A Comprehensive Threat Management Framework for a Crop Biosecurity National Architecture

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ABSTRACT - Our Nation's ability to rapidly detect and identify plant pests and pathogens either in offshore native habitats or soon after introduction into the U.S. is inadequate. This inability to anticipate the arrival of agricultural threats allows them to spread more readily, results in greater damage, and makes it more difficult and expensive to respond with mitigation or eradication efforts. There are important fundamental gaps in our knowledge of foreign plant pests and pathogens that pose a threat to U.S. agricultural production. These gaps reduce the reliability and timeliness of risk assessments and risk management decisions that may be available to U.S. decision makers in the event of a real or perceived crop biosecurity threat. Results from this research will enhance the nation's defense posture for crop biosecurity threats, and will serve as a prototype for the application of this systems approach to other such select agents for important agricultural crop species. It is initially being exercised with a real threat to U.S. crop biosecurity – Asian soybean rust (Phakopsora pachyrhizi) which was detected in the southeastern United States in November 2004. This paper will describe the results of an ongoing end-to-end systems study and a technology readiness baselining for the problem of agricultural crop biosecurity.

Keywords: Homeland security, Crop Biosecurity, Remote Sensing

I. INTRODUCTION

Although confidence in the U.S. plant-based food production system and infrastructure remains high (sustained by an abundance of options that may be used to adjust production – alternate crops, varieties, cultural techniques, etc.), the national perspective has changed from one of assessing the likelihood of human assisted attacks directed at food production to one of assessing the readiness of the process in place to manage the return to normalcy. As a result, there is a critical need to understand the current condition of our crop biosecurity system, baseline the various components, and seek ways to enhance the responsiveness of the overall system.

Within this study, we will focus on the pre-harvest timeframe of agricultural crops and will use a hierarchical definition of agricultural threats, which may include disease, insects, or weeds. To assess the efficacy of the proposed framework a "reference scenario" of Asian soybean rust (Phakopsora pachyrhizi) was selected. Specifically, in our reference scenario a pathogen will cause a disease that is an agricultural threat.

The conceptual framework of this project encompasses the full scope of the requisite national architecture (including Anticipation, Prevention, Detection, Response, and Recovery), including elements of the 'problem space' that are the programmatic, action, and regulatory responsibility of other 'sector-specific' departments and agencies (e.g., United States Department of Agriculture (USDA) units Animal and Plant Health Inspection Service (APHIS), Agricultural Research Service (ARS), Food Safety and Inspection Service (FSIS); Department of Health and Human Services (DHSS) and its Food and Drug Administration (FDA); Environmental Protection Agency (EPA), in order to adequately understand the full scope of the challenges and to effectively bound the technology and R&D requirements.

Within this context, a systems study focuses on the necessary technological requirements (including current capabilities, R&D gaps, potential architectures, and trade-offs) for the soybean rust pathogen, and definition of detection and/or surveillance architecture for further development. An important assessment of current capabilities is provided by a remote sensing and geospatial technology baseline, which provides a historical perspective on the progression of soybean rust (environmental, meteorological, cultural, temporal), defines the current state-of-the-art for direct and indirect measurements of soybean rust, definition of the full spectrum (optical, thermal, radar backscatter) characteristics of the disease progression, inventory and assessment of disease vector models, and a conceptual demonstration of the components of the system in an integrated form. This work could lead to the requirements for an active data product (updateable at an appropriate interval, e.g., daily, weekly, monthly) for soybean rust in the Americas.

II. SOYBEAN RUST PRIMER

Soybean rust, caused by the pathogen Phakopsora pachyrhizi and often referred to as Australasian or Asian rust, is a serious disease of soybean that causes crop losses in many parts of the world, including Asia, India, Africa, Australia, and most recently South America [1, 2]. In November 2004, it was detected in the southeastern United States. APHIS listed

P. pachyrhizi in the Federal Register in August 2002 as one of nine agents or toxins that potentially pose a severe threat to plant health in the U.S. Prior to 1994, soybean rust was confined primarily to Asia and Australia [1,3,4].

In the past 10 years, soybean rust has spread rapidly around the world. P. pachyrhizi has been confirmed in Africa, Hawaii, and South America. In 1994, rust was confirmed on four Hawaiian Islands [5]. Soybean rust was then confirmed on the African continent in 1996 in the countries of Kenya, Rwanda, and Uganda [1]. From 1996 to 2001, a southward and westward movement of soybean rust was documented on the African continent. Soybean rust is present in Africa as far south as South Africa and as far west as Nigeria [1, 6]. Of more pressing concern to U.S. soybean production was the February 2001 detection of soybean rust in Paraguay along the Parana River bordering Brazil. By 2002, soybean rust was widespread throughout Paraguay and had moved into areas of Brazil bordering Paraguay [1, 7] and into the province of Misiones in northern Argentina [8]. By 2003, soybean rust was present in most of the soybean growing areas of Brazil.

Yield losses from Asian soybean rust can range from 10 to 90% depending on environmental conditions and treatment strategies. Yield losses in Paraguay and Brazil for 2002 ranged from 10 to 50%, depending on the location [9]. As early as the mid 1980's, the potential negative economic impact of Asian soybean rust on United States agriculture and consumers was estimated at $7.2 billion [10]. In 1991, it was estimated >10% soybean yield loss from Asian soybean rust in most soybean growing regions of the U.S., with greater yield losses (>50%) occurring in the Mississippi Delta and Southeastern regions of the country where conditions are more conducive to disease development and the potential for pathogen over-wintering on alternative host plants is high [11]. Recent studies predicted net economic losses from soybean rust establishment in the U.S. range from $640 million to $1.3 billion for the first year of the pathogen's establishment and from $240 million to $2.0 billion for subsequent years of infestation. However, prior to November 2004, soybean rust did not exist naturally on the U.S. mainland, and Kulcher [10] reminded us that the behavior of soybean rust in the U.S. could only be conjectured and that yield losses estimates and models were based on data collected in other parts of the world where rust is endemic. Nevertheless, it is apparent that damages from soybean rust establishment in the U.S. could easily exceed $1 billion dollars annually even using conservative yield loss estimates. As can be seen from Table 1, soybeans represent the largest acreage of planted crops with the U.S. and the second highest value crop. In addition, soybeans have multiple uses in the food chain (Representative).

Ranking	Acreage Planted		Value of Production	
	Crop	10^6 acres	Crop	\$B
1	Soybeans	73.4	Corn (grain)	24.8
2	Corn (grain)	71.1	Soybeans	17.5
3	All Hay[1]	63.3	All Hay[1]	12.3
4	All Wheat	61.7	All Wheat	8.0
5	Cotton	13.5	Cotton	5.6
6	Sorghum (grain)	7.8	Potatoes	2.7
7	Barley	5.3	Sugar Crops[2]	2.1
8	Oats	4.6	Rice	1.5
9	Rice	3.0	Sorghum (grain)	0.97
10	Sugar Crops[2]	2.5	Peanuts	0.78

[1] Acreage harvested
[2] 2002 data

Table 1. Top 10 crops in acreage planted and value of production in 2003 [12].

III. CONCEPTUAL FRAMEWORK

The conceptual framework of the project will encompass the full scope of the requisite national architecture proposed by the U.S. Department of Homeland Security (see Table 2). This framework is similar to that proposed by the NRC study, countering Agricultural Bioterrorism [13] and it also bears close resemblance to the APHIS Strategic Plan to Minimize the Impact of the Introduction and Establishment of Soybean Rust on Soybean Production in the United States [14].

DHS	NRC Study	APHIS
Anticipation	Deterrence	Protection
Prevention	Prevention	
Detection	Detection	Detection
Response	Response	Response
Recovery	Recovery	Recovery

Table 2. A comparison of the conceptual framework of the DHS requisite national architecture with that proposed by NRC and USDA/APHIS.

We recognize there are no precise boundaries that separate this framework into five distinct elements. For example, knowledge about pest entry pathways is necessary in Anticipation, Prevention, and Detection, and education and outreach are necessary in all elements. A technology such as remote sensing might be used to accomplish all five elements. Therefore, there will naturally be overlap as the framework evolves. To help understand terms we will use the following descriptions in applying this framework to agriculture:

- *Anticipation* primarily involves surveillance and modeling. Surveillance will be the monitoring of foreign pests in offshore locales using a variety of assets (e.g., human, remote sensing).
- *Prevention* involves improving our scientific understanding of the offshore pest so various strategies can be developed and assessed for their efficacy in preventing entry of the pest by either accidental or intentional means.
- *Detection* is the onshore monitoring for the foreign pest. Detection and Prevention are closely related. For example, genomic information for a pathogen might be the basis of a ground monitoring system used in a port of entry to scan for the presence of the pathogen.

- *Response* is the action that U.S. authorities and producers will take in the current growing season. For example, this pest management response may include an interdiction to destroy the infected crop or to apply a chemical treatment.
- *Recovery* is the action that U.S. authorities and producers principally take in future growing years. These might include alternate crops, development of resistant varieties, etc.

The following outline gives a first order perspective of some of the issues that are being addressed within the framework.

Anticipation
- 1.1 Reference scenario
- 1.2 Information gathering
- 1.3 Surveillance
- 1.4 Modeling
- 1.5 Information technology
- 1.6 Assets inventory (e.g., chemical stock and prospective Section 18 label assessments)
- 1.7 Education and outreach

2.0 Prevention
- 2.1 Historical analysis and case studies
- 2.2 Analysis of current Government programs and policies
- 2.3 Strategies to prevent or delay entry
- 2.4 Modeling
- 2.5 Technology gaps and research requirements
- 2.6 Socio-economic & psychological gaps
- 2.7 Education and outreach

3.0 Detection
- 3.1 Detection systems
- 3.2 Validation of detection systems
- 3.3 Technology gaps, research gaps, and updates to detection guidelines (national strategic plans)
- 3.4 Socio-economic & psychological gaps
- 3.5 Education and outreach

4.0 Response - current growing season
- 4.1 Communications
- 4.2 Implement pest specific response plan
- 4.3 Incident response
- 4.4 Technical gaps and research requirements
- 4.5 Socio-economic & psychological gaps
- 4.6 Education and outreach

5.0 Recovery – future crops/growing seasons
- 5.1 Update end-to-end system (new specifications for component systems)
- 5.2 Monitor recovery
- 5.3 Communication
- 5.4 Validate recovery
- 5.5 Forecast future incidents
- 5.6 Update mitigation procedures
- 5.7 Socio-economic & psychological gaps
- 5.8 Education and outreach

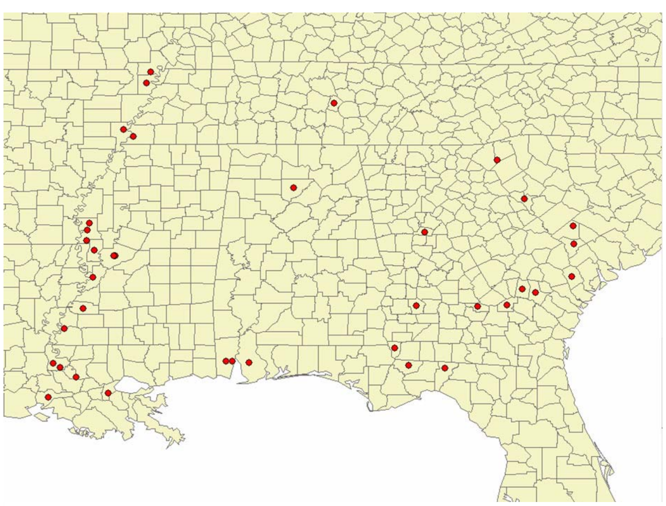

Figure 1. Locations of positive soybean rust discoveries.

IV. SOYBEAN RUST MAKES IT TO USA

In November 2004, Asian soybean rust was found on a farm in Louisiana. It is believed that the pathogen spores were blown into the United States because of a hurricane. Hurricane Ivan has been the prime suspect. This discovery resulted in a search of over 10,000 square miles. This search resulted in the discovery of the pathogen in soybeans in nine southern states - Alabama, Arkansas, Florida, Georgia, Louisiana, Missouri, Mississippi, South Carolina, and

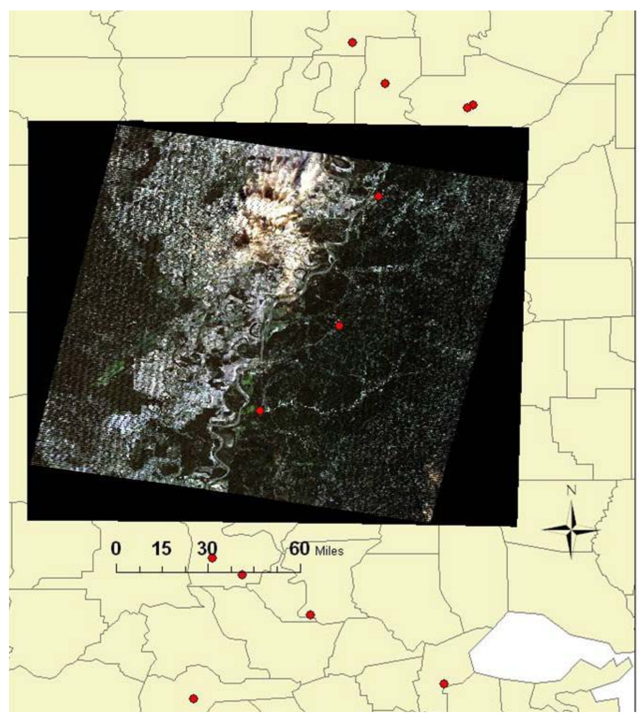

Figure 2. September 2004 Landsat imagery showing soybean locations near Natchez, MS

Tennessee (Figure 1). The pathogen was also discovered in a host plant (kudzu) in Georgia and Florida.

Figure 2 shows an ongoing effort to assess the viability of using multispectral space based assets for identifying the pathogen in the southeastern soybean fields. Additional commercial and government owned satellite imagery are being acquired for further assessments. In addition to the space-based observations, we have also initiated a program to measure the reflectance of rust infected soybean plants in situ.

The in situ measurements are being made on USDA farms in Paraguay. These measurements are being conducted over a 4-month period during their 2004-05 growing season (January – April 2005). Figure 3 shows the spectral reflectance of leaves collected from three soybean plants ranging from healthy to heavy infection. As the plant becomes stressed with the SBR fungus, you can clearly see a change in spectral reflectance of the leaves (Figure 3). Damage to internal leaf structures causes a lower reflectance in the Near Infrared (NIR) region 750nm to 1250nm of the Heavily Infected leaf. In addition, there is a higher reflectance in the red region (650nm) from chlorosis of the leaf resulting from a degradation of chlorophyll.

There are only slight differences (1.5% - 2.0%) in the spectral characteristics between the Lightly Infected Leaf and a Healthy Leaf in the visible and NIR regions, but a greater difference may be observed in the SWIR (2000-2500nm). In the SWIR region, especially between 2100 – 2250nm, one can see a marked difference between the Lightly Infected and Healthy plants. This may be a region of opportunity for detecting SBR before it completely takes over the plant. Again, the differences are just a few percent.

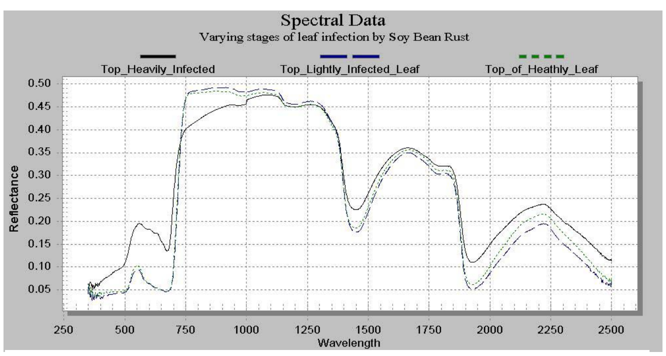

Figure 3. Spectral reflectance of control versus infected soybeans.

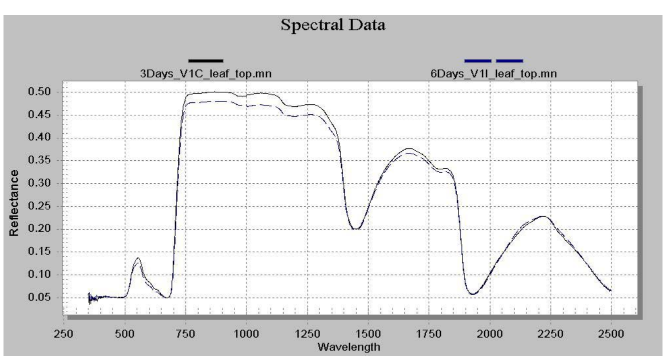

Figure 4. Temporal progression of SBR infection in soybeans.

Figure 4 shows some results from measuring the reflectance of the disease progression. Preliminary measurements indicate some promise, but more on-going extensive testing will be required before any automated detection algorithms may be developed.

V. CONCLUSIONS

At the conclusion of this project, we will recommend a framework through which the threat of a particular agricultural pest can be assessed. This framework will encompass the use of a variety of geospatial tools and measurement systems. In addition, we will recommend a process through which individuals interested in homeland security can assess the readiness of our scientific understanding and technologies necessary for implementing the framework. We also hope to have more specific understanding of the spectral reflectance of Asian soybean rust (Phakopsora pachyrhizi) and possible algorithms that may be used to detect it from imagery.

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