A Coordinated Effort to Manage Soybean Rust in North America: A Success Story in Soybean Disease Monitoring

E. J. Sikora • T. W. Allen • K. A. Wise • G. Bergstrom • C. A. Bradley • J. Bond • D. Brown-Rytlewski • M. Chilvers • J. Damicone • E. DeWolf • A. Dorrance • N. Dufault • P. Esker • T. R. Faske • L. Giesler • N. Goldberg • J. Golod • I. R. G. Gómez • C. Grau • A. Grybauskas • G. Franc • R. Hammerschmidt • G. L. Hartman • R. A. Henn • D. Hershman • C. Hollier • T. Isakeit • S. Isard • B. Jacobsen • D. Jardine • R. Kemerait • S. Koenning • M. Langham • D. Malvick • S. Markell • J. J. Marois • S. Monfort • D. Mueller • J. Mueller • R. Mulrooney • M. Newman • L. Osborne • G. B. Padgett • B. E. Ruden • J. Rupe • R. Schneider • H. Schwartz • G. Shaner • S. Singh • E. Stromberg • L. Sweets • A. Tenuta • S. Vaiciunas • X. B. Yang • H. Young-Kelly • J. Zidek

Existing crop monitoring programs determine the incidence and distribution of plant diseases and pathogens and assess the damage caused within a crop production region. These programs have traditionally used observed or predicted disease and pathogen data and environmental information to prescribe management practices that minimize crop loss (3,69). Monitoring programs are especially important for crops with broad geographic distribution or for diseases that can cause rapid and great economic losses. Successful monitoring programs have been developed for several plant diseases, including downy mildew of cucurbits, Fusarium head blight of wheat, potato late blight, and rusts of cereal crops (13,36,51,80).

A recent example of a successful disease-monitoring program for an economically important crop is the soybean rust (SBR) monitoring effort within North America. SBR, caused by the fungus *Phakopsora pachyrhizi* Sydow, was first identified in the continental United States in November 2004 (59; Sidebar 1: Soybean rust disease cycle). SBR causes moderate to severe yield losses globally (6,25,42,54). The fungus produces foliar lesions on soybean (*Glycine max* Merrill) and other legume hosts. *P. pachyrhizi* diverts nutrients from the host to its own growth and reproduction. The lesions also reduce photosynthetic area. Uredinia rupture the host epidermis and diminish stomatal regulation of transpiration to cause tissue desiccation and premature defoliation (Fig. 1) (6). Severe soybean yield losses can occur if plants defoliate during the mid-reproductive growth stages (25,38).

Since 2004, soybean has been produced on approximately 30 million hectares annually in the United States, with a value between $18 billion and $32 billion (74). Therefore, the threat of this destructive disease warranted the attention of farmers, agricultural industries, university scientists, and national and state/provincial governmental agencies. The rapid response to the threat of SBR in North America resulted in an unprecedented amount of information dissemination and the development of a real-time, publicly available monitoring and prediction system known as the Soybean Rust-Pest Information Platform for Extension and Education (SBR-PIPE). Several comprehensive reviews of SBR and the SBR-PIPE were published (6,21,23,29,33,79). The objectives of this article are (i) to highlight the successful response effort to SBR in North America, and (ii) to introduce researchers to the quantity and type of data generated by SBR-PIPE. Data from this system may now be used to answer questions about the biology, ecology, and epidemiology of an important pathogen and disease of soybean.

Soybean Rust Origin and Impact

SBR was first reported in Japan in 1902 and confirmed in several other Asian countries and Australia by 1934 (7,27). The disease was reported in Africa (Kenya, Rwanda, and Uganda) in the mid-1990s (54,55). Wind currents may have dispersed the pathogen from southern Africa to South America, where it was first reported in Paraguay in 2001 (47,48,83). Within 3 years, SBR was widespread throughout South America, causing significant yield losses in soybean. During 2003, *P. pachyrhizi* was detected in the soybean-producing regions of Brazil and reduced yields by an estimated 2.2 million metric tons, or approximately 5% of annual production (48,57,83). Although SBR was first reported in the United States in 1994 on cultivated soybean in Hawaii (35), it is unlikely that *P. pachyrhizi* reached the mainland from this pathogen source (22).

Planning for SBR in North America

In a proactive approach to prepare for the potential arrival of SBR, scientists in the United States created predictive yield loss estimates for soybean production areas in North America, based on the pattern of spread of *P. pachyrhizi* in South America (29,83). These estimates were at least 10% of annual soybean yield in the north-central United States and 50% or greater in the southeastern United States if infection occurred at an early phenological stage of soybean development (82). Initial predictions, based on high levels of overwintering inoculum, suggested that without effective management, losses in soybean could exceed 80% (8,25). In 2004, the United States Department of Agriculture (USDA) Economic Research Service estimated that annual net economic losses would range from $240 million to $2 billion, depending on the severity and extent of subsequent outbreaks (40).

University plant pathologists and scientists from the USDA-Animal Plant Health Inspection Service (USDA-APHIS) and USDA-Agricultural Research Service (USDA-ARS) and the Ontario Ministry of Agriculture and Food mobilized in January of 2003 to form a North Central Regional Association (NCRA) committee designated NC-504 "Soybean Rust: A New Pest of Soybean Production" to prepare for the anticipated arrival of SBR in continental North America. The purpose of the committee was to develop plans for SBR detection, monitoring, and management, and to develop educational materials for other scientists and agribusiness personnel, including farmers.

One of the first limitations to SBR management was that few foliar fungicides were labeled for use on soybean in North America in 2003. Fungicide applications are the primary management tool

Corresponding author: K. A. Wise, E-mail: kawise@purdue.edu

E. J. Sikora, T. W. Allen, and K. A. Wise share first authorship.

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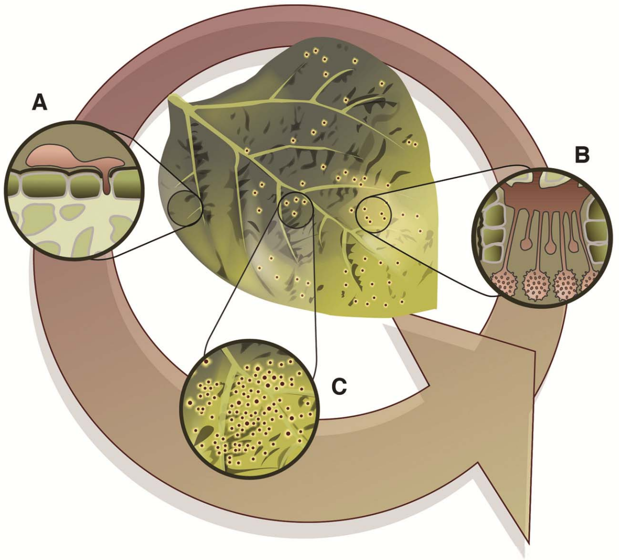
Sidebar 1: Soybean rust disease cycle



Sidebar Fig. 1. Disease cycle of the soybean rust pathogen *Phakopsora pachyrhizi* (15). **A,** Urediniospore germination and leaf penetration. **B,** Pustules develop on infected leaves. **C,** Urediniospores produced in pustules can be dispersed on wind currents to other plants.

The urediniospore of *Phakopsora pachyrhizi* is the only spore stage known to infect host plants. The alternate host is still unknown. Urediniospores are carried to host plants by prevailing winds, and land on the upper surface of the leaf (Sidebar Fig. 1). If free water is present on the leaf surface, urediniospore germination will occur in 12 to 14 h under optimum temperatures (18 to 26°C). Relative humidity between 75 and 80% is generally necessary for urediniospore germination and leaf infection. Therefore, frequent rainfall and heavy dews favor infection and disease development. The fungus will form appressoria and directly penetrate the leaf. The first symptoms of the disease can be observed on the upper leaf surface approximately 4 days after infection. However, pustule formation and urediniospore release will not occur for at least 7 days after initial infection. A single pustule can produce urediniospores for up to 3 weeks. These urediniospores are wind-dispersed, resulting in additional infections near the initial disease focus, but long-distance dispersal also contributes to additional disease spread outside the local area. Rapid increases in disease incidence and severity coincide with soybean canopy closure and the beginning of crop flowering, which signifies reproductive growth (termed R1 in soybean [16]). The repeating stage of the disease cycle will continue until the plant is defoliated or environmental conditions no longer favor disease development. In rare situations, telia can form on infected leaves. However, the role of telia in soybean rust is unknown. In the United States, urediniospores survive on leaves of host plants, such as kudzu (*Pueraria montana* var. *lobata*), in areas that do not experience freezing temperatures. When conditions are favorable for disease development, urediniospore production increases, and urediniospores are dispersed to surrounding host plants, including soybean (*Glycine max*), thus initiating an annual disease cycle.

for this disease. In cooperation with the Environmental Protection Agency (EPA), a template was developed in 2003 to facilitate submissions of Section 18 emergency use application labels for each soybean-producing state. In Canada, a similar process of emergency use registrations was established by the Pest Management Regulatory Agency (14). Fungicides selected for Section 18 applications were based in part on product performance in fungicide efficacy trials conducted in Africa and South America (39,43–46). As a result, eight fungicides received EPA Section 18 emergency registration in the United States, and four fungicides were labeled in Canada.

In addition to increasing SBR management options, numerous education efforts were implemented before detection of SBR in North America. Plant pathologists in soybean producing states and Canadian provinces informed farmers and other stakeholders about SBR at county, state, and regional meetings. Meetings were also conducted in conjunction with the American Soybean Association (ASA) and national and state/provincial soybean commodity boards to help farmers become better informed about the impacts and potential spread of SBR within North America.

Time to Monitor: Detection of SBR in North America

SBR was first detected in the continental United States in the fall of 2004 in a soybean field near Baton Rouge, LA (60,68). The disease was observed in eight additional southern states in subsequent weeks (58). These detections followed the inland track of Hurricane Ivan, which made landfall on 16 September 2004 near Gulf Shores, AL. *P. pachyrhizi* may have been transported to the United States from the Caribbean or South America in this tropical weather system (31,33).

The detection of SBR in soybean resulted in the rapid development of tools to monitor and predict disease impact for the 2005 growing season and beyond. The NC-504 group began to disseminate information on SBR at state, national, and international levels. This group (which evolved into the North Central Extension and Research Activity or NCERA-208 "Response to emerging threat: Soybean rust" Committee in 2006) coordinated a weekly conference call during the growing season among state extension specialists and soybean researchers. The calls provided updates on SBR confirmations and coordinated management efforts across multiple states. These conference calls had as many as 40 participants weekly from North America.

During February of 2005, the USDA unveiled a coordinated framework for SBR surveillance, reporting, prediction, management, and outreach (33,75–78). The framework linked federal and state/provincial agencies, soybean farmers, and agricultural industry representatives. North American soybean stakeholders were now equipped with a critical decision support system to assist in managing SBR. The USDA-Risk Management Association (RMA) provided funding for SBR surveillance and monitoring to allow real-time reporting and mapping of the disease and models to simulate and predict disease spread. The goal of the framework was to reduce economic losses from SBR. The framework included cooperation and support from USDA agencies such as APHIS, ARS, and the Cooperative State Research Education and Extension Service (CSREES), as well as national and state/provincial soybean commodity groups, and state departments of agriculture. A comprehensive overview of the SBR-PIPE development and funding structure can be found in VanKirk et al. (79).

The aforementioned framework and collaborative effort among agencies was the driving force behind the development of the SBR-PIPE (32,33). One of the goals in developing the SBR-PIPE was to provide stakeholders with a coordinated and comprehensive website where they could obtain: (i) accurate and near real-time information on the distribution and severity of SBR in North America; (ii) time-sensitive SBR risk assessments; (iii) information on SBR management options; and (iv) links to educational tools for SBR (5,18,29,63).

SBR-PIPE is a real-time system used to monitor distribution and severity of SBR and provide a "warning" network for tracking the spread of the disease in North America (18) (Fig. 2). A large, coordinated effort is required to obtain the data necessary to populate SBR-PIPE and develop predictive models on *P. pachyrhizi* dispersal and disease development. These data are generated primarily from the disease monitoring efforts of those involved in the SBR "sentinel" plot program. The sentinel plot program, although independent of the SBR-PIPE, provides the bulk of the data for SBR-PIPE observations and predictive models. Since 2005, the monitoring efforts essential for maintaining the sentinel plot network have been funded through the USDA, the United Soybean Board (USB), the North Central Soybean Research Program (NCSRP), the Grain Farmers of Ontario in Canada, and numerous Qualified State Support Boards (QSSBs).

The disease-monitoring network consists of soybean sentinel plots established in multiple locations within cooperating states and provinces. Several papers are available describing the details of the sentinel plot monitoring system (19,28,29). These plots typically are planted earlier than commercial soybeans to provide an early warning system for commercial soybean fields. The plots utilize a variety of soybean maturity groups to extend monitoring throughout the season. Additional hosts of *P. pachyrhizi* are also monitored for SBR, including kudzu (*Pueraria montana* var. *lobata* (Willd.) Sanjappa & Predeep) (Fig. 3), coral bean (*Erythrina herbacea* L.), and Florida beggarweed (*Desmodium tortuosum* (Sw) DC.) (11,17,62) (Sidebar 2: Kudzu in the city: Soybean rust overwintering in urban environments). For a complete list of currently recognized hosts of *P. pachyrhizi*, see Rytter et al. (59), and Slaminko et al. (66,67).

SBR monitoring begins with collecting and observing leaves from sentinel plots at regular intervals throughout the season (Fig. 4). For example, in Alabama and many other states, soybean sentinel plots are sampled every 2 weeks prior to soybean flowering (flowering signifies growth stage R1 [16]), then weekly thereafter. Plots are primarily monitored by individuals trained in SBR identification under the guidance of the state SBR coordinator. Because SBR is difficult to detect at low incidence within fields, many individuals collect leaves and confirm the disease under controlled laboratory conditions. Leaves are examined under a dissecting microscope (×100 magnification) following a 24- to 48-h incubation period to promote sporulation. At this magnification, pustules of *P. pachyrhizi* can be observed, confirming the presence of the pathogen. Consequently, SBR can be detected when three to four pustules are present on a single soybean leaflet, which can be difficult to detect using traditional field scouting methods.

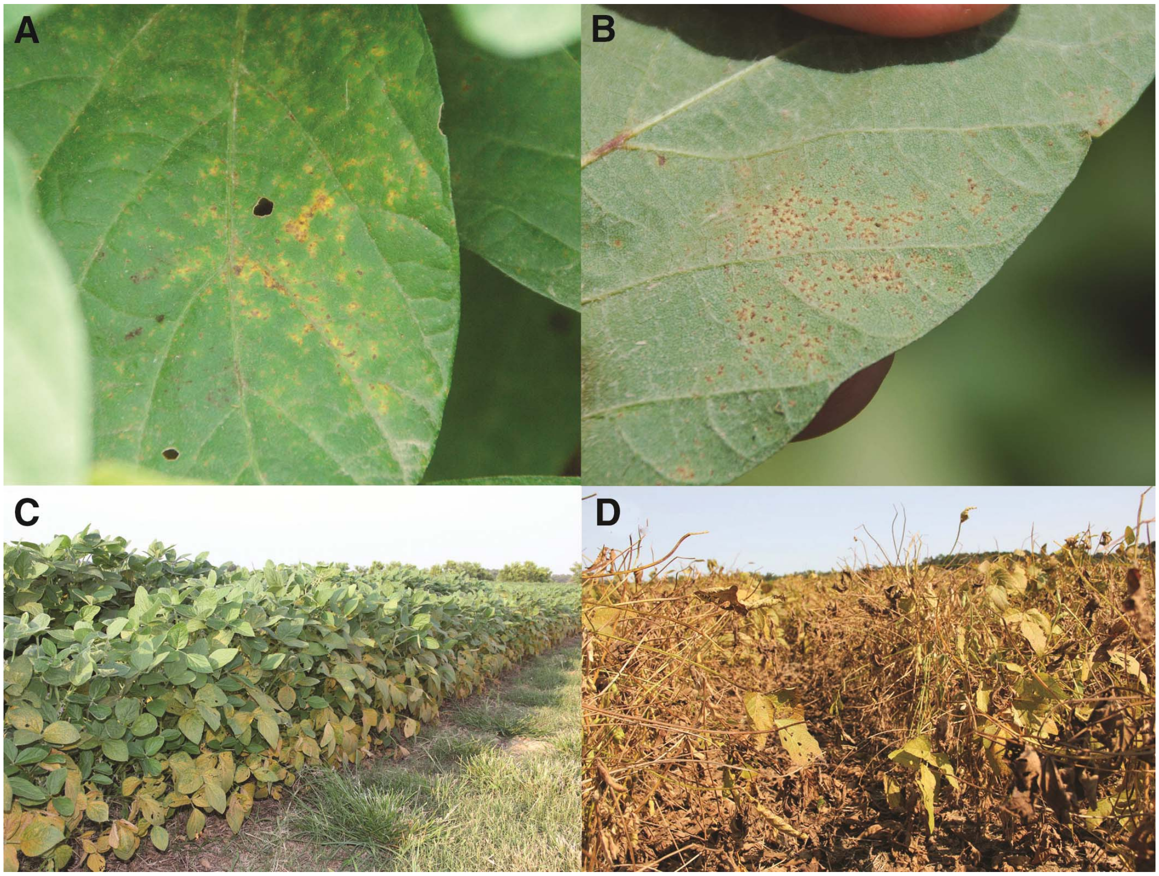


Fig. 1. Symptoms and signs of soybean rust caused by *Phakopsora pachyrhizi* on soybean. **A,** Initial symptoms appear as small, brown or brick-red lesions on the upper leaf surface. **B,** Pustules form primarily on undersides of leaves. **C,** Infected leaves turn yellow. **D,** Soybean plants severely affected by soybean rust defoliate prematurely resulting in yield loss.

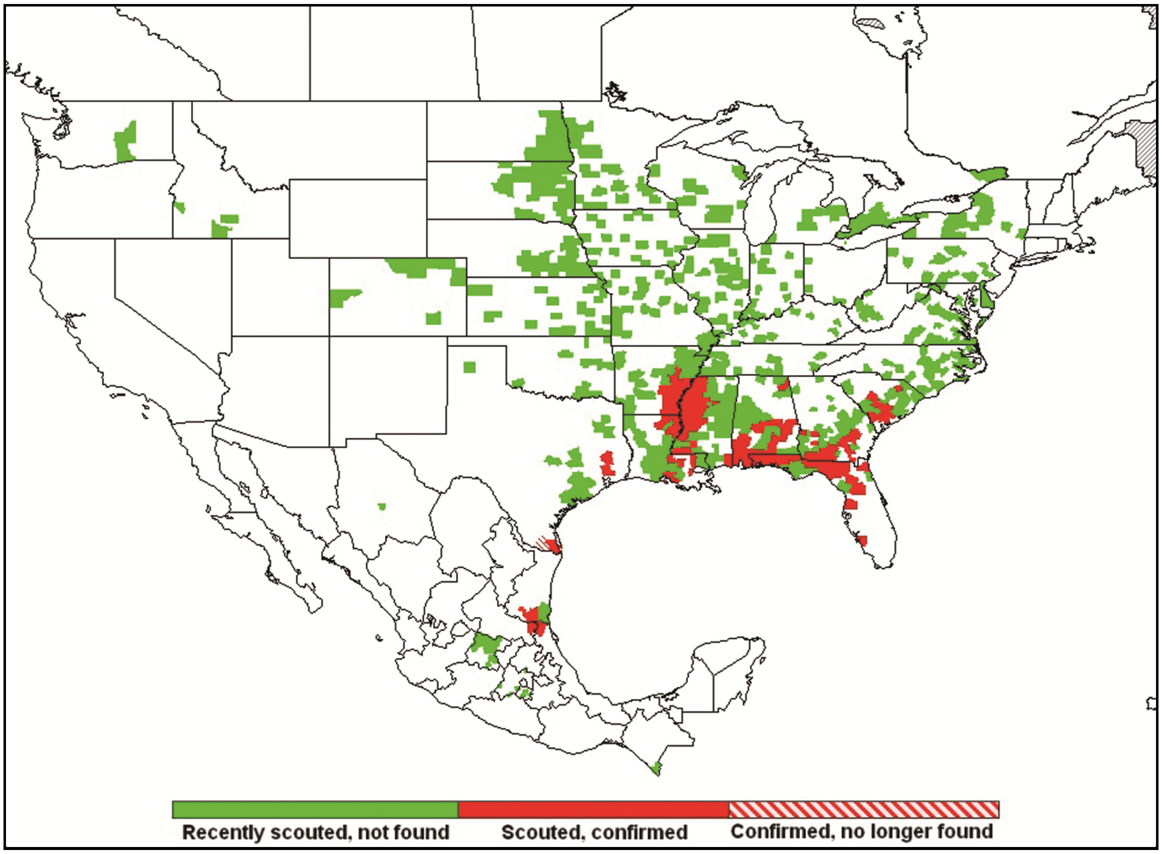


Fig. 2. Example of soybean rust monitoring observations from the publically available SBR-PIPE website: http://www.sbrusa.net. Map depicts observations and reports from 30 September 2008.

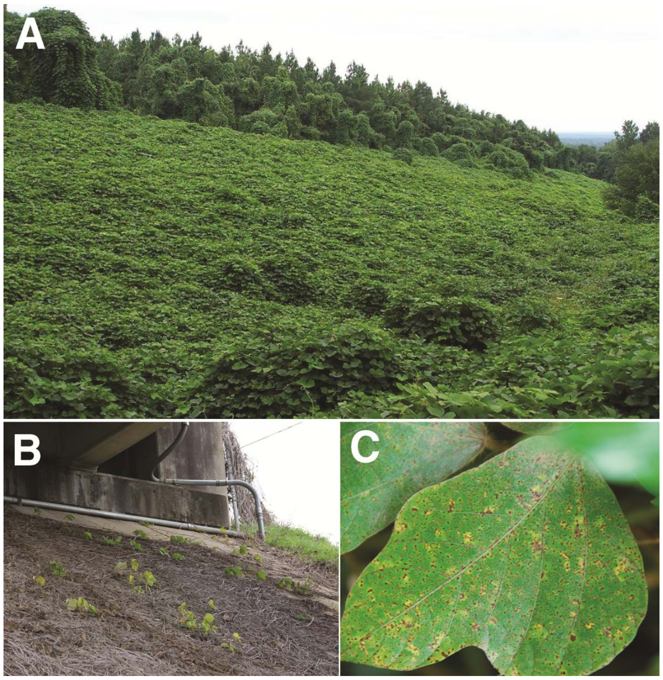


Fig. 3. The perennial weed kudzu (*Pueraria montana* var. *lobata*) serves as the primary overwintering host of *Phakopsora pachyrhizi* in the southern United States. Kudzu is an invasive plant prevalent throughout the southern United States, **A,** covering large open areas, and **B,** in secluded areas. *P. pachyrhizi*-infected leaves survive the winter months in several settings, including **(C)** urban areas.

Monitoring for SBR also occurs in commercial soybean fields to supplement the data derived from sentinel sites. This "as needed" scouting approach has been termed "mobile-scouting" and evolved into the main form of SBR monitoring in states where SBR occurs rarely.

Disease observations are collected and data uploaded into the SBR-PIPE database managed by ZedX, Inc., where they are available for a variety of uses. The primary purpose of the observation data are to populate a publically available map of North America to indicate presence and location of SBR and provide state-specific commentary on risk and management to stakeholders. Extension specialists also can access predictive models for the spread and dispersal of SBR. *P. pachyrhizi* urediniospores can be transported long distances by wind currents (1,2,37), and accurate predictions of pathogen movement and spore deposition can improve regional suggestions for timely fungicide applications.

Predictive Modeling for SBR

One of the active modeling systems adapted to monitor the movement of *P. pachyrhizi* is the Hybrid Single-Particle Lagrangian Integrated Trajectory, or HYSPLIT model (15). The HYSPLIT model is maintained by the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory, and was originally intended to track the atmospheric transport and deposition of pollutants and hazardous materials on wind currents from a known point source (15). The HYSPLIT model was adapted for use with SBR, and creates a three-dimensional prediction of possible spore dispersal and concentration using wind current data available from NOAA. Initially, this and other experimental spore deposition models were available to university specialists having access to a secure and restricted website within the SBR-PIPE platform. These models predicted potential inoculum dispersal and spread using confirmed disease observations from the monitoring program. Based on model predictions, additional scouting occurred in areas of putative inoculum deposition. Field observations from the disease-monitoring program are the most important data used to develop predictive models for SBR development (2,31,37, 72,81). The HYSPLIT model is often used in predictive modeling for future SBR events.

Sidebar 2: Kudzu in the city: Soybean rust overwintering in urban environments

Sidebar Fig. 2. A, *Phakopsora pachyrhizi*-infected kudzu surviving the winter in downtown Montgomery, AL along a southeast facing wall of an abandoned business; **B,** covering an abandoned building in an urban area; and **C,** growing on an abandoned house.

Initially, it was believed that *Phakopsora pachyrhizi* could only overwinter between growing seasons along the Gulf Coast because all known hosts could not survive extended periods of freezing temperatures (54). Opinions changed when soybean rust (SBR) was detected in kudzu patches in an urban Montgomery, AL neighborhood in January of 2006 (Sidebar Fig. 2A and B) (65). Although most of the kudzu patches observed were dormant, remaining green foliage in these protected environments was infected with *P. pachyrhizi* (Sidebar Fig. 2C), thus allowing the pathogen to overwinter to a limited extent much farther north than originally predicted. In 2013, SBR was detected under a bridge in downtown Selma, AL over 200 km north of the Florida panhandle and the northernmost point where SBR has successfully overwintered in the United States. In addition to these isolated inland locations, *P. pachyrhizi* has been readily detected on kudzu during the winter in urban areas close to the Gulf Coast in Alabama, Florida, Georgia, and Louisiana. The significance of these isolated kudzu sites in relation to the overall SBR inoculum levels prior to the soybean growing season is not known. Kudzu and other hosts of *P. pachyrhizi* found in South Florida, Mexico, and the Caribbean Basin are generally considered more important sources of inoculum when considering a potential SBR epidemic in the United States. However, with the potential of climate change providing milder weather in the south during the winter months (26), these urban islands of SBR-infected kudzu could become an important source of inoculum in North America.

Fig. 4. Example of a soybean rust monitoring sentinel plot established in Amite County, Mississippi.

In addition to the HYSPLIT model, the Soybean Rust Aerobiology Prediction System (SRAPS) was created as an application of the Integrated Aerobiology Modeling System, or IAMS (31). Initially created to predict introduction potential of important invasive plant pathogens, IAMS uses large, archived meteorological data sets to determine potential *P. pachyrhizi* deposition events. The model uses disease-monitoring observations on the SBR-PIPE, and daily predicts where spores will be deposited. Predicted spore depositions are mapped and uploaded onto the restricted website to be used by university extension specialists (30,32). This model was used to further support the notion that SBR inoculum likely arrived in the continental United States in association with Hurricane Ivan (31,33).

At the public level, data from these and other SBR-PIPE models and the results from the disease-monitoring program are integrated into maps that illustrate SBR distribution. Stakeholders are advised of the status of SBR monitoring activities and risk of SBR development with an SBR-observation map of North America on the public SBR Website (Fig. 2). This map includes links to both national and state commentaries. State extension coordinators supply state-specific commentary as to where SBR has been detected, the extent of infection (incidence and severity), crop or plant growth stage, risk advisories, and suggested management practices.

Initially, a total of 35 states within the United States and five Canadian provinces established soybean sentinel plots for SBR monitoring in 2005. Since 2004, SBR has been reported from 20 states and as far north as Ontario, Canada. SBR has been monitored on a near-daily basis since 2005 through the use of over 4,500 sentinel plots. These data are analyzed and used to create maps and inputs for the models described above to predict where and when SBR is most likely to develop in North America. The number of sentinel plots (soybean and other hosts) in North America peaked at 984 in 2008, and has gradually declined to 285 in 2012. The decline is in part due to reduced funding for monitoring efforts across the United States, particularly in northern states where the disease has not been a significant problem to date (Sidebar 3: Soybean rust in the north: The disease that cried wolf).

In addition to documenting the location and distribution of SBR in the United States, the SBR-PIPE also collects and stores data for epidemiological research. The system quantifies the timing and amount of in-season and overwintering *P. pachyrhizi* spore produc-

Sidebar 3: Soybean rust in the north: The disease that cried wolf

The unprecedented disease monitoring and education effort for soybean rust (SBR), while ultimately beneficial, also had unintended consequences. In the beginning, educational efforts in the major soybean producing regions in the North Central United States and Ontario, Canada, were especially intense, and hundreds of meetings were organized to train agribusiness personnel and farmers about the disease. The chemical industry prepared for SBR by ensuring ample amounts of fungicides were available to protect the millions of hectares of soybean in the north. After 2005, nearly everyone involved with soybean production and processing was informed about the threat of SBR. They could monitor the SBR-PIPE website and read updates in the media as they anxiously awaited the arrival of the disease in the north. There was much to prove with SBR—farmers had been assured that the disease could be detected and managed when it arrived in the north. So much work went into preparing for SBR that when the disease never materialized as a significant threat, it was a huge letdown for many. After a few years of constant vigilance for SBR, the tide turned and many in the northern agricultural community began to doubt that SBR was the threat it was portrayed to be. Interest in the disease waned, and the disease monitoring effort lost support financially and emotionally. The term "rust fatigue" was coined to describe the attitudes of people burned out on the intense disease monitoring programs, and also those in agribusiness who believed that the continued discussion of SBR by university personnel was similar to the classic Aesop's fable: The Boy That Cried Wolf.

Despite this criticism, the monitoring and education programs made many in agribusiness more aware of other soybean diseases, foliar fungicides, and spray application technology. Chemical companies found new markets for fungicides, and agricultural retailers released stockpiled fungicides, beginning a trend of foliar fungicide use in soybean and other field crops, such as corn. The full impact that SBR could have on the northern United States may not yet be realized, but many university personnel still believe the concern about SBR was justified, given the lack of knowledge of this disease in temperate climates, the devastation it caused in Brazil, and a long history of rust diseases of other crops in North America.

tion for use in SBR aerobiology prediction models. The combination of long-term disease incidence and severity data, and environmental data housed within SBR-PIPE, represents the most extensive data set available on epidemic development and pathogen spread over eight growing seasons of any plant disease (71). Additionally, some datasets include multiple disease observations from the same site (sentinel plot or commercial soybean field) within a single growing season, strengthening the power of within-season and long-term data analysis. From 2005 to 2012, 82,649 observations were uploaded to the site (Table 1). These data are available to researchers by request, and could be used to answer many important epidemiological questions that still remain for SBR. For example, SBR-PIPE data collected from 2005 to 2011 have been modeled in several studies. One study concluded that the initial focus size of SBR is positively related to the final extent of continental disease spread on a national scale (50). Christiano and Scherm (10) used these data to study the epidemiological interactions of *P. pachyrhizi* in kudzu and soybean populations. Data used in each of these studies were all obtained from the publically available website (http://SBR.ipmpipe.org/cgi-bin/SBR/public.cgi) of the SBR-PIPE platform.

Although extensive data are available for analysis, the data interpretation can be difficult because not all datasets are uniform. Also, missing data or inconsistent data formats can complicate analyses. Even with a standard protocol in place, data are voluntarily contributed to SBR-PIPE, and not all data conform to protocol guidelines. These discrepancies can skew or bias analyses of data collected from public or private SBR-PIPE databases. NCERA-208 has formed a subcommittee to help those interested in analyzing available data to gain access to datasets and provide additional observations for accurate data interpretation.

Management Advances for SBR

The observations gained from disease monitoring have greatly improved our understanding of SBR and ability to manage the disease. For example, monitoring efforts have helped identify and quantify the role of additional hosts in rust development. Kudzu, the primary overwintering host of *P. pachyrhizi* in the southern United States, is genetically diverse. Biotypes exist that resist disease development, which influences the potential for inoculum development and predicted disease dispersal (4,34,70). Additional information on the inoculum load contributed from other known hosts of SBR is important to continued disease prediction and modeling efforts. Research on the influence of environmental variables upon disease development also has aided modeling efforts. Young et al. (84) reported that sunlight reduces survival of spores of *P. pachyrhizi* in the upper soybean canopy, whereas spore viability and disease severity increased in the shaded, lower canopy. These findings suggest that spore survival within a canopy could impact disease development and models for disease spread.

Advancements in understanding diversity of *P. pachyrhizi* in the United States also have influenced the development of management practices. The U.S. population of *P. pachyrhizi* contains a high level of genetic diversity, which influences the ability to assess impact of disease spread and development, as well as attempts to develop rust-resistant soybean varieties (73,86). Despite these challenges, efforts to detect resistance within soybean germplasm accessions are ongoing. To date, five major resistance loci (*Rpp1*, *Rpp2*, *Rpp3*, *Rpp4*, and *Rpp5*) have been identified for SBR (53). Due to the genetic diversity within *P. pachyrhizi* populations, there is a need to explore breeding for partial resistance, and to screen existing commercial and public lines for minor genes (24). Partial resistance may be a more durable and useful management tool, especially because questions remain as to how cultivars with monogenic resistance should be integrated into widespread commercial production, given the limited spread of the disease into the major soybean producing regions of North America.

The coordinated efforts by federal and state agencies, stakeholders, and the agricultural industry to combat the disease have largely fallen to the NCERA-208 committee, which continues today. It is estimated that this collaborative multi-state project saved North American soybean farmers over $600 million between 2006 and 2011 in unnecessary fungicide costs, thereby reducing chemical exposure to the environment and food supply, and diminishing apprehension within the soybean industry (12). NCERA-208 promotes productive interactions among extension and research scientists, soybean farmers, and the agricultural industry, mobilizes regional resources, and builds relationships with international partners in Canada and Mexico to provide a structured, North American response to SBR.

Currently, successful SBR management is achieved through well-timed applications of fungicides. Current members of

NCERA-208 continue to assist in evaluating fungicides for efficacy to determine effective rate, timing, and number of applications per season needed to protect against SBR (Fig. 5). The number of fungicide trade products labeled to manage SBR increased from five in 2002 to approximately 70 in 2010 (20). The SBR-PIPE also aids in preventing unwarranted fungicide applications by providing information on where SBR is not considered a threat to soybean production. It is estimated that the SBR-PIPE system saves farmers over $200 million annually in unnecessary fungicide applications (28,29,56). In a 2008 survey of U.S. certified crop advisors (CCAs), a majority of respondents indicated that the SBR-PIPE is a valuable tool and that they were somewhat to very confident in the observations provided by the sentinel plot network. Of the 361 survey respondents across 7 states, 60.8% responded that they would be very concerned if the SBR sentinel plot network were to be discontinued (5). These survey results indicate the value of this program to stakeholders.

The detection of SBR in North America also allowed extension specialists and educators to train a generation of soybean farmers and agricultural professionals in the science of plant pathology. Training programs incorporate educational materials including scouting videos, field identification cards in multiple languages, radio and television broadcasts, telephone hotlines, twitter accounts, websites, newsletters, and blogs. Additionally, over 200,000 manuals entitled *Using Foliar Fungicides to Manage Soybean Rust* were distributed (http://oardc.osu.edu/soyrust/) (Sidebar 4: Extension in action: Impact of soybean rust educational materials). Scientists have also shared their knowledge through symposia, conferences, and workshops devoted to SBR (Fig. 6). Monitoring and education programs for SBR have also made many in agribusiness more aware of other soybean diseases, foliar fungicides, and spray application technology. Farmers now have a greater understanding of the role of the environment on disease development and have new management tools at their disposal.

Table 1. Total number of soybean rust monitoring observations uploaded to the Soybean Rust-Pest Information Platform for Extension and Education (SBR-PIPE) by individual country, state, and province collaborators from 2005 to 2012

Soybean rust monitoring location	Individual observations submitted[a]
Alabama	2,797
Arkansas	3,682
Colorado	259
Delaware	1,180
Florida	10,371
Georgia	9,298
Idaho	167
Illinois	2,763
Indiana	842
Iowa	793
Kansas	1,586
Kentucky	2,667
Louisiana	3,254
Maryland	356
Michigan	421
Minnesota	1,398
Mississippi	5,871
Missouri	2,425
Montana	2,425
Nebraska	1,095
New Jersey	290
New Mexico	253
New York	457
North Carolina	2,384
North Dakota	843
Ohio	1,492
Oklahoma	775
Oregon	133
Pennsylvania	1,822
South Carolina	1,872
South Dakota	1,640
Tennessee	2,176
Texas	1,242
Virginia	2,726
Washington	365
Wisconsin	439
West Virginia	249
Wyoming	120
Ontario, Canada	2,634
Mexico	7,087
Total	82,649

[a] Totals by state/province or country include both positive and negative observations of disease on soybean and other hosts of *Phakopsora pachyrhizi.*

Fig. 5. Example of field plots set up for fungicide efficacy trials to determine effective rate, timing and number of applications needed to protect soybean against *Phakopsora pachyrhizi.*

Fig. 6. Participants in a soybean rust identification workshop held in Quincy, FL. The facility trained more than 700 people over 8 years.

Fig. 7. Commercial soybean field in Alabama experiencing severe defoliation from soybean rust in 2012.

Sidebar 4: Extension in action: Impact of soybean rust educational materials

Sidebar Fig. 3. Examples of the many educational materials developed in response to the threat of soybean rust in North America.

University Extension specialists and researchers have provided many educational materials that have assisted farmers in identifying and managing soybean rust (SBR). These include scouting videos and DVDs, field disease identification cards printed in English, Spanish, and French, and numerous national or state-based fact sheets on the disease (Sidebar Fig. 3). The Extension product that has likely had the greatest impact is the *Using Foliar Fungicides to Manage Soybean Rust* manual (http://oardc.osu.edu/soyrust/). This 111-page manual was developed through the NCERA-208 “Response to emerging threat: Soybean rust” Committee, and printed by The Ohio State University. This book compiled the current knowledge on SBR, including information on the following topics: soybean growth and development, the causal pathogen *Phakopsora pachyrhizi,* sentinel plot monitoring, and disease risk assessment. Additionally, this manual provided important information on fungicide use in soybean, which was a new practice to many farmers in 2007. To date, more than 200,000 copies of this manual have been distributed in the United States, Canada, and Mexico. This book also served as one of the precursors of the new APS Press book, *Fungicides for Field Crops* (49).

Table 2. Number of individuals involved in soybean rust monitoring in the United States and Canada from 2007 to 2012

	Year					
Personnel category[a]	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Extension educators	268	250	209	122	98	61
Extension specialists	65	54	53	43	35	27
Research associates	35	34	37	27	28	26
Graduate students	10	6	7	2	2	1
Department of Agriculture	18	14	1	18	2	9
Consultants	31	18	15	9	8	11
Undergraduates	30	20	21	21	5	1
Other	18	26	16	13	10	7
Total	475	422	359	255	188	143

[a] Individuals are classified according to personnel employment category.

Despite having extensive disease monitoring programs and predictive efforts in place, yield losses due to SBR still occur. The disease was especially problematic in Alabama during 2012, where SBR reduced yield by up to 60% in over 200 hectares of poorly managed soybeans (64) (Fig. 7). These losses are the greatest observed in the United States as a result of SBR, and are equivalent to those recorded in South America in the early 2000s (48,83). Farmers who lost yield to SBR claimed they did not apply a fungicide because the disease was not problematic for them in the two preceding years, which had been characterized as having environmental conditions unfavorable for SBR development. The farmers also did not react to SBR alerts provided through SBR-PIPE and the Alabama Cooperative Extension System early in the production season.

Unfortunately, SBR predictive models have not always been effective as an early warning system for potential disease development. The inability to accurately predict disease development may be due to several factors, most importantly the number and extent of unreported SBR infections in potential source regions. This factor has been enhanced by the recent reductions in disease monitoring observations uploaded to the SBR-PIPE. Additional research is needed to determine the impact of environment and production practices, such as fungicide use, on model accuracy. More importantly, despite gains in knowledge and improved prediction and management tools, challenges to implementing effective SBR management programs still exist.

Future of the Monitoring Network

The SBR monitoring program is now entering a new phase. Concern about the disease in the north-central United States has waned, and effective management strategies are now available across the southern United States. These factors have reduced the interest and funding available for the applied field research required to adequately monitor and manage SBR. Even though the number of sentinel plots in North America has decreased by over 70% since 2008, the level of disease monitoring is still regarded as acceptable, due to increased efficiency and familiarity with the monitoring system and adoption of mobile scouting methods. In fact, the number of personnel (as determined by an annual survey of sentinel plot coordinators) involved in SBR scouting has been reduced from 475 people in 2007 to 143 people in 2012 (Table 2). The SBR monitoring program will remain effective as long as the SBR-PIPE infrastructure is maintained, and plant pathologists in the southern United States continue to monitor for early-season outbreaks.

The NCERA-208 group has shifted focus from responding to an emerging threat to maintaining an ongoing program of SBR monitoring and management. The group meets annually and conducts conference calls as needed to discuss SBR development during the growing season. Although the intensity of education efforts for SBR has decreased since 2005, the group has evolved to focus on improving management tools for SBR, and is applying lessons learned from SBR to other economically important diseases of soybean. For example, beginning in 2013, results from disease monitoring programs for the detection of QoI-fungicide-resistant isolates of *Cercospora sojina* Hara, causal organism of frogeye leaf spot of soybean, were added to the SBR-PIPE (85). The location of QoI-resistant isolates of *C. sojina* in the United States is available to farmers and agribusiness personnel via the public SBR-PIPE website. In addition, the PIPE platform coordinates programs and distributes information on other crops, including corn, cucurbits, legumes, and pecans (9,41,52,61). The SBR-PIPE will also provide access to data for those interested in analyzing and interpreting long-term data on *P. pachyrhizi* distribution and movement in North America. This vast database can now be used to answer epidemiological and biological questions on the pathogen and the disease. Additionally, the database encourages collaboration among plant pathologists and climatologists as we attempt to answer questions on the impact of changing environmental patterns and impact of tropical storms and hurricanes on SBR development and spread. Most importantly, scientists addressing emerging plant diseases can use the SBR monitoring program as an example of how to quickly and collaboratively provide effective disease monitoring and management information to stakeholders.

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Literature Cited

1. Aylor, D. E. 1990. The role of intermittent wind in the dispersal of fungal pathogens. Annu. Rev. Phytopathol. 28:73-92.
2. Barnes, C. W., Szabo, L. J., and Bowersox, V. C. 2009. Identifying and quantifying *Phakopsora pachyrhizi* spores in rain. Phytopathology 99:328-338.
3. Berger, R. D. 1977. Application of epidemiological principles to achieve plant disease control. Annu. Rev. Phytopathol. 15:165-183.
4. Bonde, M. R., Nester, S. E., Moore, W. F., and Allen, T. W. 2009. Comparative susceptibility of kudzu accessions from the southeastern United States to infection by *Phakopsora pachyrhizi*. Plant Dis. 93:593-598.
5. Bradley, C. A., Allen, T. W., Dorrance, A. E., Dunphy, E. J., Giesler, L. J., Hershman, D. E., Hollier, C. A., Horn, V., and Wrather, J. A. 2010. Evaluation of the soybean rust pest information platform for extension and education (PIPE) public website's impact on certified crop advisers. Online. Plant Health Progress doi:10.1094/PHP-2010-0701-01-RS
6. Bromfield, K. R. 1984. Soybean rust, Monogr. No. 11. American Phytopathological Society, St. Paul, MN.
7. Bromfield, K. R., and Hartwig, E. E. 1980. Resistance to soybean rust and mode of inheritance. Crop Sci. 20:254-255.
8. Caldwell, P., and McLaren, N. W. 2004. Soybean rust research in South Africa. Pages 354-360 in: Proc. VII World Soybean Res. Conf., IV Int. Soybean Processing and Utilization Conf., III Congresso Mundial de Soja (Brazilian Soybean Conf.). F. Moscardi, C. B. Hoffman-Campo, O. Ferreira Saraiva, P. R. Galerani, F. C. Krzyzanowski, and M. C. Carrão-Panizzi, eds. Embrapa Soybean, Londrina, Brazil.
9. Calixto, A., Birt, A., Lee, N., Dean, A., Ree, B., and Harris, M. 2011. Pecan ipmPIPE: Harnessing the internet for stakeholders in production agriculture. J. Int. Pest Manag. 2: 2011; DOI: http://dx.doi.org/10.1603/IPM10016
10. Christiano, R. C. S., and Scherm, H. 2007. Quantitative aspects of the spread of Asian soybean rust in the southeastern United States, 2005 to 2006. Phytopathology 97:1428-1433.
11. Delaney, M. A., Sikora, E. J., Delaney, D. P., Palm, M. E., Haudenshield, J. S., and Hartman, G. L. 2012. First report of soybean rust (*Phakopsora pachyrhizi*) on Florida beggarweed (*Desmodium tortuosum*) in Alabama. Plant Dis. 96:1374.
12. Delheimer, S. 2012. Emerging soybean rust threat. NCERA-208 Impact Statement. North Central Regional Association of State Agricultural Experiment Station Directors.
13. De Wolf, E. D., Madden, L. V., and Lipps, P. E. 2003. Risk assessment models for wheat Fusarium head blight epidemics based on within-season weather data. Phytopathology 93:428-435.
14. Dorrance, A. E., Hershman, D. E., and Draper, M. A. 2008. Economic importance of soybean rust. Pages 11-19 in: Using Foliar Fungicides to Manage Soybean Rust. A. E. Dorrance, M. A. Draper, and D. E. Hershman, eds. The Ohio State University Publ. SR 2008.
15. Draxler, R. R., and Hess, G. D. 1998. An overview of the HYSPLIT_4 modeling system of trajectories, dispersion and deposition. Aust. Meteorol. Mag. 47:295-308.
16. Fehr, W. R., Caviness, C. E., Burmood, D. T., and Pennington, J. S. 1971. Stage of development description for soybeans *Glycine max* (L.) Merrill. Crop Sci. 11:929-931.
17. Gevens, A. J., Nequi, N., Vitoreli, A., Marois, J. J., Wright, D. L., Harmon, C. L., and Harmon, P. F. 2008. First report of soybean rust caused by *Phakopsora pachyrhizi* on *Erythrina herbacea* (coral bean). Plant Dis. 92:1472.
18. Giesler, L. J., and Hershman, D. E. 2005. Overview and value of sentinel plots for 2005. In: Proc. 2nd Nat. Soybean Rust Sympos. American Phytopathology Society.
19. Giesler, L., Kemerait, R., and Sconyers, L. 2007. The sentinel plot system: Monitoring movement of an invasive pathogen. Pages 35-38 in: Using Foliar Fungicides to Manage Soybean Rust, 2nd ed. A. E. Dorrance, M. A. Draper, and D. E. Hershman, eds. The Ohio State University, Columbus, OH.
20. Godoy, C. V. 2012. Risk and management of fungicide resistance in the Asian soybean rust fungus *Phakopsora pachyrhizi*. Pages 87-95 in: Fungicide Resistance in Crop Protection: Risk and Management. T. S. Thind, ed. CAB International, Oxfordshire, UK.
21. Goellner, K., Loehrer, M., Langenbach, C., Conrath, U., Kock, E., and Schaffrath, U. 2010. *Phakopsora pachyrhizi,* the causal agent of Asian soybean rust. Mol. Plant Pathol. 11:169-177.
22. Hartman, G. L., and Haudenshield, J. S. 2009. Movement of *Phakopsora pachyrhizi* (soybean rust) spores by non-conventional means. Eur. J. Plant Pathol. 123:225-228.
23. Hartman, G. L., Hill, C. B., Twizeyimana, M., Miles, M. R., and Bandyopadhyay, R. 2011. Interaction of soybean and *Phakopsora pachyrhizi*, the cause of soybean rust. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. Doi:10.1079/ PAVSNNR 20116025
24. Hartman, G. L., Miles, M. R., and Frederick, R. D. 2005. Breeding for resistance to soybean rust. Plant Dis. 89:664-666.
25. Hartman, G. L., Wang, T. C., and Tschanz, A. T. 1991. Soybean rust development and the quantitative relationship between rust severity and soybean yield. Plant Dis. 75:596-600.
26. Hatfield, J. L., Boote, K. J., Kimball, B. A., Ziska, L. H., Izaurralde, C., Ort, D., and Thomson, A. 2011. Climate impacts on agriculture: Implications for crop production. Agron. J. 103:351-370.
27. Hennings, P. 1903. Some new Japanese Uredinale. IV. Hedwigia 42:107-108.
28. Hershman, D. E. 2009. Changes in the 2010 Sentinel Plot System. In: Proc. 4th Nat. Soybean Rust Sympos. American Phytopathological Society.
29. Hershman, D. E., Sikora, E. J., and Giesler, L. J. 2011. Soybean rust PIPE: Past, present, and future. J. Integrated Pest Manag. 2: DOI: http://dx. doi.org/10.1603/IPM11001
30. Isard, S. A., Barnes, C. W., Hambleton, S., Ariatti, A., Russo, J. M., Tenuta, A., Gay, D. A., and Szabo, L. J. 2011. Predicting soybean rust incursions into the North American continental interior using crop monitoring, spore

trapping, and aerobiological modeling. Plant Dis. 95:1346-1357.

31. Isard, S. A., Gage, S. H., Comtois, P., and Russo, J. M. 2005. Principles of the atmospheric pathway for invasive species applied to soybean rust. BioScience 55:851-861.
32. Isard, S. A., and Russo, J. M. 2007. Sentinel plots in the United States: Modeling the seasonal spread of SBR in North America. Pages 39-40 in: Using Foliar Fungicides to Manage Soybean Rust. A. E. Dorrance, M. A. Draper, and D. E. Hershman, eds. The Ohio State University, Columbus, OH.
33. Isard, S. A., Russo, J. M., and DeWolf, E. D. 2006. The establishment of a national Pest Information Platform for Extension and Education. Online. Plant Health Progress doi:10.1094/PHP-2006-0915-01-RV
34. Jordan, S. A., Mailhot, D. J., Gevens, A. J., Marois, J. J., Wright, D. L., Harmon, C. L., and Harmon, P. F. 2010. Characterization of kudzu (*Pueraria* spp.) resistance to *Phakopsora pachyrhizi*, the causal agent of soybean rust. Phytopathology 100:941-948.
35. Killgore, E., and Heu, R. 1994. First report of soybean rust in Hawaii. Plant Dis. 78:1216.
36. Krause, R. A., Massie, L. B., and Hyre, R. A. 1975. Blitecast: A computerized forecast of potato late blight (*Phytophthora infestans*). Plant Dis. Rep. 59:95-98.
37. Krupa, S., Bowersox, V., Claybrooke, R., Barnes, C. W., Szabo, L., Harlin, K., and Kurle, J. 2006. Introduction of Asian soybean rust urediniospores into the Midwestern United States – A case study. Plant Dis. 90:1254-1259.
38. Kumudini, S., Godoy, C. V., Board, J. E., Omielan, J., and Tollenaar, M. 2008. Mechanisms involved in soybean rust-induced yield reduction. Crop Sci. 48:2334-2342.
39. Levy, C. 2005. Epidemiology and chemical control of soybean rust in Southern Africa. Plant Dis. 89:669-674.
40. Livingston, M., Johansson, R., Daberkow, S., Roberts, M., Ash, M., and Breneman, V. 2004. Economic and policy implications of wind-borne entry of Asian soybean rust into the United States. Electronic Outlook Report. U.S. Dep. Agric. Econ. Res. Serv., OCS-04D-02.
41. Magary, R. D., Fowler, G. A., Borchert, D. M., Sutton, T. B., Colungua-Garcia, M., and Simpson, J. A. 2007. NAPPFAST: An internet system for the weather-based mapping of plant pathogens. Plant Dis. 91:336-345.
42. Miles, M. R., Frederick, R. D., and Hartman, G. L. 2003. Soybean Rust: Is the U.S. soybean crop at risk? APSnet Features. Online. doi: 10.1094/APSnetFeature-2003-0603
43. Miles, M. R., Hartman, G. L., Levy, C., and Morel, W. 2003. Current status of soybean rust control by fungicides. Pestic. Outlook 14:197-200.
44. Miles, M. R., Levy, C., and Hartman, G. L. 2004. Summary of the USDA fungicide efficacy trials to control soybean rust in Zimbabwe 2003-2004. USDA National Information System for the Regional IPM Centers. Online publication.
45. Miles, M. R., Morel, W., and Hartman, G. L. 2003. Summary of the USDA fungicide efficacy trials to control soybean rust in Paraguay 2002-2003. USDA National Information System for the Regional IPM Centers. Online publication.
46. Miles, M. R., Morel, W., Steinlage, T. A., and Hartman, G. L. 2004. Summary of the USDA fungicide efficacy trials to control soybean rust in Paraguay 2003-2004. USDA National Information System for the Regional IPM Centers. Online publication.
47. Morel, W., Scheid, N., Amarilla, V., and Cubilla, L. E. 2004. Soybean rust in Paraguay, evolution in the past three years. Pages 361-364 in: Proc. VII World Soybean Res. Conf., IV Int. Soybean Processing and Utilization Conf., III Congresso Mundial de Soja (Brazilian Soybean Conf.). F. Moscardi, C. B. Hoffman-Campo, O. Ferreira Saraiva, P. R. Galerani, F. C. Krzyzanowski, and M. C. Carrão-Panizzi, eds. Embrapa Soybean, Londrina.
48. Morel, W., and Yorinori, J. T. 2002. Situacion de la roja de la soja en el Paraguay. Bol de Diulgacion No. 44. Ministerio de Agricultura y Granaderia, Centro Regional de Investigacion Agricola, Capitan Miranda, Paraguay.
49. Mueller, D. S., Wise, K. A., Dufault, N. S., Bradley, C. A., and Chilvers, M. I., eds. 2013. Fungicides for Field Crops. American Phytopathological Society, St. Paul, MN.
50. Mundt, C. C., Wallace, L. D., Allen, T. W., Hollier, C. A., Kemerait, R. C., and Sikora, E. J. 2013. Initial epidemic area is strongly associated with the yearly extent of soybean rust spread in North America. Biol. Invasions 15:1431-1438.
51. Ojiambo, P. S., and Holmes, G. J. 2011. Spatiotemporal spread of cucurbit downy mildew in the eastern United States. Phytopathology 101:451-461.
52. Ojiambo, P. S., Holmes, G. J., Britton, W., Keever, T., Adams, M. L., Babadoost, M., Bost, S. C., Boyles, R., Brooks, M., Damicone, J., Draper, M. A., Egel, D. S., Everts, K. L., Ferrin, D. M., Gevens, A. J., Gugino, B. K., Hausbeck, M. K., Ingram, D. M., Isakeit, T., Keinath, A. P., Koike, S. T., Langston, D., McGrath, M. T., Miller, S. A., Mulrooney, R. P., Rideout, S., Roddy, E., Seebold, K. W., Sikora, E. J., Thornton, A., Wick, R. L., Wyenandt, C. A., and Zhang, S. 2011. Cucurbit downy mildew ipmPIPE: A next generation web-based interactive tool for disease management and extension outreach. Plant Health Progress doi:10.1094/PHP-2011–0411-01-RV
53. Pham, T. A., Hill, C. B., Miles, M. R., Nguyen, B. T., Vu, T. T., Vuong, T. D., VanToai, T. T., Nguyen, H. T., and Hartman, G. L. 2010. Evaluation of soybean for resistance to soybean rust in Vietnam. Field Crop. Res. 117:131-138.
54. Pivonia, S., Yang, X. B., and Pan, Z. 2005. Assessment of epidemic potential of soybean rust in the United States. Plant Dis. 89:678-682.
55. Pretorius, Z. A., Kloppers, F. J., and Frederick, R. D. 2001. First report of soybean rust in South Africa. Plant Dis. 85:1288.
56. Roberts, M. J., Schimmelpfennig, D., Ashley, E., and Livingston, M. 2006. The value of plant disease early-warning systems: A case study of U.S. Department of Agriculture's soybean rust coordinated framework. United States Department of Agriculture, Economic Research Service, Economic Research Report No. 18. (http://www.ers.usda.gov/publications/err-economic-research-report/err18.aspx).
57. Rossi, R. L. 2003. First report of *Phakospora pachyrhizi*, the causal organism of soybean rust in the Provence of Misiones, Argentina. Plant Dis. 87:102.
58. Rupe, J., and Sconyers, L. 2008. Soybean Rust. The Plant Health Instructor. American Phytopathological Society. DOI:10.1094/PHI-I-2008-0401-01
59. Rytter, J. L., Dowler, W. M., and Bromfield, K. R. 1984. Additional alternative hosts of *Phakopsora pachyrhizi*, causal organism of soybean rust. Plant Dis. 68:818-819.
60. Schneider, R. W., Hollier, C. A., Whitam, H. K., Palm, M. E., McKemy, J. M., Hernandez, J. R., Levy, L., and DeVries-Paterson, R. 2005. First report of soybean rust caused by *Phakopsora pachyrhizi* in the continental United States. Plant Dis. 89:774.
61. Schwartz, H. F., Langham, M. A. C., Golod, J., Tolin, S. A., LaForest, J., and Cardwell, K. F. 2009. Legume ipmPIPE: The next evolution of web-based interactive tools for disease management and extension outreach. Online. APSnet Features. doi: 10.1094/APSnetFeature-2009-0509
62. Sconyers, L. E., Kemerait, R. C., Jr., Brock, J. H., Gitaitis, R. D., Sanders, F. H., Phillips, D. V., and Jost, P. H. 2006. First report of *Phakopsora pachyrhizi*, the causal agent of Asian soybean rust on Florida beggarweed in the United States. Plant Dis. 90:972.
63. Sconyers, L. E., Kemerait, R. C., Brock, J., Phillips, D. V., Jost, P. H., Sikora, E. J., Gutierrez-Estrada, A., Mueller, J. D., Marois, J. J., Wright, D. L., and Harmon, C. L. 2006. Asian Soybean Rust Development in 2005: A Perspective from the Southeastern United States. 2006. Online. APSnet Features. doi:10.1094/APSnetFeatures-2006-0106
64. Sikora, E. J. 2013. Observations on soybean rust management in Alabama in 2012. Proc. Southern Soybean Dis. Workers. 40th Annu. Meeting.
65. Sikora, E. J., Delaney, D., Delaney, M., and Mullen, J. 2007. Asian soybean rust in Alabama. Alabama Coop. Ext. System ANR-1310.
66. Slaminko, T. L., Miles, M. R., Frederick, R. D., Bonde, M. R., and Hartman, G. L. 2008. New legume hosts of *Phakopsora pachyrhizi* based on greenhouse evaluations. Plant Dis. 92:767-771.
67. Slaminko, T. L., Miles, M. R., Marois, J. J., Wright, D. L., and Hartman, G. L. 2008. Hosts of *Phakopsora pachyrhizi* identified in field evaluations in Florida. Online. Plant Health Progress doi:10.1094/PHP-2008-1103-01-RS
68. Stokstad, E. 2004. Plant pathologists gear up for battle with dread fungus. Science 306:1672-1673.
69. Strandberg, J. O. 1986. Disease and pathogen detection for disease management. Pages 153-179 in: Plant Disease Epidemiology; Population Dynamics and Management, Vol. 1. K. J. Leonard and W. E. Fry, eds. Macmillan Publishing Company, New York.
70. Sun, J. H., Li, Z. C., Jewett, D. K., Britton, K. O., Ye, W. H., and Ge, X. J. 2005. Genetic diversity of *Pueraria lobata* (kudzu) and closely related taxa as revealed by inter-simple sequence repeat analysis. Weed Res. 45:255-260.
71. Sutrave, S., Scoglio, C., Isard, S. A., Hutchinson, J. M. S., and Garrett, K. A. 2012. Identifying highly connected counties compensates for resource limitations when evaluating national spread of an invasive pathogen. PLoS ONE 7: e37793. doi:10.1371/journal. pone.0037793
72. Tao, Z., Malvick, D., Claybrooke, R., Kurle, J., Gay, D., and Bowersox, V. 2009. Predicting the risk of soybean rust in Minnesota based on an integrated atmospheric model. Int. J. Biometerol. Doi:10.1007/s00484-009-0239-y
73. Twizeyimana, M., and Hartman, G. L. 2012. Pathogenic variation of *Phakopsora pachyrhizi* isolates on soybean in the United States from 2006 to 2009. Plant Dis. 96:75-81.
74. U.S. Dep. Agric. 2012. United States soybean prices. Online. U.S. Dep. Agric./ National Agricultural Statistics Service, Washington, DC.
75. U.S. Dep. Agric. 2005. Agriculture secretary approves funding for soybean rust surveillance and monitoring. Online. USDA News Release No. 0160.05. USDA, Washington, DC.
76. U.S. Dep. Agric. 2005. National road map for integrated pest management. Online. USDA Regional IPM Centers Information System, USDA and National Science Foundation, Washington, DC.
77. U.S. Dep. Agric. 2005. A coordinated framework for soybean rust surveillance, reporting, prediction, management and outreach. Online. Soybean Rust Resources, Emergency and Domestic Programs, Plant Protection and Quarantine (PPQ), USDA-APHIS, Washington, DC.
78. U.S. Dep. Agric. 2005. USDA expands national soybean rust risk management tool. Online. USDA News Release No. 0465.05. USDA, Washington, DC.
79. VanKirk, J. R., Isard, S. A., Cardwell, K. F., and Draper, M. 2012. The ipmPIPE: Overview, lessons, opportunities, and challenges. J. Int. Pest

Manag. DOI:http://dx. doi. org/10.1603/IPM11015
80. Verreet, J. A., Klink, H., and Hoffmann, G. M. 2000. Regional monitoring for disease prediction and optimization of plant protection measures: The IPM wheat model. Plant Dis. 84:816-826.
81. Wang, H., Yang, X. B., and Ma, Z. 2010. Long-distance spore transport of wheat stripe rust pathogen from Sichuan, Yunnan, and Guizhou in southwestern China. Plant Dis. 94:873-880.
82. Yang, X. B., Dowler, W. M., and Royer, M. H. 1991. Assessing the risk and potential impact of an exotic plant disease. Plant Dis. 75:976-982.
83. Yorinori, J. T., Paiva, W. M., Frederick, R. D., Costamilan, L. M., Bertagnolli, P. F., Hartman, G. L., and Nunes, J., Jr. 2005. Epidemics of soybean rust (*Phakopsora pachyrhizi*) in Brazil and Paraguay from 2001 to 2003. Plant Dis. 89:675-677.
84. Young, H. M., George, S., Narváez, D. F., Srivastava, P., Schuerger, A. C., Wright, D. L., and Marois, J. J. 2012. Effect of solar radiation on disease severity of soybean rust. Phytopathology 102:794-803.
85. Zhang, G. R., Newman, M. A., and Bradley, C. A. 2012. First report of the soybean frogeye leaf spot fungus (*Cercospora sojina*) resistant to quinone outside inhibitor fungicides in North America. Plant Dis. 96:767.
86. Zhang, X. C., Freire, M. C. M., Le, M. H., Oliveira, L. O. D., Pitkin, J. W., Segers, G., Concibido, V. C., Baley, G. J., Hartman, G. L., Upchurch, G., Pedley, K. F., and Stacey, G. 2012. Genetic diversity and origins of *Phakopsora pachyrhizi* isolates in the United States. Asian J. Plant Pathol. 6:52-65.

E. J. Sikora
Department of Entomology and Plant Pathology, Auburn University, Auburn 36849

T. W. Allen
Department of Biochemistry, Molecular Biology, Entomology and Plant Pathology, Delta Research and Extension Center, Mississippi State University, Stoneville 38776

K. A. Wise
Department of Botany and Plant Pathology, Purdue University, West Lafayette 47907

G. Bergstrom
Department of Plant Pathology and Plant-Microbe Biology, Cornell University, Ithaca 14853

C. A. Bradley
Department of Crop Sciences, University of Illinois, Urbana 61801

J. Bond
Department of Plant, Soil, and Agricultural Systems, Southern Illinois University, Carbondale 62901

D. Brown-Rytlewski and M. Chilvers
Department of Plant, Soil, and Microbial Sciences, Michigan State University, East Lansing 48824

J. Damicone
Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater 74078

E. DeWolf
Department of Plant Pathology, Kansas State University, Manhattan 66506

A. Dorrance
Department of Plant Pathology, The Ohio State University, Wooster 44691

N. Dufault
Department of Plant Pathology, University of Florida, Gainesville 32611

P. Esker
Escuela de Agronomia, Universidad de Costa Rica, San José, Costa Rica 10111

T. R. Faske
Department of Plant Pathology, University of Arkansas Lonoke Research and Extension Center, Lonoke 72086

L. Giesler
Department of Plant Pathology, University of Nebraska-Lincoln, Lincoln 68508

N. Goldberg
Department of Plant Sciences, New Mexico State University, Las Cruces 88003

J. Golod
Department of Plant Pathology and Environmental Microbiology, Pennsylvania State University, University Park 16802

I. R. G. Gómez
Sistema Nacional de Vigilancia Epidemiologica Fitosanitaria, Centro Nacional de Referenceia Fitosanitaria, Col. Del Carmen, Coyoacan, Mexico

C. Grau
Department of Plant Pathology, University of Wisconsin, Madison 53706

A. Grybauskas
Department of Plant Science and Landscape Management, University of Maryland, College Park 20742

G. Franc
Deceased

R. Hammerschmidt
Department of Plant, Soil, and Microbial Sciences, Michigan State University, East Lansing 48824

G. L. Hartman
United States Department of Agriculture/Agricultural Research Service, Urbana 61801

R. A. Henn
Department of Biochemistry, Molecular Biology, Entomology, and Plant Pathology, Mississippi State 39762

D. Hershman
Department of Plant Pathology, University of Kentucky Research and Education Center, Princeton 42445

C. Hollier
Department of Plant Pathology and Crop Physiology, Louisiana State University Agricultural Center, Baton Rouge 70803

T. Isakeit
Department of Plant Pathology & Microbiology, Texas A&M University, College Station 77843

S. Isard
Department of Plant Pathology and Environmental Microbiology, Pennsylvania State University, University Park 16802

B. Jacobsen
Department of Plant Sciences and Plant Pathology, Montana State University, Bozeman 59717

D. Jardine
Department of Plant Pathology, Kansas State University, Manhattan 66506

R. Kemerait
Department of Plant Pathology, University of Georgia, Tifton 31793

S. Koenning
Department of Plant Pathology, North Carolina State University, Raleigh 27695

M. Langham
Department of Plant Science, South Dakota State University, Brookings 57007

D. Malvick
Department of Plant Pathology, University of Minnesota, St. Paul 55108

S. Markell
Department of Plant Pathology, North Dakota State University, Fargo 58108

J. J. Marois
Department of Plant Pathology, University of Florida, Gainesville 32611

S. Monfort
Edisto Research and Education Center, Clemson University, Blackville 29817

D. Mueller
Department of Plant Pathology and Microbiology, Iowa State University, Ames 50011

J. Mueller
Edisto Research and Education Center, Clemson University, Blackville 29817

R. Mulrooney
Department of Plant and Soil Science, University of Delaware, Newark 19716

M. Newman
BASF Corporation, Jackson, TN 38301

L. Osborne
Dupont Pioneer, Brookings, SD 57007

G. B. Padgett
Department of Plant Pathology and Crop Physiology, Louisiana State University Agricultural Center,
Baton Rouge 70803

B. E. Ruden
South Dakota Wheat Growers Association, Aberdeen 57401

J. Rupe
Department of Plant Pathology, University of Arkansas, Fayetteville 72701

R. Schneider
Department of Plant Pathology and Crop Physiology, Louisiana State University Agricultural Center,
Baton Rouge 70803

H. Schwartz
Department of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins 80523

G. Shaner
Department of Botany and Plant Pathology, Purdue University, West Lafayette 47907

S. Singh
Department of Plant, Soil and Entomological Sciences, University of Idaho, Kimberly 83341

E. Stromberg
Department of Plant Pathology, Physiology, and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg 24061

L. Sweets
Division of Plant Sciences, University of Missouri, Columbia 65211

A. Tenuta
Ontario Ministry of Agriculture and Food, and Ministry of Rural Affairs, Ridgetown, Ontario, Canada, NOP2CO

S. Vaiciunas
New Jersey Department of Agriculture, Trenton 08625

X. B. Yang
Department of Plant Pathology and Microbiology, Iowa State University, Ames 50011

H. Young-Kelly
Department of Entomology and Plant Pathology, University of Tennessee West Tennessee Research and Education Center, Jackson 38301

J. Zidek
ZedX Incorporated, Bellefonte, PA 16823