas12a. Our methods were validated with plants under chamber and field conditions, an indication that this method shows promise for detection of RB-TSWV in the field.

The Advanced Plant Phenotyping Laboratory: A Phenomics Platform for Dissecting Genomics of Plant Performance and Health

Larry M. York, Stan Martin, Mac McLennan, Wellington Muchero, and Dave Weston

Oak Ridge National Laboratory, Oak Ridge, TN

The Advanced Plant Phenotyping Laboratory (APPL, pronounced 'apple') houses a conveyor system to automatically move plants through imaging stations for sophisticated measurements of physiological, compositional, and architectural plant properties. The imaging modalities currently include chlorophyll fluorescence, hyperspectral, 3D laser scanning, multispectral, thermal, and RGB color imaging. These modalities allow inference of photosynthetic efficiency, plant leaf area and biomass, and compositional attributes like nitrogen content or specific metabolic profiles. These multimodal data capabilities will allow us to use machine learning approaches and explainable AI to generate unique 'health fingerprints' for every plant. APPL also allows automatic watering and weighing of plants to impose specific water stress regimes. This research highlights recent advancements in the use of this phenomics platform for genome wide association studies (GWAS) in poplar (*Populus trichocarpa*), monitoring of heat-stress tolerance in pennycress (*Thlaspi arvense*), and drought tolerance in switchgrass (*Panicum virgatum*). Central to the success of these projects is the APPL Public Interface (APPL PI, pronounced 'pie') that combines state-of-the-art data management tools and computational infrastructure to facilitate the research. We demonstrate how multiple modalities increase statistical power to uncover gene candidates using GWAS in poplar. Chlorophyll fluorescence uncovers heat tolerance in pennycress. Water use efficiency and leaf temperature from thermal cameras uncover mechanisms of drought tolerance in switchgrass. We will discuss in the context of plant disease epidemics. APPL is a state-of-the-art phenotyping platform allowing researchers to push the boundaries of phenomics and genomics to address challenges of the 21st century.

Automating Severity Assessment of Southern Leaf Blight in Corn Leaves Using Machine Learning

Chanae Ottley, Cranos Williams

Department of Electrical and Computer Engineering; NC State University

Efficient identification of abiotic and biotic stress experienced in an uncontrolled environment by plants is a prominent issue in agriculture. The use of machine learning approaches with computer vision allows for the estimation of disease progression and the early detection of diseases so that mitigation techniques can be applied before crops become too infected for recovery or before the disease spreads to neighboring plants. This work aims to develop an efficient, objective computational pipeline capable of estimating the disease severity caused by Southern Leaf Blight in images of field-grown maize plants. We collected visible light (RGB) field images of maize leaves from lines susceptible and resistant to southern leaf blight and obtained field severity scores of the maize lines. We have shown a strong correlation, $r(262) = .935$, $p < .0001$, between the field severity scores and the severity score of an image with an individual leaf, indicating that images of a leaf provide consistent grading as would be done in the field for a plot of plants. We propose a multistage approach to quantify infected tissue based on a heatmap produced by a convolutional neural network trained to identify the lesions. This research could provide a road map to early stress detection in the field, which could be used as a decision support tool to identify cultivars that are more resistant to abiotic or biotic stress, monitor epidemics, and understand a plant's stress state such that resources are optimized.

Revolutionizing Plant Pathogen Detection and Monitoring: Portable VOC Fingerprinting and Continuous Monitoring in Agriculture

Oindrila Hossain[1], Zheng Li, Giwon[1] Lee, Sina Jamalzadegan[1], Yuxuan Liu,[1] Rajesh Paul[1], Amanda C. Saville[2], Tatsiana Shymanovitch[2], Dorith Rotenberg[2], Anna E. Whitfield[2,3] Jean B. Ristaino[2,3], Yong Zhu[1], and Qingshan Wei[1,3]

1. Department of Chemical and Biomolecular Engineering; 2. Department of Entomology and Plant Pathology, NC State University; 3. Emerging Plant Disease and Global Food Security Cluster, NC State University

The conventional methods of detecting plant pathogens require complicated molecular assays that are time-consuming and only available in centralized laboratories. To overcome this limitation, a set of cost-effective and miniature volatile organic compound (VOC) sensor platforms were developed for non-invasive diagnosis of plant diseases such as late blight caused by *Phytophthora infestans* in the field. The first platform is based on a smartphone device, which integrates a disposable colorimetric VOC sensor array that can detect key plant volatiles at ppm level within one minute of reaction. The smartphone-based VOC sensor device demonstrated a detection accuracy of ≥95% for both laboratory-inoculated and field-collected tomato leaves, as well as the ability to detect *P. infestans* in symptomless tomato plants in the greenhouse setting. On the other hand, a lower leaf surface-attached multimodal wearable sensor was developed for continuous monitoring of plant physiology. The device integrates multiple sensors for detecting VOC, leaf surface humidity/temperature, and environmental humidity into a single platform. The wearable device can quantitatively detect tomato spotted wilt virus (TSWV) as early as four days after inoculation. The wearable sensor has also been coupled with a machine learning model to integrate multi-channel sensor data and predict the minimally needed sensor number. These in-field sensor technologies have the potential to enhance agricultural productivity by providing real-time information about the plant microenvironment and physiological status.

Tailoring Named Entity Recognition (NER) to Extract Pest Event Data from Online News and Tweets

Ariel Saffer, Laura Tateosian, Makiko Shukunobe, Chelsey Walden-Schreiner

Center for Geospatial Analytics, NC State University

Plant pest and pathogen (pest, for brevity) observation and distribution data for biosecurity measures and forecasting models commonly come from field observations, official reports, and genetic records consolidated through published literature and databases. While vital, these data can suffer from latency and spatial and temporal sparseness, due to the cost of collecting and collating these data at scale. These limitations have implications for the predictive capabilities of models and the success of control and eradication programs. At the same time, there is growing evidence that Web media, such as online news and Twitter, could be a valuable source of supplementary data to boost coverage and tap into up-to-date information for predicting pest encroachments. We present our results demonstrating the value of data from web media to supplement official records of pest invasions, using Spotted Lanternfly and *Tuta absoluta* as case study species. Our ongoing research explores and evaluates text analysis and Natural Language Processing approaches like Named Entity Recognition (NER) for automating the extraction of structured data from these unstructured sources, with potential for both historical and real-time applications.

Prediction of Leaf Wetness Duration and *Botrytis*, and Validation in Strawberry Fields with Multi-Sensor Arrays

Ashley N. Philbrick[1], Joshua C. Larsen[2], Michael W. Kudenov[2], Tika B. Adhikari[3], Roger D. Magarey[1]

1. Center for Integrated Pest Management, North Carolina State University; 2. Department of Electrical and Computer Engineering, North Carolina State University; 3. Department of Entomology and Plant Pathology, North Carolina State University

Botrytis cinerea (Botrytis fruit rot) is one of the most destructive pathogens affecting strawberry production in North Carolina. Disease caused by *B. cinerea* is also commonly referred to as gray mold due to the visible colonization of the fungus on plant tissues, most often observed on fruits. *Botrytis cinerea* infection is not limited to the field as symptoms can continue to develop post-harvest affecting strawberry production on the grower, shipper, and consumer level. The ideal environmental conditions for *B. cinerea* infection are cool and wet. Therefore, variables such as temperature, leaf wetness, and relative humidity are important factors to consider when making management decisions. Models like the Bulger infection model, which consider these variables, have proven to be useful tools for predicting the infection risk for *B. cinerea*; however, they are limited by the accuracy of the data gathered from local weather stations, which may differ significantly from the actual conditions observed in the field. Additionally, variables such as leaf wetness can be very difficult to measure, so an alternative is leaf wetness simulation models. An experiment is being conducted to evaluate the leaf wetness and *Botrytis* prediction models using sensors deployed in the field. The field sensors include a Phytos leaf wetness sensor, Temperature, RH, along with custom visual and infrared sensors for detecting leaf wetness. Model predictions made from in-field weather sources will be compared to those made from two local weather stations (ECONet and Wilmington, NC) and a numerical 2.5 km grid weather source NOAA NCEP URMA.

Pest or Pathogen Spread Model Case Study with Late Blight

John Polo[1], Chris Jones[1], Jean Ristaino[2,3], Amanda C. Saville[2], Inga Meadows[2], Ella Reeves[2]

1. Center for Geospatial Analytics, NC State University; 2. Department of Entomology and Plant Pathology, NC State University; 3. Emerging Plant Disease and Global Food Security Cluster, NC State University

Late blight, a disease caused by the pathogen *Phytophthora infestans*, is a major concern for potato and tomato production around the world. The disease spreads via sporangia that germinate when weather conditions are suitable and can wipe out a field of the host in a matter of days. The Pest or Pathogen Spread model, "PoPS", was developed as a species-agnostic model for forecasting disease or pests in various systems with an explicit spatio-temporal framework. It simulates reproduction, dispersal, and establishment of study organisms based on weather, host, and environmental conditions. It is flexible with scale and resolution in both the spatial and temporal domains. We used Late Blight data from a small field study in Western North Carolina as a case study of the disease with PoPS to calibrate the model and produce a forecast of the spread of the disease, which we validate with data collected during the study.

Summary of Day Two Workshop		
Session Topic	Presenters	Key Takeaways
Demonstration of the PoPs Dashboard and tangible landscape of the PlantAid Database (PlantAid Database)	*Dr. Chris Jones Anna Petrasova Vashek Petras, Center for Geospatial Analytics, NC State University , Raleigh, NC*	Workshop participants were shown how a plant disease pathogen can be identified and mitigated. Feedback from participants after the demonstration were situated in the form of questions and suggestions to consider to improve the tool/model.
Developed themes: Small Group Discussion	*Led by Dr. Jason Delborne, Rex Alirigia, Department of Forestry, NC State University, Raleigh NC*	The discussions of the PlantAid Database (PlantAid Database) by the participants brought out a series of very important topics that were categorized into themes. These include: • Complexity of data sharing and data management • Tool adoption • The distinction of the tool as a public or private good • The integration of genetic data into the tool
Technology Demonstration: Tomato Production Simulation Software	*Dr. Kelly Zering Dr. Zaemyung Lee, Department of Agriculture and Resource Economics, NC State University, Raleigh, NC*	This economic model integrates various economic models to simulate a dynamic plant disease control system, incorporating detailed data on practices, inputs, products, prices, costs, revenues, disease effects, and management response, with the ability to incorporate real-time data for updated projections of production, costs, and revenues.
Technology Demonstration: Smartphone-based LAMP and VOC Sensors; Rapid Plant DNA/RNA Extraction Methods: Field Sensors for Plant Disease and Stress Monitoring	*Dr. Qingshan Wei[1] Oindrila Hossain[1] Amanda Mainello[2] Dr. Tatsiana Shymanovic [2], [1]Department of Chemical and Biomolecular Engineering, [2]Department Entomology and Plant Pathology*	This tool leverages digital disease diagnostic technology innovations to monitor, detect and predict plant disease. The two innovative technology platforms include a field-compatible microneedle (MN) LAMP assay, and a volatile-based sensor.
Technology Demonstration: Utilizing On-Field Cameras to Monitor Crop Conditions with Remote Sensing Data: Near Real-time Decision Making Under Uncertainty for Disease Mapping, Monitoring, and Prediction	*Dr. Raju Vatsavai Ezio Mei, Department of Computer Science*	Remote sensing data is utilized in conjunction with machine learning simulations to enable timely disease diagnosis and decision-making, with the comparison of images between infected and healthy plants collected over different months/seasons to detect changes in color as a potential indicator of plant disease infection.

Summary of Day Two Workshop		
Technology Demonstration: Acquiring and processing pest outbreak data from online media: Case Studies in Mining Text for Plant Pests and Pathogens	*Dr. Laura Tateosian Ariel Saffer, Makiko Shukunobe, Center for Geospatial Analytics*	This model utilizes real-time text mining to detect and predict plant pests and pathogens by collecting data from various online sources, allowing for faster detection and extraction of time-sensitive pest information globally.
Workshop Survey Results		Participant satisfaction, most promising technologies, most important idea/issue, future workshop suggestions

Symposium on Predicting the Next Plant Pandemic: Summary Report of Day 2

Drafted by Rex Alirigia and Jason Delborne

Background

Plant diseases, both endemic and recently emerging, are spreading because of climate change, expanding global food trade networks, and the evolution of new pathogen genetic lineages. Crop diseases threaten food security in many areas of the world, including the US. In order to improve pandemic prediction and tackle plant disease spread, a new set of predictive tools are needed. In view of this, the National Science foundation (NSF) funded Predictive Intelligence for Pandemic Preparedness (PIPPs) phase one (1) project has developed a computational framework for a pandemic prediction system called the Plant Aid Database (PlantAid Database). The PlantAid Database is designed to handle data from multiple spatial and temporal scales, including plant disease sensor data, micro-climate data, regional weather data, national-scale satellite imagery, structured and unstructured text mining and genomic surveillance data.

The aim of this workshop is to understand the nuances and complexities of the PlantAid Database's design, use, and its ability to co-exist and succeed in a social, political, economic and cultural environment, the Predictive Intelligence for Pandemic Preparedness research team invited both a broad group of stakeholders (from organizations working on mitigating plant pathogen diseases) and experts, including data scientists, climate modelers, growers, extension specialists, the USDA APHIS Plant Protection and Quarantine personnel, the Department of Homeland Security inspectors, diagnosticians and other research scientists to participate in a workshop on predicting the next plant pandemic. The workshop and an associated symposium were held in the new Plant Sciences Building on Centennial Campus at North Carolina State University on April 5-6, 2023.

Workshop objectives

- To demonstrate the design and function of the PlantAid Database tool and other plant disease prediction technologies
- To learn about the essential components of the PlantAid Database tool and discuss current practices in detecting and mitigating plant disease threats
- To gather stakeholder perspectives on design options for the PlantAid Database and other technologies on real time data challenges
- To engage and gather stakeholder input into future design decisions of the PlantAid Database and engagement of additional stakeholders

Workshop Structure

On Day Two of the symposium, various activities took place. First, there was a demonstration of the Pest or Pathogen Spread (PoPS) dashboard and the tangible landscape of the PlantAid Database. Following this, the participants engaged in discussions about the challenges and concerns associated with the PlantAid Database. The feedback from these discussions was grouped into four themes, which were then further discussed by four small groups. These groups deliberated on the specific issues within their assigned themes in relation to the PlantAid Database. Additionally, the research team showcased other technologies developed for detecting and predicting plant pathogen disease spread. The day concluded with a final discussion among the participants, where they identified additional groups and stakeholders who should be included in the ongoing conversation about the project.

Demonstration of the PoPs Dashboard and tangible landscape: Dr. Chris Jones, Anna Petrasova, Vashek Petras.

The PoPS dashboard and tangible landscape are fully functioning iterative near-term forecasting platforms for plant disease. These platforms continuously calibrate model parameters and validate forecasts as new pathogen outbreak data becomes available. This iterative approach allows for ongoing model improvement based on the pace of data availability. The data collected from remote and in situ sensors significantly enhances this iterative updating cycle, leading to more relevant short-term forecasts and increased accuracy in long-term management efforts.

The purpose of this demonstration was to showcase the functionality and utility of the Pest or Pathogen Spread (PoPS) dashboard and the tangible landscape of the PlantAid database (PlantAid Database). Workshop participants were divided into two groups, allowing them to alternate between the demonstrations and actively participate in learning about how the technology is used to mitigate real-time plant disease threats.

Discussion: Questions and Suggestions

During the PoPs dashboard and tangible landscape demonstration of the PlantAid Database (PlantAid Database), workshop participants were shown how a plant disease pathogen can be identified and mitigated. Feedback from participants after the demonstration were situated in the form of questions and suggestions to consider to improve the tool/model.

Questions:

- Does the tool/model have the ability to detect deviations, errors and track the number of times you do a simulation for a plant pathogen?
- Can the tool/technology predict a particular plant disease at a particular time period or season?
- Does the tool/model have the ability to capture and integrate data from transportation networks and climate data?
- Does the tool/model have the ability to predict the range and parameter values of a plant disease host?
- What are the social pressures, concerns and reactions of many of the landowners in areas where the tool is used? (*"most of whom have libertarian views"*).

- Can the tool/model be used to perform similar functions in other regions or countries?
- Does the tool/technology have the ability to track genotype variations, lineages, data on the size of lineage since it is not constant.
- who (forestry officials, crop growers, landscapers, policy makers etc.) and at what level is this tool/model designed for?
- What are the data management and data sharing strategies for the data that is used and generated from this tool/model?
- What type of data do we use for the purposes that serve the common goal?
- How does policy ensure that people are available to collect data to sustain this tool?
- How can this tool/model promote further investment in other related tools and education on social responsibility?
- The use of this tool/model is to solve a public goods problem, but how does it conflict with private goods requirements?
- What current management practices are likely to be improved or affected by this tool?

Suggestions:

- The tool/model should be designed to include and combine other data sources and data sets, as well as make data generated from the tool easily accessible.
- And consider who specifically the model is designed for (policy maker, scientist, economist, socio-economist, aid organizations) or design it for many users.
- The tool/model should be designed to consider different needs and objectives of resource managers, policy makers and other users in order to respond to different user needs.
- The tool/model should include data from google network road maps, rail data, ship/vessel movement, trade and travel data.
- The tool/model should be designed to fit with other models like climate models, risk maps, climate matching, transportation maps etc.
- The tool designers should consider the need for a data sharing agreement on the data types, data sources, data sharing methods and data management (agreement on what data to share and agree to basic standards of data sharing) .
- The tool/model should incorporate genotype and phenotype data, as well as consider the type genetic data to sequence.

Developed themes

The discussions of the PlantAid Database by the participants brought out a series of very important topics that were categorized into themes. The include, complexity of data sharing and data management, tool adoption, the distinction of the tool as a public or private good and the integration of genetic data into the tool.

Complexity of Data Sharing and Management

The complexities surrounding the type of data, sources of data, and data sharing of the data used in the PlantAid Database is critical and unclear. Also, there's the need for data sharing and agreement on basic data standards between crop growers, government agencies, and other entities on data management strategies. Some of these issues are stated below.

- Data Sharing and data access is considered a huge concern, therefore, there is the need to address data limitations concerning the issues and implications of collecting and sharing the same and/or different data types. Also, key data agreements should include what data to share and basic standards for data sharing.
- There is the need for the model designers and the research team to take lessons from already existing data management practices to incorporate into the data management strategy for this model.
- The research team also needs to make decisions based on the worth/value of the type data, the minimum number of data to collect and use for a prediction in the model since data can be costly to obtain.
- There is transparency in the agreement of the types of data to use and clearly defined data sharing agreement among different users.
- The model should integrate other data sources, such as Google Earth.

Adoption/Uptake

In order for the PlantAid Database to be adopted and used effectively and efficiently by targeted users, it has to consider and address the following issues:

- The tool should be designed to make it easy to use, incorporate different data types, data sources, and have multiple functions to complement existing models to support different user needs.
- Data generated from the model should be accurate and easy to interpret by different users.
- The purpose of the model, and its defined users should be well established in the design to make it clear exactly who the target user of this tool/model is designed for.
- The tool should fit into existing strategies and common practices for predicting plant diseases.
- The model incorporates and includes social, political, economic and cultural concerns, feedback and participation in the model design and implementation.

Data: Private or Public

There is the need to distinguish whether or not the PlantAid Database and data generated should be considered available to the public. It is important to streamline this process to ensure better use of the PlantAid Database.

- Incentivize individuals and institution to share their data.
- Reduce redundancies and replicating models that could end up not being useful.
- Consider the value in making this data open access vs. limited access to help define the purpose of this model.
- Consider the type of data to use for the purposes that serve the common goal.

Genetic Data

Genetic data information and sequencing is not adequately used and defined in the PlantAid Database. There is a need to incorporate new and pre-existing genetic data into the model, and update this data in a timely manner. Recommendations for incorporating this genetic data are:

- Incorporate genotype and phenotype into model
    - Normally, detection tools provide a simple positive or negative result regarding the presence of a pathogen. However, relying solely on a yes or no answer lacks the genetic information needed for a more accurate assessment of the pathogen threat and the movement/spread of different genotypes. Different genotypes can display distinct phenotypes, which have implications for managing the pathogen. For instance, in a forest affected by P. ramorum, the EU1 and NA1 genotypes exhibit different phenotypes, with EU1 being more virulent than NA1. By incorporating genotype data into a model, we can better predict how these phenotypic differences impact the pathogen's spread.
    - Incorporating genotype data also allows us to understand when a novel genotype enters the study areas, which can spark different management decisions or research questions.
- Assume benign purpose (misuse is a possibility).
    - The intention here is to acknowledge that territorial behavior or overprotectiveness may arise when different genotypes are observed, potentially leading to limitations on their movement into specific regions.
- Consider different pathogen pressures on the same host.
    - Different genotypes of the same species can pose varying levels of problems on a shared host. For example, the EU1 and NA1 lineages of P. ramorum demonstrate differences in their sporulation ability on the same host, emphasizing the importance of knowing the genotypes present in different areas.
    - Additionally, hosts like tomatoes can harbor multiple pathogens simultaneously or within a growing season. Tracking the shift in pathogen populations over time aids in understanding their spread in a system.
- Collaborate with pre-existing groups for genetic data collection.
    - Maintenance and updates of models and databases should be considered.
    - Genetic sequencing methods such as whole genome sequencing offer comprehensive data but are more expensive and not suitable for routine surveying. Other methods like microsatellites or multilocus sequence analysis are easier to implement regularly but provide less information. Each method can be used for population genetics research, but preferences may vary based on the models.
    - However, sequencing work requires the isolation of organisms, which can be challenging and time-consuming.
- Track phenotype.
    - Understanding the genotypes and phenotypes present in a pathogen population influences how the population is managed.

- Acknowledge the host species as a data gap.
    - Host data is not consistently integrated into all models, despite the significant influence of the host on pathogen spread.
    - Another challenge is obtaining information about the host range, including the locations of susceptible hosts within a landscape. Although research has been conducted on how different lineages of P. ramorum move on various hosts, determining the presence of all other susceptible hosts in a landscape remains difficult.

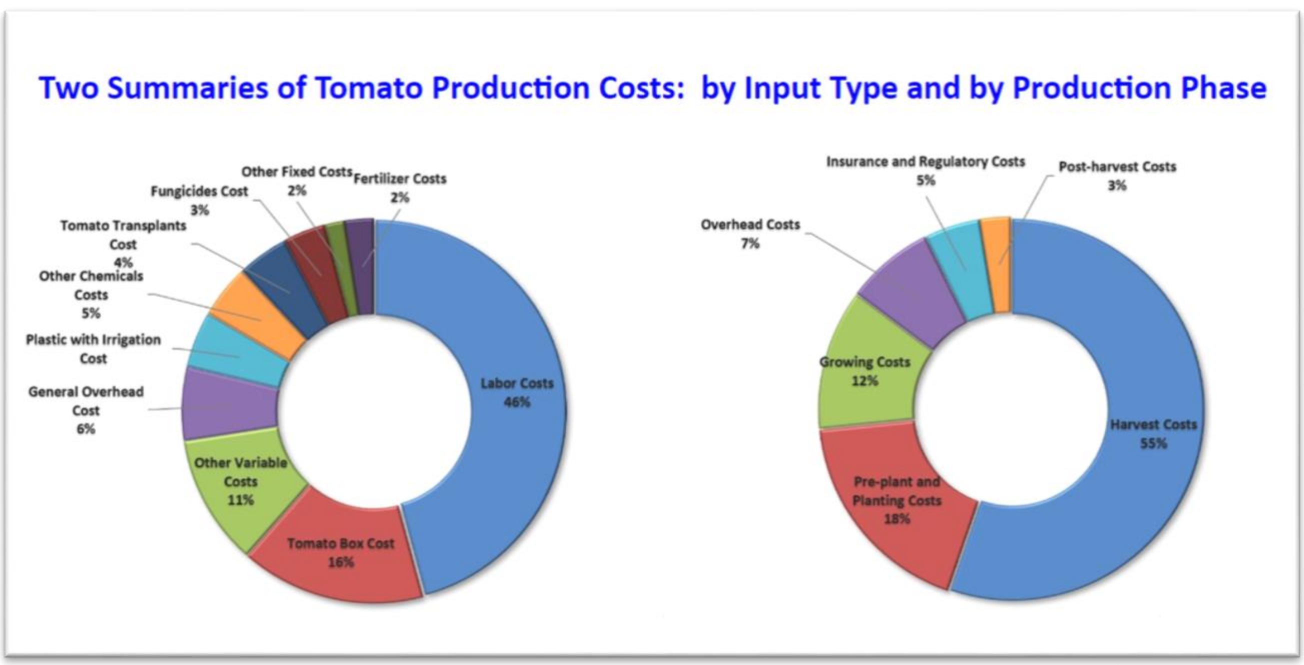
Technology Demonstrations

There were four technologies that were demonstrated by the team members of the research project with the aim of showcasing various strategies in predicting plant diseases.

Tomato production simulation software

Dr. Kelly Zering, Dr. Zaemyung Lee

Dr. Kelly Zering led a demonstration of a database being developed for uploading and visualizing observations related to late blight data in the USA. The open data platform is more complex than anticipated and there is a need to discuss privacy and data protection. The database allows users to query observations by year and visualize the number of observations by county. The goal is to connect the database with genetic components and create data sets for researchers. This presentation demonstrated how users can upload new observations, including location type, organic status, and



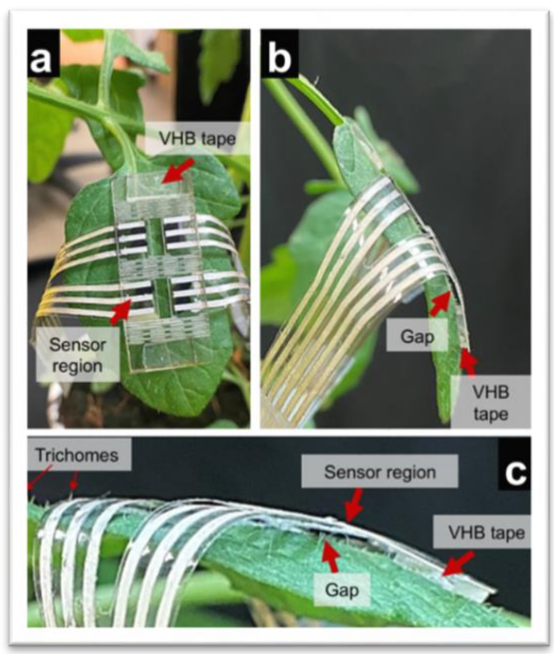
control methods used. Dr. Zering discussed the integration of sensor data and machine learning algorithms for real-time disease detection.

During the discussion, questions arose about the minimum information required for user submissions and the validation process for positive or negative results. The potential to incorporate information about where pathogens are not found was also mentioned, as it can help improve models and risk assessments. The importance of considering biases in data collection methods was emphasized when combining data sets from different sources. The inclusion of negative data is seen as a way to mitigate bias. The limitations and challenges of sharing real-time data while maintaining trust and privacy were raised.

- This is an economic model that is designed to combine selected economic models on a range of scales that together, model a dynamic plant disease pandemic control system. It also has the capacity to identify data streams and integrate the data into the model.
- The criteria used for the modeling include detailed practices, inputs, products, prices, costs and revenues, disease effects, management response to diseases, and key factors related to disease to generate predicted outcomes.
- This model has the capacity to add and receive data from programs such as PoPS dashboard to create near-real time updates of projected probabilistic production, costs, and revenues.

Smartphone-based LAMP and VOC sensors; rapid plant DNA/RNA extraction methods: Field Sensors for Plant Disease and Stress Monitoring

Dr. Qingshan Wei, Oindrila Hossain, Amanda Mainello, Dr. Tatsiana Shymanovic



Determination of plant diseases and stresses is currently dependent on time-consuming and complicated measurement technologies that are usually performed in centralized laboratories, which is inadequate for early detection and rapid responses. Recently, we demonstrated a set of miniaturized sensor devices that can perform molecular diagnosis of plant pathogens or monitoring of plant stresses directly in the field. The sensor platforms include a micro-needle smartphone device for performing rapid DNA/RNA extraction and isothermal amplification, and noninvasive volatile organic compound (VOC) sensors based on smartphones or wearable sensor patches. These cost-effective sensors have been thoroughly tested in greenhouses for the detection of a range of tomato pathogens, such as *Phytophthora infestans*, *Alternaria linariae*, and Tomato spotted wilt virus (TSWV) with high detection accuracy. Together, these sensor devices demonstrated the feasibility of in-field detection of plant diseases and stresses of great concern.

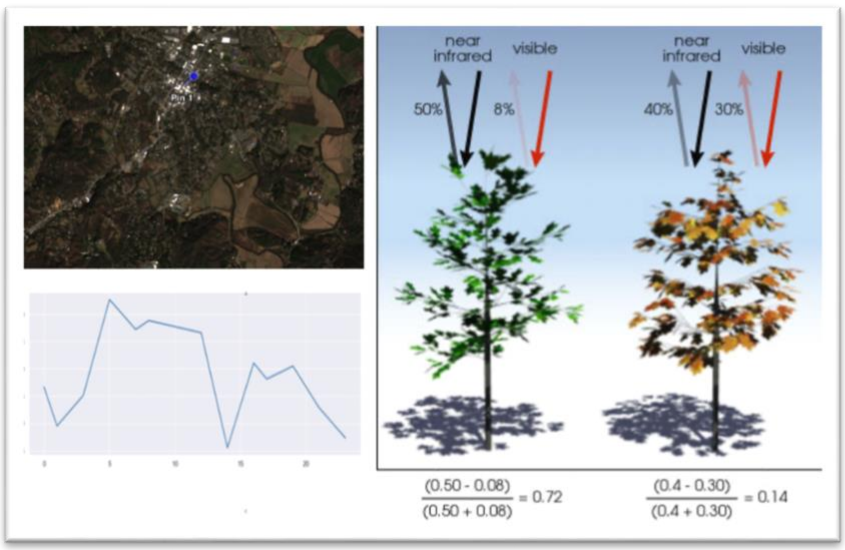
- This tool leverages digital disease diagnostic technology innovations to monitor, detect and predict plant disease.

- The two innovative technology platforms include a field-compatible microneedle (MN) LAMP assay, and a volatile-based sensor (VOC) dubbed the "Plant Sniffer" integrated with a smartphone and PlantAid Database to speed the identification of plant pathogens in the field

Utilizing On-Field Cameras to Monitor Crop Conditions with Remote Sensing Data: Near Real-time Decision Making Under Uncertainty for Disease Mapping, Monitoring, and Prediction

Dr. Raju Vatsavai, Ezio Mei

Disease mapping, prediction, and management are based on the appropriate data. Farmers are under tremendous pressure to adapt their decision making to not only a changing climate but also to resource scarcity (e.g., water), reductions in arable lands, and crop diseases. Traditional forecasting systems are based on assumptions about pathogens' interactions with the host and the environment. On the other hand, remote sensing data plays an important role in mapping crop health over time and provides an opportunity to build machine-learning-based forecasting systems.



By integrating diverse datasets such as weather, local sensor measurements, and on-demand remote sensing data (e.g., UAVs), one could hope for more accurate and timely predictions for farmers with actionable spatial and temporal knowledge (where, when, and by how much) about water, fertilizers, and pesticides.

Dr. Vastavai presented ongoing work on incorporating in-situ and remotely sensed measurements into machine learning models, in particular models for making decisions under uncertain conditions. The presentation discussed opportunities for integrating this framework with farm equipment (tractors and UAVs) to generate near-real-time actionable knowledge for farmers.

- Remote sensing data is used for disease diagnosis with machine learning simulations to make near real-time decisions.
- Remote sensing data or images are collected from different months/seasons and then used to compare between infected and healthy plants. This is done when data for the year the plant has no infection is collected as baseline and compared with subsequent data of the plant as a potential plant disease infection as the plant changes in color.

Question:

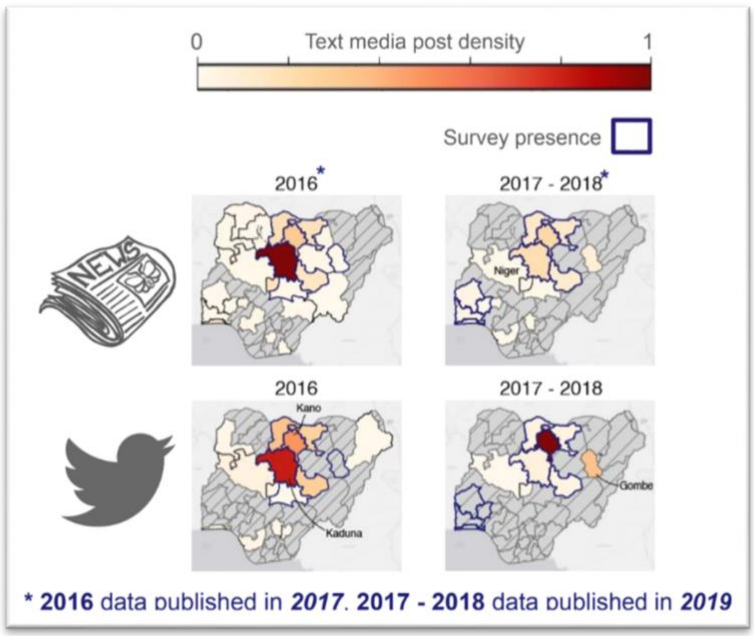
- How do you account for weather or wind information in the model?

Acquiring and processing pest outbreak data from online media: Case Studies in Mining Text for Plant Pests and Pathogens

Dr. Laura Tateosian, Makiko Shukunobe

Pest observation and distribution data for biosecurity measures and forecasting models commonly come from field observations, official reports, and genetic records consolidated through published literature and databases. While vital, these data can suffer from latency and spatial and temporal sparseness due to the cost of collecting and collating these data at scale. These limitations have implications for the predictive capabilities of models and the success of control and eradication programs. At the same time, there is a wealth of historical text data as well as growing evidence that Web media could be a valuable source of supplementary data to tap into information for understanding pest encroachments. Gathering data from these sources presents its own challenges.

In this presentation, Dr. Tateosian discussed practical considerations for processing historical text records and collecting online media in order to extract data from text to support pest biosurveillance. She documented the presence of mentions of invasive pests and pathogens in these sources through contemporary case studies regarding *Lycorma delicatula*, *Tuta absoluta*, and *Phytophthora infestans* as well as an exploration of the early history of *P. infestans* through historical documents. The results using past data demonstrated that these sources provide valuable spatial information describing pest presence and spread.



- Real-time text mining is utilized to detect and predict plant pests and pathogens, collecting pathogen observation and distribution data from field observations, published databases, peer-reviewed journal articles, and genetic sequencing to model and provide valuable information on pathogen spread.
- Information about reported pests and pathogens spread is located, fetched, filtered, and distilled from online data sources such as brandwatch, the global database of events, Language and Tone (GDELT), Google News, Twitter, and others.
- This model enables faster detection of plant pests and pathogens through online sources, facilitating the extraction of continuous and time-sensitive pest information from around the world.

Discussion of Additional Stakeholders

The workshop ended with a discussion on future workshop engagement. This discussion with the workshop participants identified other relevant group stakeholders to include in future conversations for the design and utilization of the PlantAid Database (PlantAid Database). These include:

- End users (Forestry, crop growers, landscapers)
- Public and private landowners.
- State and federal regulators.
- Policy scholars.
- Large agricultural and food companies.
- Seed companies.
- The Consortium of International Agricultural Research Centers (CGIAR).
- Food And Agriculture (FAO).
- United State Agency for International Development (USAID)
- Gates Foundation
- Large tech companies (Google, Intel, etc.)

Survey results

After the workshop, participants were asked to complete a Google form regarding their experience. A total of 23 participants responded to the form. The responses to the question "What motivated you to attend this workshop? What did you hope to learn and/or contribute?" were analyzed and summarized as follows:

- Participants expressed interest in the relevance of the topic and the research project's focus on predicting the next plant pandemic to address the spread of plant pests and diseases.
- They wanted to learn about current and future biotechnological applications for managing plant diseases and detecting emerging plant diseases.
- Participants also aimed to share their perspectives, represent their respective groups, learn from other participants, and gain insights into the direction of plant science disease and other technologies.

Figure 1. Results of survey question regarding the workshop's alignment with the participants' expectations.

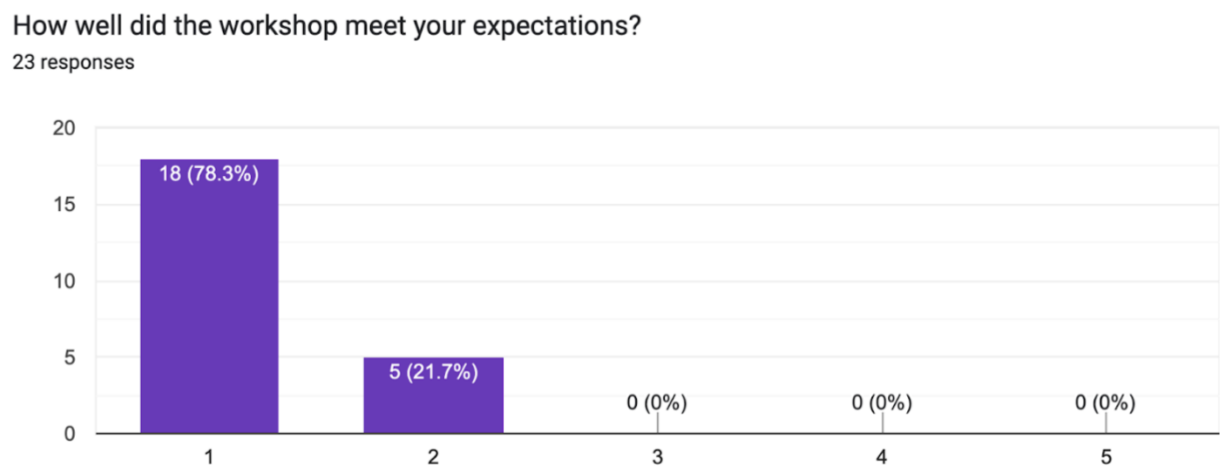
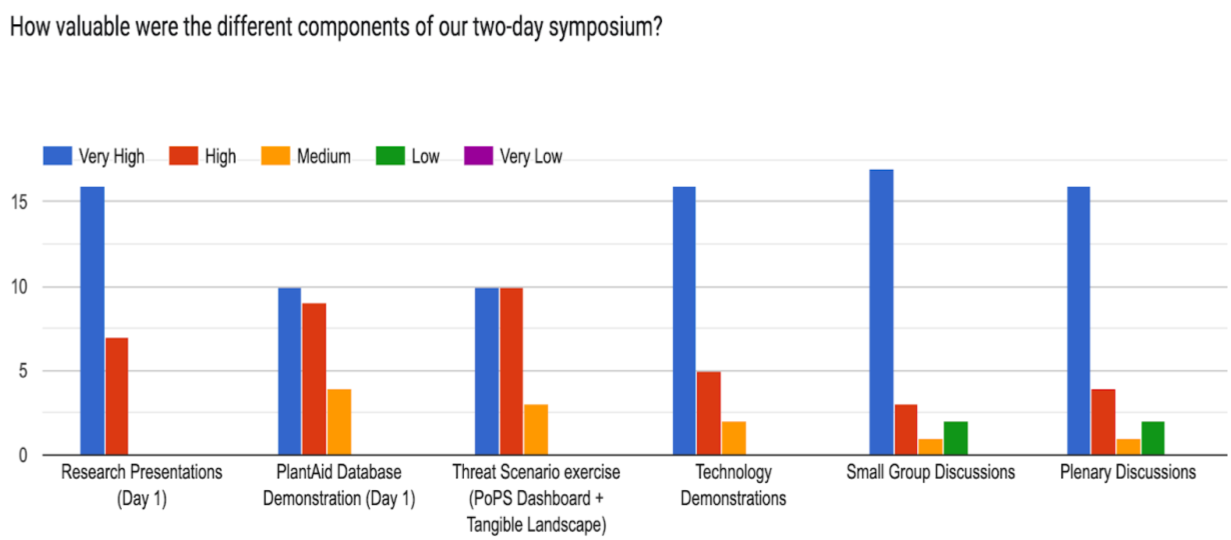


Figure 2. Value assigned to workshop components.



The participants were asked to identify the technologies or strategies they found promising or exciting for predicting the next plant pandemic. Here are the responses and choices mentioned by the participants:

- Real-time LAMP, genotyping, and sensor technologies for early plant disease detection.
- Data sharing.
- Proactive large-scale biomolecular surveillance.
- Horizon scanning using multiple data sources.
- The PlantAid Database.

Some participants highlighted that the technology itself is not the primary focus, but rather the decision-making process. Others emphasized the importance of dialogue and collaboration in this space. Furthermore, participants were asked about the most important idea or issue for the ongoing development of the PlantAid Database. Here are some direct quotes capturing important concerns and issues identified for improving the database:

- "I hope PlantAid can include observation output that we can use as input for our simulations. We often rely on observed appearance to predict disease severity, so simulating spectral data under specific infections would be helpful for future studies."
- "Defining the end-user is a key concern. It would help determine the needed level of confidentiality and additional parameters to include in localized models."
- "Data sharing and management strategies."

Overall, these responses provide valuable insights for enhancing and refining the PlantAid Database.

We also requested participants to provide additional feedback for the technology and tool developers who presented on Day Two (2). Here are some of the feedback statements:

- "Ensuring consistent reliability of these tools is crucial for their adoption in diagnostic labs or field settings."
- "The economic modeling and tractor-based sensor work may have limited scope for global predictions. The PlantAid Database interface should be expanded to include other diseases and locations, as it currently focuses only on diseases in the USA."
- "The tools should demonstrate how they can work together to prevent and mitigate diseases."
- "Consider distributing some of these tools to farmers in the field for testing purposes."

Finally, we asked participants to provide suggestions for future workshops to better meet their expectations. While most responses indicated a well-organized workshop, there were a few suggestions for improvement, as indicated in the quotes below:

- "Review the stakeholder list to include industry people."
- "Include clear entry points for cooperation with the project for various stakeholders."
- "Provide more frequent bathroom breaks on Day One (1), and consider extending time periods for the meeting rounds on Day Two (2) to avoid a rushed schedule."
- "Include more presentations on specific approaches addressing current challenges in the plant science field to facilitate idea exchange and understanding of the issues."

These suggestions will help shape the planning of future workshops for a more successful and satisfying experience.