SOYBEAN PATHOLOGY WHITE PAPER

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EXECUTIVE SUMMARY

Soybean has a prominent role in the agriculture of the United States being used as a forage, a grain crop for humans and livestock, in numerous industrial applications, and most recently as a biofuel. During the past 75 years, average soybean yields have more than tripled from 12 bushels per acre in 1924 to almost 43 bushels per acre in 2006. Much of this yield gain can be attributable to genetic improvement through breeding, including disease and insect resistance. Host resistance will likely remain the primary means to protect yield potential of soybean from plant pathogens. The acreage and intensity of soybean production appears unsettled at the present time. Soybean pathologists will need to adjust research activity on cultural practices and soybean diseases to remain relevant to soybean growers. Although fungicides, other than as seed treatments, have not been a common approach to disease control, the occurrence of soybean rust in the US has resulted in an unprecedented interest in fungicides to promote plant health.

Specific soybean diseases are important for varying reasons. The soybean cyst nematode (SCN) is widespread, frequently unrecognized by growers and although resistant varieties are available, recent data suggest a common source of resistance is defeated by variants of the pathogen. In some cases specific diseases are highly yield-limiting, but in a smaller geographic area or when less than common environmental conditions occur. Soybean viruses are dependent on activity of insect vectors, thus their importance varies with insect activity. For several diseases, such as sudden death syndrome (SDS), the causal agents appear to still be in an establishment phase in many states. And lastly, diseases such as soybean dwarf and Asian rust have recently been diagnosed and their importance is an unknown at this time. These situations make it difficult for pathologists and funding agencies to determine where research resources and funding should be directed.

Soybean cultivar development has changed dramatically in recent years moving from public institution development to primarily private company development. With this change, there has been a decrease in the local adaptation of varieties and an increase in turnover rate. Due to these changes, it can be expected that there may be an increase in what are currently minor diseases such as frogeye leaf spot, powdery mildew and bacterial pustule. As breeders develop varieties for special use markets, the genes that contribute to these specific traits take precedence over disease resistance genes. Since the grain quality of these special varieties can be impacted by seed coat blemishes, diseases such as purple stain, Phomopsis seed rot and viruses are likely to become more important. Pathogen adaptation to deployed resistance genes has been the bane of breeders since cultivar development was first used as a primary tool for disease management. Examples include the adaptation of SCN to varieties developed from the PI88788 and the discovery of *Phytophthora sojae* populations that are virulent to the *Rps*1c and *Rps*1k resistance genes. Thus, it is critical for pathologist to work independently or with soybean breeders to identify new and superior sources host resistance, and transfer resistance to soybean germplasm of agronomically acceptable types. For example, a high research need is finding new sources of resistance to SCN, sequencing of the *Heterodera glycines* genome to better understand what drives selection to more virulent pathotypes and knowledge of agronomic practices that lower selection pressure for more virulent pathotypes of SCN.

Research on the basic biology of soybean pathogens has dwindled in recent decades. Research of this type needs to be increased to better understand which control strategies are possible and how to apply management strategies for a crop of ever changing methods of production and uses. Characterization of pathogen populations, what they are in the different regions and best management strategies to manage these diseases is required for continued improvements in soybean yield.

Pathologists and representatives of funding agencies will make prioritize research needs soybean pathology. A select group of examples are as follows. For Phytophthora root rot, research needs include additional identification of sources of both Rps and partial resistance genes, development of molecular diagnostic tools that enable rapid and accurate identification of races of *P. sojae,* and a better understanding of how edaphic factors affect disease development. SDS research needs include developing improved screening tests with increased consistency between greenhouse and field tests and tests across locations, a better understanding of phenotypic and genotypic pathogen variability in order to support breeding efforts and improved understanding of the etiology of the disease. To better manage charcoal rot, improved screening methods are needed to more quickly identify resistant germplasm. Other needs include a better understanding of the potential interaction between charcoal rot and other root infecting pathogens and how host preference affects population diversity. Seedling diseases involve a complex of pathogens including *Fusarium* and *Pythium* spp. and *Rhizoctonia solani*. Research questions that need to be addressed include whether biofumigation (green manure crops, etc) can reduce the inoculum or impact of seedling diseases; can molecular tools be developed to help aid in diagnosing the causal agents of seedling disease; and can resistance mechanisms be identified and selected for or be engineered? Brown stem rot is a significant pathogen in northern growing areas. Two genotypes (A and B) have been identified. Research needs include characterization of resistance sources and cultivars to the two genotypes, understanding the pathogenic variability within each genotype and improving the understanding of environmental and field site influences on brown stem rot development. Virus research needs include assessing the distribution of the different viruses, evaluating the impact of soybean aphid resistance on virus incidence and the development of varieties resistant to multiple viruses. Other diseases highlighted in the report include Sclerotinia stem rot and the foliar disease complex. For Sclerotinia stem rot, research needs include improving the efficiency of biological control, identifying germplasm with improved levels of partial resistance and determining mechanisms of resistance. For foliar diseases, top needs include development of accurate yield loss assessment tools, development of resistant cultivars and determining the efficacy of fungicides to specific leaf pathogens, particularly soybean rust. Research needs for the *Diaporthe-Phomopsis* complex include developing real-time PCR methods to monitor pathogen activity and determining genetic relatedness among isolates of the pathogen, determining important sources of inoculum, and assessing resistance in current varieties, germplasm and plant introduction lines.

Lastly, fungal and Oomycete culture collections are imperative for advancements in understanding disease development. Many current collections are depositories of isolates used in research studies. What is needed are working collections where both the aggressiveness (pathogenicity) and virulence pathotype are routinely screened and maintained. Traditional university and ARS laboratory-based collections are disappearing as funding decreases. If breeders are to make progress, funding to maintain or reestablish collections to provide standardized isolates will be needed.

The final outcome of all of these activities will be better, more widely adapted, higher yielding soybean varieties for the region. Breeders/companies will have better information on which pathogens and which isolates of these pathogens to use in screening for development of resistance. Moreover, experiments which compare differential gene expression affected by the infection process of many of these pathogens may help to elucidate common defense pathways. Currently over 3,000 genes, associated with resistance, change expression in response to infection to *P. sojae, Pseudomonas syringae* and *S. sclerotiorum* (Tyler et al., unpublished; Clough et al., unpublished). Studies which begin to tie these molecular responses to each of these pathogen groups is now needed. The potential outcome will be better molecular markers for molecular assisted selection to accommodate development of varieties with multiple stacked quality traits combined with resistance to *Macrophomina phaseoli, F. virguliformes, S. sclerotiorum,* and *Phytophthora sojae.* This type of strategy will facilitate expansion of the suitable range for a variety to extend from Nebraska to Ohio, and Wisconsin to Southern Illinois, the extremes of the north central soybean belt.

With this as a background, the following report is the outcome of a meeting of soybean plant pathologists from the North Central Region and Canada held at New Glarus, Wisconsin in August of 2006. From these discussions, several high priority areas were identified and what follows is a more detailed “State of the Situation” and research needs to successfully manage soybean pathogens but also to enhance soybean production in the North Central Region. This white paper is a collaboration among the many scientists whose primary focus is the development and implementation of disease management strategies for soybean. Each pathogen has different research needs based on the research that has already been accomplished. We are all in agreement that the lack of information/understanding of some very basic biology across all of these pathogens is making it very difficult to develop effective disease management strategies in a timely manner.

INTRODUCTION

Soybean (*Glycines max* (L.) Merr.) has a prominent role in the agriculture of the United States and many other countries. The versatility of this crop has allowed it to achieve its prominence among crops of the world. Beginning as a forage crop for livestock, soybean has changed dramatically to usage as a grain crop for human and livestock consumption and numerous industrial uses, and is positioned to become a major alternative energy source. During the past 75 years, average soybean yields have more than tripled from 12 bushels per acre in 1924 to nearly 43 bushels per acre. Although the annual rate of yield increase for this entire period has averaged 0.34 bushels per acre, it has accelerated to an average of 0.5 bushels per acre per year since 1972. Much of this yield gain can be attributable to genetic improvement through breeding, including disease and insect resistance. However, as successful as past soybean improvement efforts have been, the pace of innovation must accelerate to keep U.S. soybean production globally competitive and to meet the demands of an increasing world population. Disease management will take on greater importance in the future as projected uses of soybean increase its value to humans and their security.

Soybean plant health is a critical component of profitable soybean production. Over 80 plant pathogens are reported to cause disease problems worldwide (Hartman et al., 1999). Disease severity and prevalence and agronomic loss are closely associated with environmental conditions (Yang and Feng, 2001), crop management practices, and reaction of soybean cultivars to infection by the multitude of plant pathogens. These pathogens of soybean vary greatly in importance based on frequency of occurrence, timing of development, regional distribution, and associated yield loss (Wrather et al., 2003; Wrather and Koenning, 2006). Advances in breeding and crop management have reduced dramatically the yield-limiting effects of several soybean pathogens. In contrast, several pathogens have emerged from minor to significant importance. For example, Sclerotinia stem rot and the sudden death pathogen (SDS) have emerged from unknowns to a status of economic importance while others such as Phytophthora root rot and soybean cyst nematode are managed with varying degrees of success. Some soybean diseases are geographically limited, whereas others are distributed widely (Hartman et al., 1999). Soybean rust and soybean dwarf are examples of diseases that have recently reached the U.S. and illustrate that soybean pathologists must be prepared to meet new challenges.

Soybean cultivar development has dramatically changed in the past five to ten years. Previously, cultivars planted throughout much of the soybean production region were developed at public institutions and tested and sold by small regional seed companies. As a result a large number of cultivars were locally adapted. Since 1998, there has been a consolidation and expansion of soybean cultivar development by private companies that market specific varieties across a greater geographic area. Thus, there is a high probability that a specific variety will not be adapted to meet pathogen pressure in some regions. Herbicide resistance has been incorporated into almost all of these cultivars, and yield advances have been made as well. Current projections from private industry are to expand and increase the turn-over of cultivars every three years. For public releases, data must be collected over three seasons prior to the release of a cultivar. The requirement of three years of data was made to ensure that a cultivar would be exposed to many environments and different disease pressures. In the north-central region, we have documented in seed-increase fields that several currently rare diseases, such as frogeye leaf spot, powdery mildew and bacterial pustule, are readily managed through host resistance. With the rapid cultivar development now in progress by private industry, we predict that several more minor diseases may cause economic damage in the U.S. in the coming decades.

Specialty markets and identity-preserved soybean varieties are also on the horizon. Many producers have already experienced an economic advantage in growing specialty tofu soybeans and now low-linolenic soybeans are grown on a greater number of acres. These cultivars are developed with specialty markets in mind and much of the breeding and selection is focused on the genes that contribute to these specific traits. Disease resistance is still important, but in the genes that contribute to the trait of interest take precedence. Besides yield loss, grain quality of specialty varieties can be impacted by seed coat blemishes caused by purple stain, Phomopis seed rot, and viruses.

Pathogen adaptation to deployed resistance has been the bane of breeders since cultivar development first became used as a primary tool to manage diseases. The process has continued and will continue to happen. The primary challenge is to keep identifying and incorporating more effective resistance in cultivars before adaptation is fixed in the pathogen population. Put more simply: keeping ahead of the game. SCN-resistant varieties derived from the breeding line PI88788 have been used very widely for SCN management. However, until 2006, there were few, if any, soybean cultivars available with SCN- resistance derived from other sources. SCN populations across the Midwest are adapting to PI88788, and only two other sources of resistance, Hartwig and Peking, are entering into commercial cultivars. *Phytophthora sojae* is another example. *Rps*1c and *Rps*1k are the most commonly found resistance genes in today's commercial cultivars. Populations of *P. sojae* that cause disease on soybeans with these genes have been found in fields across the North Central region. *Rps*8 should enter the marketplace in the next few years, but what is in the pipeline to replace this gene? Rotation of resistance sources or rotation of resistance genes ensures longevity, but also prevents losses during the adaptation.

Several recent discoveries have also caused some concern in the past few years. For example, *Pythium spp.* were identified in Ohio that are very aggressive on soybeans, but some species of *Pythium* are insensitive to some active ingredients in fungicide seed treatment products (Dorrance et al., 2004; Broders et al., 2007). Studies are underway to determine whether combining different active ingredients into seed treatment products will provide a solution for this problem.

It is common for soybean to encounter multiple pathogens in a single field. Traditionally each pathogen has been addressed alone. Research has been initiated to study the interaction between SCN and the brown stem rot pathogen, and SCN and the SDS pathogen. Knowledge of interactions among other pathogens is a gap in the basic understanding of soybean disease epidemiology and should be addressed in the future.

Research on the basic biology of soybean pathogens has dwindled in recent decades. Research of this type needs to be increased to better understand which control strategies are possible and how to apply management strategies for a crop of ever changing methods of production and uses. Characterization of pathogen populations, what they are in the different regions, and best management strategies to manage these diseases is required for continued improvements in soybean yield.

Table 1. Estimated reduction of soybean yields for 13 north-central states

	Yield loss in metric tons (x10^3) per year						
Disease group	1999	2000	2001	2002	2003	2004	2005
Leaf	91.4	201.0	46.1	86.9	23.7	62.8	199.8
Stem	706.9	708.2	1,114.7	455.0	768.9	2,381.9	848.9
Root	1,785.5	3,414.9	2,419.5	2,784.6	3,674.5	2,519.5	1,831.1
Seedling	261.3	495.0	772.1	502.9	644.5	1,023.3	762.6
Seed	99.3	20.9	30.1	106.7	27.2	6.9	83.9
Nematode	4,132.2	3,393.3	3,568.4	3,350.4	2,586.9	3,198.2	1,718.3
Virus	208.3	926.0	380.7	754.3	170.4	44.0	31.3

Leaf diseases = bacterial diseases, brown spot, downy mildew, frogeye leaf spot.
Stem diseases = anthracnose, brown stem rot, pod and stem blight, Sclerotinia stem rot, stem canker.
Root diseases = charcoal rot, Fusarium root rot, Phytophthora root rot, sudden death syndrome.

ROOT DISEASES

Charcoal Rot, *Macrophomina phaseolina*

Current Importance, Distribution, Incidence

From 1999 to 2002, it was estimated that 113 million bushels of soybeans were lost to production in the United States due to charcoal rot, caused by the fungus *Macrophomina phaseolina*. This ranks third among all soybean diseases, behind soybean cyst nematode (SCN) and *Phytophthora* root rot. During years with exceptional heat and drought, it is usually the most significant disease. During that four-year period, it was reported on soybeans in all of the north-central states and Ontario, Canada except for Iowa, Michigan, and Minnesota. Since then, it has been reported from Iowa and Minnesota.

Short-term Research Needs

Short term research projects might include the effect of different tillage systems on inoculum survival and disease development. Previous experiments have not been conclusive. It has been demonstrated that the presence of SCN increases the levels of charcoal rot by eight-fold. It is not known how other root infecting pathogens such as *Phytophthora sojae, Rhizoctonia solani,* or *Fusarium solani f. sp. glycines* may interact with *Macrophomina*. Better methods of screening for resistance where large numbers of lines can be screened rapidly need to be developed. Current fungicides and seed treatments are ineffective in controlling charcoal rot. *Trichoderma harzianum* has been linked to declines of *Macrophomina* in decaying roots, but further research on the role of biological controls needs to be done.

Long-term Research Needs

Long term research needs include the development of more resistant germplasm. A germplasm with an improved level of resistance was recently released for maturity group 5 soybeans, but better sources of resistance are needed for all of the earlier maturing groups. Two Macrophomina-associated mycotoxins have been identified (phaseolonone and (-)-botryodiplodin), but their role in disease development needs to be further elucidated. Host preference among *Macrophomina* populations has been demonstrated, but little is known about the fungus with regard to population diversity.

Phytophthora Root Rot, *Phytophthora sojae*

Current Importance, Distribution, Incidence

Phytophthora root and stem rot (PRR) is one of the most economically important diseases of soybean and occurs in every soybean growing region in the world. In 2005, yield suppression by PRR was estimated to cost over $250 million (Wrather and Koenning, 2006). PRR is caused by the oomycete *Phytophthora sojae* which can infect plants at all stages of growth. Early season symptoms include pre- and post-emergent damping off which results in loss of plant stands or replanting. Mid- to late-season symptoms are characterized by stunting of plants, overall chlorosis and stem and root rot. Disease development is most rapid at soil temperatures above 60° F and high soil moisture. It is most common in low areas of a field, on poorly drained or compacted soils, and in soils with high clay content, although it is not limited only to these sites or conditions. It may also occur on well-drained hillsides during wet growing seasons.

Management of PRR has been achieved by planting resistant soybean cultivars or planting partially resistant cultivars supplemented with fungicides applied to seed. Highly effective resistance genes have been used since the 1960’s but have become ineffective due to new races of *P. sojae*. Partial resistance, although relatively stable against all forms of the pathogen, presents a challenge to soybean breeders. Future research needs to seek the means to improve these strategies to manage PRR

Over the past five years, collaborative research on Phytophthora root rot among soybean pathologists in the north-central region has led to the following accomplishments:

- A comprehensive investigation of *P. sojae* pathotypes (races) in each state across the region has been completed
- Isolates representative of all these pathotypes have been screened for resistance to metalaxyl/mefenoxam. Resistance to this primary fungicide was not identified in any of the populations sampled.
- Evaluation of new sources of resistance to *P. sojae* is in progress, but preliminary results are promising for PI399073.
- Evaluation of the use of seed treatment fungicides in combination with varieties with partial resistance for improved early season disease management
- Extension modules – fact sheets and PowerPoint presentations are available on the Plant Health Initiative website

In addition, the following advances have been made by other researchers

- The genome of *Phytophthora sojae* has been sequenced and data is publicly available (http://genome.jgi-psf.org/.)
- Affymetrix GeneChip® Soybean Genome Array includes probe sets to identify more than 15,000 transcripts from for *P. sojae*
- A library of 3000 EMS mutagenized *P. sojae* individuals has been constructed by Dr. K Lamour's Laboratory at the University of Tennessee

Short-term Research Needs

- o Continue to identify sources of both Rps gene and partial resistance
- o Identify QTLs associated with currently identified sources of paritial resistance, as a patent has been issued for Genetic Loci associated with Phytophthora tolerance in soybean (U.S. Patent No. 20060059580).
- o Characterize the biochemical and genetic mechanism(s) associated with partial resistance expressed in different sources of resistance as preliminary data from a microarray studies indicate that there are different mechanisms of partial resistance
- o Identify the mechanism by which *P. sojae* generates and maintains genetic diversity in populations
- o What factors control the dormancy and germination of oospores in soil?
- o What molecular mechanisms influence pathogenicity?
- o What roles might avirulence genes play in infection and colonization?
- o Are there additional elicitors which are important for pathogenicity?
- o What molecular mechanisms drive changes in the population?
- o Numerous transposable elements have been identified in the genome of *P. sojae*. How mobile are these elements and what factors trigger their mobility?
- o Do various soybean lines impose selection pressure on endemic *P. sojae* populations, and if so to what extent?

Mutants of *P. sojae* are available and should be used to address questions concerning the basic biology of *P. sojae*. In addition, the availability of the complete genome sequence of *P. sojae*, and the Affymetrix GeneChip® Soybean Genome Array will facilitate improved understanding of soybean-*P. sojae* interactions.

Molecular diagnostic tools that enable rapid and accurate identification of races of *P. sojae* are very much needed, since it is important to know which virulence phenotypes are present in the field before selecting a cultivar with specific resistance. Presently, identification of races of *P. sojae* is tedious and is done in the greenhouse using 14 differential soybean lines in a bioassay. This method requires that all isolates of *P. sojae* be purified and then screened, a process that can take a few weeks.

Long-term Research Needs

Evidence is increasing that interactions between various pathogens can influence disease development. Some pathogens interfere with resistant mechanisms in plant hosts which can result in increased susceptibility to infection and disease development by another pathogen, e.g. SCN and BSR. Not only do negative impacts of interactions with other pathogens and PRR need to be identified, but resistant sources need to be screened for resistance to all pathogens, so that a complete profile of resistance for each line is readily available to all breeders.

Environmental conditions influence the development of PRR, specifically saturated soils. Improving water drainage through the soil using tiles has been shown to reduce the incidence of PRR disease, but improvements could be made. In addition, an improved knowledge of the effect of other factors (pH, micronutrients, soil type) on *P. sojae* biology and PRR disease development is needed.

Root-Seedling Disease Complex in Soybean, *Fusarium* spp, *Pythium* spp. and *Rhizoctonia solani*

Current Importance, Distribution, Incidence

A complex of pathogens including *Fusarium spp*,, *Rhizoctonia solani* and *Pythium* spp. are the least understood and characterized of the soybean pathogens and during wet years can cause substantial losses. The seedling, root, and stem diseases caused by these pathogens are exacerbated by three factors: 1) Poor drainage resulting from limited slope and relief, 2) prolonged soil saturation resulting from a combination of poor drainage and heavy clay soils, and 3) slow spring soil warm-up accompanying prolonged saturation and delayed by late warm-up in northern areas of this region. The expansion of reduced tillage or no tillage systems throughout the region continues to contribute to these losses, as reduced soil disturbance and increased residue cover further delays soil warm-up and soil drying. As a result, temperatures at the 6” depth may remain below 60^{o} F. through May and early June when most of the infection likely occurs. In addition to their early season effects, the root pathogens probably contribute to yield losses by impairing root development throughout the season. They also interact with other root pathogens such as soybean cyst nematode, to cause more severe yield losses than that resulting from the additive effect of each disease alone.

Fusarium Root Rot of Soybean

Fusarium root rot of soybean, caused by *Fusarium solani*, is known to cause damage in the upper Great Plains in North Dakota and Minnesota. The pathogen causes light to dark brown lesions that are often shrunken, and is considered a cortical root rotter that can kill plants. The strains that cause this root rot are different from the ones that cause sudden death syndrome and appear to be influenced by a different set of environmental factors. This disease has received little attention. We do not know the importance of this disease in the major soybean growing areas and the basic biology of disease is not understood. Since this root rot causes the loss of lateral roots the damage is unlikely to be noticed by visually inspecting plants, thus may often be overlooked. Loss of yield may often be the only evidence of disease. *F. solani* is involved in the seedling disease complex since it causes pre-emergence damping-off at high densities of conidia in the soil. In addition to *F. solani, F. oxysporum* and *F. graminearum* have also been implicated in root and seedling disease in other areas of the soybean production region.

Biotic and abiotic plant stress may predispose seedlings to infection by these different *Fusarium* spp. For example current studies indicate that one-month-old plants can be infected by *F. solani*, but not show any root rot while growing under ideal growing conditions. Stress appears to be an important factor in severe disease development in adult plants, but no studies have attempted to identify or quantify the role of stress in this disease. There may also be a strong cultivar genotype x stress x root rot interaction in the field. Furthermore, there have been no studies to characterize the populations of root rotting strains of *F. solani* on soybean in the United States either for virulence, molecular or other traits. There are many unanswered questions about this disease. Research should focus on understanding the basic biology of disease development.

Pythium spp.

Pythium spp. are widespread soil-borne pathogens that can infect seeds, seedlings and roots of soybean. At low soil temperatures (10 – 15° C), a complex of *Pythium* species contributes to poor stands, delayed emergence, and poor early season plant development. Members of this group are also favored by prolonged periods of saturated soils. A number of the species can infect both soybeans and corn. As a result, the planting of short crop sequences consisting predominantly of corn and soybeans have probably resulted in an increase of inoculum of these species in fields in this area. Although seed treatments containing metalaxyl, mefanoxam, and strobilurins are considered effective in controlling oomycetes including *Pythium* spp., they are not applied regularly by large numbers of soybean growers in the region. In addition, no one active ingredient is effective across all of the different Pythium spp. that have been indentified in some production regions. Host resistance to *Pythium* is available, but it is not pursued in most soybean breeding programs. Resistance to *Pythium aphanidermatum* and other *Pythium* species may be associated with *Rps 1k* and *Rps 6* which confer resistance to P. sojae.

Rhizoctonia solani

Rhizoctonia solani is a soilborne fungus that can cause pre- and post-emergence damping off, seedling blight, and root rot of soybean and many other crops. Different “strains” of the fungus are present throughout the north-central United States. Strains are characterized by their ability to anastomose, or fuse, with each other, and are placed into different anastomosis groups (AGs). The most common AGs that cause diseases of soybean are AG-2-2 and AG-4. *Rhizoctonia* is able to infect and cause disease under many different temperature and moisture regimes, and the most conducive conditions for disease may vary slightly depending on the AG. Additional sources of stress on soybeans, such as from herbicides, hail injury or nematodes, may increase the damaging effects of *Rhizoctonia*. Some fungicide seed treatments can provide short-term protection against *Rhizoctonia*, but none provide season-long protection. Complete-resistance to *Rhizoctonia* has not been found in commercial soybean varieties or germplasm accessions; however, differences in susceptibility do occur. The fungus has a wide host range, which makes crop rotation less effective in controlling the disease. Although broadleaf crops such as soybean, dry edible bean, and sugarbeet tend to be affected most severely by *Rhizoctonia*, cereal crops such as corn may also be affected depending on the aggressiveness and AG of the fungus. Some soybean cultivars are considered to be less susceptible to *R. solani*, but resistance breeding has received little emphasis.

Basic *knowledge gaps*

- Which of these pathogens are most common and damaging, and when, where and under which conditions?
- What sources of resistance and mechanisms of resistance can be exploited in soybean cultivars?
- Evaluation of the efficacy of seed treatment fungicides against all of these pathogens.
- Can we map and characterize fields that are most prone to seedling disease problems and have the greatest chance of return from the use of seed treatment fungicides?
- What are the best management strategies for root, seed, and seedling diseases?
- Do these pathogens interact with each other to create even more severe problems?

Research needs for short-term management strategies

- What are the baseline sensitivity levels of root, seed and seedling disease pathogens to fungicides, and what type of monitoring efforts for fungicide resistance is needed?
- Are currently available biological seed treatments effective and economical?
- Can significant differences in susceptibility among cultivars be identified?

- Can germplasm screening methods be developed or improved to be more efficient and accurately in identifying resistance?
- When and where do different tillage treatments affect disease incidence and severity?
- Can molecular tools be developed to help aid in conducting research and in diagnosing the causal agents of seedling diseases? Development of a diagnostic array – specific for each production region.
- Does biofumigation (green manure crops, etc.) reduce the inoculum or impact of seedling diseases?
- Which management practices enhance or decrease the levels of bacteria populations whose activity reduces the levels and severity of root, seed and seedling diseases?

Research needs for long-term management strategies

- Can resistance mechanisms be identified and selected for or be engineered?
- Are any soil treatments effective for reducing populations of the pathogens in the soil?
- Can more effective seed treatment fungicides or biologicals be identified?
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Soybean Cyst Nematode, *Heterodera glycines*

Current importance, distribution, incidence, and epidemiology

The soybean cyst nematode, *Heterodera glycines*, is the most important yield-reducing pathogen throughout the US (Wrather and Koenning 2006). An NCSRP-funded, random survey of six midwestern states in the mid-1990s revealed that SCN was present in 46% to 83% of fields in individual states (Workneh et al. 1999). Despite the widespread nature of SCN, infestations in many fields go undiagnosed because aboveground symptoms do not always occur (Niblack et al. 2006). Furthermore, results of soybean-checkoff-funded research revealed that significant yield loss can occur in the absence of noticeable aboveground symptoms (Wang et al. 2003).

Once infestations are identified, SCN is managed primarily through the use of SCN-resistant soybean varieties grown in rotation with nonhost crops, such as corn (Niblack 2005). There are hundreds of SCN-resistant soybean varieties available for soybean growers in the north-central U.S. (Shier 2006, Tylka 2006). But a great majority (95% to 97%) of the SCN-resistant soybean varieties possess resistance from the breeding line PI88788 (Shier 2006, Tylka 2006).

SCN-resistant soybean varieties can produce yields that are 50% or more than susceptible varieties in fields infested with the nematode (MacGuidwin et al. 1995, Tylka et al. 2006, Wang et al. 2003). Additionally, the resistant varieties keep SCN population densities from increasing and may even decrease the population densities, whereas SCN population densities increase 5- to 10- fold or more when susceptible varieties are grown (Donald et al. 2006, Tylka et al. 2006).

There have been published reports of the build-up of SCN populations capable of reproducing on PI88788 from states in the north-central U.S. For example, Sikora and Noel (1991) reported that 27% of 44 SCN populations from Illinois had elevated reproduction on PI88788. Niblack et al. (2003) found nearly 60% of 183 SCN populations obtained through a random survey of Missouri had elevated virulence on PI88788. During 2005-2006, Niblack et al. (personnel communication) found that 84% of SCN populations recovered from a survey of Illinois had elevated reproduction on PI88788. Also, nematologists and plant pathologists in the north-central states are receiving more frequent anecdotal reports of PI88788 resistance not being as effective as it once was. It is no longer uncommon for SCN populations to be able to reproduce on PI88788. And this is troubling because there are so few SCN-resistant soybean varieties with any other source of SCN resistance.

The complex soil environment impacts the life history of SCN. A survey indicated that no-tillage fields on average had lower population densities than intensively tilled fields (Workneh et al, 1999). Recent studies have confirmed that reproduction of SCN increases with increasing soil disturbance applied during tillage (Westphal and Vyn, 2005). Other studies have demonstrated that biologically suppressive soils exist that reduce the reproduction and damage of SCN (Xing and Westphal, 2005, 2006). The exploitation of biological control mechanisms and how cultural practices impact biological soil suppressiveness are important investigative topics. Methods on how to study these suppressive soils have recently been summarized (Westphal, 2005).

Agronomic practices may have additional side effects on SCN reproduction. In the central and southern part of the north-central region, reproduction of SCN on winter annual weeds has been documented under field conditions (Creech et al., 2005). The impact of these non-soybean populations on damage thresholds and HG-type of field populations needs exploring.

Top research needs required to develop short-term management strategies (in no particular order)

a. SCN education and outreach for soybean producers (not a research need, but critical for short-term SCN management)
b. develop a quick test for SCN virulence (ability to reproduce on sources of SCN resistance)
c. Incorporate and combine newly identified resistance QTLs for SCN in commercially viable germplasm for development of soybean varieties with SCN resistance from a source other than PI88788 (not looking for more new sources of resistance)
d. develop standard methods of greenhouse screening of soybeans for SCN resistance
e. develop a centralized collection of SCN isolates and identify a standard set of isolates to be used for certain types of research
f. develop a standard and geographically broad (numerous states) system to test new chemical and biological technologies marketed for SCN management for efficacy
g. develop a technique to stain viable (live) SCN eggs
h. determine the impact of winter annuals on population dynamics and shifts of HG-types in field populations

Top research needs required to develop long-term management strategies (in no particular order)

a. investigate what makes a soil biologically suppressive
b. investigate the impacts of tillage on SCN reproduction
c. complete sequencing of the *H. glycines* genome
d. develop a genetic approach to the analysis of SCN
e. characterize the molecular response of soybean to infection (i.e. compatible and incompatible)
f. investigate mechanisms of nematode pathogenesis
g. develop novel plant resistance technologies using biotechnology
h. develop whole-genome methods of analysis of SCN (microarray)
i. develop proteomic methods of analysis
j. develop metabolomic methods of analysis
k. develop high-throughput methods of functional analysis (e.g. RNAi) of SCN gene products
l. develop high-throughput methods for subcellular localization
m. develop IPM strategies for the exploitation of natural SCN-suppressing phenomena
n. develop agronomic practices that delay pathotype development within SCN

Sudden Death Syndrome, *Fusarium verguliforme*

Current importance of the pathogen, distribution, incidence and epidemiological factors

Sudden death syndrome (SDS) was observed first in Arkansas in 1971 and is now widespread in the major soybean producing areas of the United States. The incidence and severity is reported to vary by state and by year. In many cases, SDS causes chronic problems that vary in intensity from asymptomtic to severe. Annual yield loss associated with SDS has averaged 573,539 x 10^3 metric tons during the period of 2003 to 2005. Yield loss estimates will likely increase as the disease becomes more common in the upper tier of the north-central states.

Although symptoms of SDS were reported in 1971, the cause of SDS was not clearly determined until the 1980's. The soilborne fungus *Fusarium solani f. sp. glycines* has been considered the causal agent of the disease, but research continues to refine the taxonomic classification of the causal agent. Currently, *Fusarium virguliforme* is proposed to replace *F. solani f. sp. glycines* in the U.S.

The fungus infects the roots and base of the stem but has never been found in above-ground plant parts. Foliar symptoms appear to be caused by one or more toxins that are produced by the fungus in the roots, and translocated to the foliage. Symptoms can appear as early as V4 but are most common from the early reproductive growth stages to pod-fill. Foliar symptoms start as scattered, interveinal, chlorotic spots that enlarge into chlorotic and necrotic streaks. Severely affected leaflets drop-off leaving the petiole attached to the stem. Infected roots show a tan to light brown discoloration of the cortex and xylem, with the pith remaining white. Blue masses of spores may be seen on the taproot under moist soil conditions.

The pathogen survives in debris and soil, and can also be isolated from the eggs and cysts of the soybean cyst nematode (SCN). The form of transport of the pathogen is not clear but movement with the SCN cysts has been suggested. Soil moisture and temperature have been shown to affect disease severity. In Indiana, symptoms often appeared following a weather front that brought cooler temperatures and rain. In Arkansas, cool, wet weather near the time of flowering was most closely associated with symptom development. In Illinois, differences in SDS severity among years correlated strongly with early season (June) rainfall and less so with late season (August) rainfall. In some areas, soil compaction has been associated with increase disease severity. In fields with moderate to high SCN population densities, SDS symptoms can occur earlier and severity is usually higher, especially in varieties that are susceptible to both the nematode and fungus.

Management of SDS is problematic and control tactics may not be effective across all soybean growing regions. The single best control measure for SDS is using resistant varieties. In maturity groups 3L – 5E, resistant varieties are readily available. In 2004 field trials, over 150 varieties were rated as resistant compared to susceptible checks for each maturity group. However, this level of success has not been attained in the earlier maturity groups. The relatively new emphasis by breeding programs for this disease, limited sources of resistance, and putative genetic variation within the causal agent may be contributing to the lack of resistant varieties in the earlier maturity groups.

Current fungicides have no or limited effectiveness, and various crop rotations have been inconsistent in preventing SDS outbreaks. Currently, variety selection, delayed planting, and cultural practices that improve drainage and reduce of SCN populations are most feasible to soybean growers.

Top research needs required to develop short term management strategies

Short-term research needs for SDS management fall into three main areas: i) developing resistant cultivars, ii) fungicide seed treatments, and iii) cultural practices.

From a grower perspective, the primary management tool is selection of resistant cultivars. Although sources of resistance to SDS have been identified, there is a pressing need for higher levels of resistance demonstrated under field conditions. A major challenge in evaluating SDS resistance is the inconsistency observed between greenhouse and field screening tests, and among fields at different locations. Screening methods need to be improved to improve the reproducibility and consistency of screening efforts, which coincides with research focused on the identification of the factors that influence disease incidence and severity. Screening for soybean resistance is particularly needed for earlier maturing groups (0-II) due to the more recent appearance of SDS in Northern states.

Seed treatments with chemical or biological agents may be useful for SDS management, at least until resistant varieties are released. Research is needed to test the efficacy of seed treatments to protect plants in early growth stages, and to clarify the importance of early infections compared to those occurring later in the season.

Cultural practices that improve soil drainage, such as tillage, or alter the soil biological environment, such as cover crops, have sometimes reduced SDS severity but with inconsistent results. Further research is needed to clarify the general or site-specific effectiveness of these practices.

Updated and reliable estimates of yield losses due to SDS are needed to determine cost effectiveness of management options.

Top research needs required to develop long term management strategies

Research on pathogen biology, disease etiology, and plant resistance mechanisms are critical for developing long-term management strategies for SDS.

At the pathogen level, a better understanding of phenotypic and genotypic pathogen variability is needed to support breeding efforts and to clarify sources of variable disease severity observed within fields and regions. Representative pathogen strains need to be collected and characterized at the regional and national level to serve as a research resource.

Disease etiology of SDS is still poorly understood and is an area with major research needs. Fundamental questions that need to be addressed include:

i) inoculum thresholds for infection and symptom expression
ii) how the pathogen overwinters and other key aspects of the disease cycle
iii) detailed characterization of the infection process, including timing of root penetration and colonization of cortex and vascular tissues
iv) the role of pathogen toxins on symptom expression, including timing and location of toxin production, and amount of toxin needed for symptom expression
v) the role of plant responses to infection, such as production of stress-induced toxins, on disease development
vi) the importance of root damage, caused by *F. virguliforme* or other root pathogens, on disease development.

These studies need to include comparisons of resistant and susceptible varieties to better understand sources of resistance to SDS. Methods to characterize and quantify toxin production in plants, and fungal mutants with knocked-out genes for toxin production, need to be developed to accomplish these studies.

Research is needed to better understand the impact of environmental factors on pathogen survival in soil and debris, on the timing of root infection, and on toxin production. Studies on the interaction between SDS and SCN are of critical importance, and interactions with other soil microorganisms antagonistic to SDS should also be considered. The impact of early versus late infections on yield reduction, and the impact of post-infection environmental conditions on disease development, needs to be clarified.

Research on plant resistance mechanisms, including mapping of resistance genes and microarray studies to determine genes turned on by SDS and SCN infection, is needed to support breeding efforts and to better understand disease etiology. The number of QTL's involved in SDS resistance needs to be determined and selected based on field resistance. Differences in QTL's for SDS and SCN resistance need to be compared, since breeders may need to incorporate both types of resistance into the same varieties.

STEM DISEASES

Brown Stem Rot, *Phialophora gregata*

Current importance, distribution, incidence

Brown stem rot (BSR) of soybeans, caused by the fungal vascular pathogen *Phialophora gregata*, is an economically important disease of soybeans in the north-central United States (Wrather and Koenning 2006). BSR is prevalent in 68 to 73% of the soybean fields of Illinois, Iowa, and Minnesota (Workneh et al. 1999). Brown stem rot can reduce seed size, seed number, yield and can causes premature defoliation. Yield losses of 10-30% occur commonly (Grau et al, 2004) There are two genotypes of *P. gregata* that differ in their ability to cause foliar symptoms on susceptible soybeans (Chen et al. 2000, Harrington et al 2003, Malvick et al 2003). Infection by genotype A of the fungus can result in mild to severe brown discoloration of the pith and severe foliar symptoms on susceptible soybeans and mild to no foliar symptom on resistant soybeans. In contrast, infection by genotype B (M) of the fungus causes mild to severe brown discoloration of the pith and mild to no foliar symptoms. Soybeans can be colonized by both genotypes of the fungus without manifesting stem or foliar symptoms (Tabor et al 2003a). Consequently, "hidden" loss due to BSR may frequently not be recognized. Infection by the soybean cyst nematode (SCN) can break resistance to BSR in most resistance sources and increase BSR (Tabor et al. 2003b,c)

Top research needs required to develop short-term management strategies

- Characterize resistance sources and cultivars to the two pathogen genotypes
- Determine whether infections without foliar or any symptoms, by both genotypes, result in yield loss
- Develop improved understanding of how various cultivars are affected by the interaction between SCN and BSR
- Determine whether foliar or seed-treatment fungicides have value in BSR management
- Understand the effect of both genotypes on seed quality
- Understand the pathogenic variability within each genotype of *P. gregata*

Top research needs required to develop long-term management strategies

- Improve understanding of environmental and field site influences on BSR development
- Improve understanding of how the BSR pathogen infects and colonizes different cultivars and how it physiologically affects the plants
- Further characterize the genes that confer resistance to BSR
- Pyramid resistance genes into cultivars
- New and better sources of resistance to BSR and to the BSR/SCN combination
- Determine if BSR interacts with other diseases or insect problems.

Sclerotinia Stem Rot, *Sclerotinia sclerotiorum*

Current Importance, Distribution, Incidence

Sclerotinia stem rot of soybean is a chronic to epidemic disease of soybean grown throughout the world (Grau et al., 2004). This disease was a locally severe problem in Michigan, Minnesota, and Wisconsin during the 1970's, but beginning in 1990, Sclerotinia stem rot became widespread in each of the Great Lakes States and by 1992, was prevalent throughout the North Central Region of the USA. Sclerotinia stem rot has progressed from a sporadic disease of localized importance, to an annual threat to soybean production throughout the upper North Central Region. Reasons for the sudden increase of Sclerotinia stem rot are not fully understood, but the unexpected outbreaks of the disease are possibly related to changes in cultural practices, changes in the genetic base of current soybean cultivars, and a high incidence of pathogen-infested seed.

Short-term Research Needs

- Determine how to improve the efficiency of natural and human mediated biological control of *S. sclerotiorum*.
- Ascertain combinations of row width and plant population that stabilize the performance of partially resistant soybean cultivars.
- Identification of soybean germplasm with levels of partial resistance that exceeds current germplasm.
- Research and methodology to combine resistance QTL in common soybean lines.

Long-term Research Needs

- Better understand the genetic basis of resistance to *S. sclerotiorum*
- Determine mechanisms of resistance.
- Enhance knowledge of etiology and pathogenesis.
- Improve understanding of variability of traits within populations of *S. sclerotiorum* that are relevant to pathogenesis.
- Basic studies to linking genotypes to phenotypes using gene expression on soybean microarrays when challenged with *S. sclerotiorum*.

Stem Canker/Diaporthe, *Diaporthe phaseolorum*

Current importance, distribution, incidence

Soybean stem health is an understudied area of soybean pathology. With the exception of white mold (Sclerotinia stem rot), other stem diseases are often overlooked or confused with climatic or seasonal changes in the growth and development of soybean. Stem canker of soybean is caused by *Diaporthe phaseolorum* var. *caulivora* (*DPC*, northern stem canker), or *D. phaseolorum* var. *meridionalis* (*DPM* southern stem canker). *D. phaseolorum* var. *sojae* (*DPS,* pod and stem blight) is another stem infecting member of the *Diaporthe*-*Phomopsis* complex, but is regarded as less yield-limiting. However, this is an assumption that is worthy of further investigation.

Stem canker occurs throughout the north central U.S. and Ontario, Canada.(Athow and Caldwell, 1954, Hilderbrand, 1954). During the early 1950's, northern stem canker was prevalent in the north central U.S., causing losses of up to 50%. The stem canker problem was solved by replacing susceptible varieties with those resistant to stem canker. However, the recent resurgence of stem canker in the north central region has not been explained. Furthermore, a high incidence of stem canker was observed in fields not planted to soybean for several years. This observation indicates more must be known on how the stem canker pathogen survives in the absence of soybean. Current loss estimates are projected at 125,000 tonnes per year. However, likely factors are associated with reduced tillage, shorten rotation systems and changes in soybean germplasm. Stem lesions typical of stem canker are observed on wilting and dying plants. However, stem lesions are not always present on plants exhibiting foliar symptoms thus raises questions related to causal agent or agents.

Top research needs required to develop short term management strategies

- Region wide assessment of susceptibility/resistance in current germplasms and varieties.
- Assessment of resistance/susceptibility of in current germplasms and varietis and plant introduction.
- Standardization and validation of inoculation techniques (field and greenhouse)
- To determine the standard method of inoculation for *D. phaseoloru*m var. *caulivor*a.
- Revisit the host range of *Diaporthe phaseolorum*.

Top research needs required to develop long-term management strategies

- Determine if stem canker is a specific disease with one causal agent, or a symptom with multiple causes.
- Determine the etiology of stem canker with focus on infection court and timing of infection and symptom development caused by the stem canker pathogen(s).
- Determine important sources of inoculum of the stem canker pathogen.
- Determine the mode of long-term survival of the stem canker pathogen
- Determine the genetic basis of resistance to the northern stem canker pathogen.
- Determine which forms of the stem canker complex are most yield-limiting and should be used in soybean breeding programs.
- Develop real time PCR methods to monitor pathogen activity and determine genetic relatedness among isolates of the pathogen.

SOYBEAN FOLIAR DISEASE COMPLEX

Current importance, distribution, incidence and epidemiology

Soybean foliage is infected by numerous fungi and bacteria, but relatively few have been considered yield-limiting in the north-central United States. Leaf -infecting pathogens of soybean are viewed differently in the southern U.S. Disease of relative importance are brown spot (*Septoria glycines*), Cercospora leaf blight and purple seed stain (*Cercospora kikuchii*), downy mildew (*Peronospora manshurica*), frogeye leaf spot (*Cercospora sojina*), powdery mildew (*Microsphaera diffusa*), soybean rust (*Phakospora pachyrhizi*), bacterial blight (*Pseudomonas savastanoi pv. glycinea*) and bacterial pustule (*Xanthomonas axonopodis pv. glycines*). Of this disease complex, brown spot, Cercospora leaf blight, and frogeye leaf spot are regarded as most problematic on an annual basis. Powdery mildew is quite sporadic in the northern part of the region and occasional outbreaks of bacterial pustule occur in the lower north-central region. Soybean rust remains an unknown, but merits respect. From 1999 to 2005, estimated yield loss due to fungal and bacterial diseases of foliage has ranged from 23.7×10^3 (2003) to 201×10^3 (2000) metric tons of grain per year. These loss estimates do not include losses caused by viruses, and are considerably lower compared to diseases of roots and stems. *Cercospora kikuchii*, *Peronospora manshurica*, and *Cercospora sojina* also infect seed and cause blemishes that impact on soybean grain quality.

The northern perception of leaf diseases may change for two reasons. First, there are numerous reports that foliar-applied fungicides result in increased soybean yield. Thus the relative importance may have been underestimated. However, data suggest that an economical yield response occurs about 33% of the time. Thus, prediction models are needed to guide growers on when to apply foliar fungicides. Second, soybean production in the north-central region is at risk due to the establishment of *Phakospora pachyrhizi* in the southern US.

Top research needs required to develop short-term management strategies

- Accurate yield loss estimates to determine merit of future research activities
- Determine effect of leaf infecting pathogens on traits associated with seed certification criteria
- Determine effect of leaf infecting pathogens on grain composition including protein and oil
- Characterize soybean commercial cultivars for reaction to leaf infecting pathogens
- Determine efficacy fungicidal active ingredients to specific leaf infecting pathogens
- Develop methods for rapid identification of leaf disease in field

Top research needs required to develop long-term management strategies

- Develop systems to predict the need for fungicide application to control the leaf disease complex
- Characterization of soybean germplasm for reaction to leaf infecting pathogens
- Transfer resistance to soybean lines with acceptable agronomic traits

VIRUS DISEASES

Current importance of pathogens, distribution, incidence and epidemiological factors.

In the north-central region, viral diseases of soybean are caused by a diverse group of pathogens which are dependent upon insect vectors for their dispersal. In years when vector populations are high, viral diseases can be widespread, leading to significant losses in yield and seed oil content and to seed discoloration that lowers crop value or makes the crop unsuitable for some markets. Because of the critical role of insect vectors in virus epidemiology, the emergence of viral diseases has paralleled recent increases in insect pests in soybean fields. For example, mild winters have allowed unprecedented overwintering populations of the bean leaf beetle (BLB) (*Ceratoma trifurcata*) that transmits *Bean pod mottle virus* (BPMV). Further, the newly introduced soybean aphid, *Aphis glycines*, transmits *Alfalfa mosaic virus* (AMV), *Soybean dwarf virus* (SbDV), and *Soybean mosaic virus* (SMV). Other viruses, such as *Tobacco ringspot virus* (TRSV) and *Tobacco streak virus* (TSV), have unexpectedly begun to spread further complicating the disease situation.

Top research needs required to develop short-term management strategies.

There is an active research community in the north-central region working to improve diagnostic capabilities, to identify and characterize emerging viruses and virus strains, and to identify virus vectors and reservoirs. In addition, research to determine roles for vector control in disease management and identification of soybean cultivars with good disease resistance or tolerance has begun. Current projects are sponsored by the North Central Soybean Research Project and various state soybean associations, but continued support is crucial. The current status of research and immediate research needs for specific virus diseases are outlined below.

- *Bean pod mottle virus* is the most common, widespread, and presently the most devastating viral pathogen of soybean in the NCR. BPMV incidence varies greatly among years and locations and is correlated with the size and distribution of BLB vector populations. Even though cultivars can differ in their response to the virus, no sources for complete resistance to the virus have been identified in soybean germplasm. Research objectives include
    - identifying perennial virus reservoirs
    - developing criteria for selecting partially resistant/tolerant cultivars
    - determining if insect resistance is useful for disease control
    - introgressing resistance from related *Glycine* species.

- *Soybean mosaic virus* is widely distributed in the region, but has a much lower incidence than BPMV. SMV is readily transmitted by soybean aphids and through seed. Research is needed to:
    - understand the role of seed transmission in disease epidemiology/etiology
    - explore the potential for incorporation and durability of identified resistance sources into commercial cultivars

- *Alfalfa mosaic virus* is prevalent in some areas of the NCR in some years. Like SMV, AMV is transmitted by soybean aphids and through seed.
    - Reservoirs for an apparent multitude of virus strains are unclear.
    - Accurate assessment of the distribution of the virus is hampered by a lack of robust serological detection systems which are, however, under development.
    - Some resistance to AMV has been identified in soybean germplasm, but it is virus strain specific and not well characterized.

- *Soybean dwarf virus* causes severe soybean yield losses in Japan and has been identified in Wisconsin and Illinois soybeans associated with heavy soybean aphid infestations. Like AMV, SbDV is prevalent in forage legumes in the NCR. Research is needed to:
    - characterize forage isolates of SbDV that are transmitted efficiently by soybean aphids
    - improve methods for screening so that soybean germplasm can be screened for SbDV resistance and tolerance

- *Tobacco streak virus*, which is transmitted by thrips, causes disease in some parts of region.
    - TSV diagnostics need to be improved so that low levels of virus in mature plants can be detected.
    - TSV resistant soybean lines should be developed and tested.
    - TRSV infections produce a damaging viral disease of soybean. The role of TRSV transmission through seed, and by leafhoppers and soybean aphids in disease needs to be investigated.

- Since soybean aphids were introduced in the late 90s they have spread throughout the soybean-growing regions of North America. The interactions among sources of resistance to soybean aphids and aphid populations need to be defined, so that aphid resistant soybeans can be developed. Impact of aphid resistance upon virus incidence needs to be measured. Aphid diversification and population structure in the north-central region needs to be defined.

Top research needs required to develop long-term management strategies.

The development of soybean lines resistant to viruses and their insect vectors is the most important long-term goal for management of soybean viral disease. Since resistance to some of the viruses may not exist in *Glycine max*, alternative approaches will be required, including wide crosses to closely related *Glycine* species and transgenic resistance, both of which are actively under development for BPMV. The production of new virus-resistant soybean lines, potentially resistant to multiple viruses, could be greatly enhanced by the development rapid approaches for the identification of virus resistance genes through gene-specific markers and/or other novel technologies, e.g., GFP-labeled viruses, VIGS (virus-induced gene silencing). Because soybean aphids are recent immigrants that are likely under diversifying selection in different regions of North America, continued genotypic and phenotypic characterization of both aphid and virus populations is needed.

For BPMV and SMV, chemical control manages the vector but not the disease. This coupled with environmental and economic concerns makes deployment of durable tolerance/resistance the top priority for disease management. However, basic knowledge of the interactions between viruses and soybeans is required but is missing to aid understanding and use of resistance. It is apparent that information on viral recognition determinants for soybean resistance genes, the responses of susceptible and resistant soybeans to virus infection, and the identification and/or construction of virus resistance genes for soybeans are compelling needs to achieve disease control. This information may lead to development of more global virus resistance in the crop.

SOYBEAN SEED PATHOLOGY

Current importance and scope

The value of soybean seed is on the rise. The popularity of herbicide-resistant varieties, plant variety protection, demand for specialty soybean varieties, and the need for elite genetics with resistance to SCN and other diseases are contributing to increasing soybean seed costs. Other transgenic traits will inevitably be implemented in soybeans, further shifting crop management costs from on-farm activities to the investment in seed. As a result, optimal soybean planting populations are being refined (reduced) (9), and there is a greater need for each seed to perform. Under these conditions, soybean seed quality is more important than ever, and the desire to protect the seed investment (with a seed treatment) is becoming more intense.

Seed pathology in soybeans involves numerous pathogens and various issues. Currently important issues can be considered in three categories:

1. Pathogens that affect seed quality (marketability or performance of seed)

   Bean pod mottle virus (BPMV) continues to affect soybean seed quality in terms of appearance; incidence of BPMV fluctuates but now is the most common virus in soybeans (4,6). It may also affect other seed quality parameters under some conditions, and some observations suggest that either the virus itself or its vectors predispose plants to infection by other seedborne pathogens. Seed infection by *Phomopsis* spp. was high in 2006 after a long period of relatively low incidence. The increase may have been associated with feeding by bean leaf beetles. During the 1980s soybean seed fields were often treated with the fungicides benomyl or thiophanate-methyl to protect seeds from infection by *Phomopsis* spp. This practice has largely been abandoned due to loss of fungicide registrations and lower incidence of infection. Recently, fungicides in the strobilurin class have been registered for soybeans and they are being applied to seed crops for reasons other than *Phomopsis* control. The potential impact of these applications on *Phomopsis* spp. and other fungi affecting seed quality and health are not clear.

2. Seed-transmitted pathogens that potentially cause economic losses in the planted crop or have phytosanitary implications

   Bean pod mottle virus is seed-transmitted (9,11) but it remains unclear under what conditions (if any) this aspect of the disease cycle is important. *Alfalfa mosaic virus* commonly infects soybeans (4) but its impact on yield and quality is undefined. It has been reported to be seed transmitted in soybean in Japan and Argentina (7,8), but it remains unclear under what conditions (if any) this aspect of the disease cycle is important. *Soybean mosaic virus* (SMV) is widely distributed in the region, but has a lower incidence than BPMV. SMV is readily transmitted by soybean aphids and through seed (5), but the role of seed transmission in disease epidemiology/etiology is unclear. *Tobacco ringspot virus*

(TRSV), long recognized as a damaging seed-transmitted viral pathogen of soybean (1,2), has remained at a relatively low incidence in recent decades. However, the disease caused by this virus (bud blight), has unexpectedly begun to spread and increase its incidence. The role of TRSV transmission through seed, in relation to spread by leafhoppers and soybean aphids is unclear.

Top research needs required to develop short term management strategies (in no particular order)

- Understanding the interactions among bean leaf beetles, BPMV, other seedborne pathogens, and seed quality / seed health
- Assessing the impact of currently available foliar fungicides on soybean seed quality and health
- Integrated studies to define the importance and interaction of SMV, AMV, and TRSV transmission through seed and by insect vectors
- Detailed studies on the impact of insecticidal seed treatments on soybean virus diseases
- Evaluation of recent optical sorting technologies for remediation of seed quality problems in soybean

Top research needs required to develop long-term management strategies (in no particular order)

- Development of strain-specific detection of seed-transmitted pathogens for epidemiological studies
- Evaluation of genetic and environmental factors that influence seed transmission
    - Virus strain
    - Host genetics
    - Soil microenvironment
- Method development for detection or estimation of soybean embryo infection by viruses

CULTURE COLLECTIONS

Fungal and oomycete culture collections are imperative for advancements in the understanding disease development but also in ascertaining disease management in host-pathogen systems. There are numerous public collections, e.g., American Type Culture Collection and Phytophthora collection at University of California (Riverside, Dr. Mike Coffey). However, these collections are not working collections. These are depositories for isolates used in research studies, first specimens found in a region and those of historical importance. A working collection is one where the both the aggressiveness (pathogenicity) and virulence pathotype are routinely screened and maintained through repeated inoculations and re-isolation from host tissues. Plant pathogens do not maintain their pathogenic traits in long-term culture or through series of subculturing, thus repeated inoculations and re-isolation are necessary to maintain their specific pathogenic traits.

Recently United Soybean Board/American Seed Trade Association and USDA funded a working soybean pathogen collection. This met with some success, but could have been expanded. In reality, these types of fungal collections were, in part, the service that Universities and ARS labs provided to both public and private sector for studies when public support for these facilities and services were high. Today, very few faculty have the luxury of hard funded technicians or students, thus collections are at risk. Two review publications, Ryan and Smith, 2004; and Kang et al., 2006; outline the dilemmas confronting plant pathologists, plant breeders and biologists in keeping and maintaining these extensive culture collections.

Standardized isolates are imperative for breeding development. Currently *Phytophthora sojae*, soybean cyst nematode, root knot nematode are all used widely by soybean companies for variety development. In addition, working collections of *Phialophora gregata, Fusarium virguliforme, Cercospora sojina* and now *Phakopsora pachyrhizi* are needed for continued development of soybean cultivars with resistance to brown stem rot, SDS, frogeye leaf spot and soybean rust, respectively. Isolates of each of these pathogens for breeding purposes require characterization for pathotype, and aggressiveness. Long and short term storage conditions are established for all of these pathogens, but facility and personnel costs to manage these collections are needed.

EXTENSION

Introduction

Agricultural extension services continue to adapt to changes in the agricultural sector, however, many challenges remain. Changes in pathogen population dynamics, technology (ex. internet), the agricultural landscape (bioeconomy, biofuels), invasive species, climate change, etc. could have severe negative economic impacts on soybean producers in the not so distant future. It is imperative that extension continues to meet these future concerns and remain an integral partner/leader in the management of soybean diseases in North America.

The delivery of extension information pertaining to soybean diseases needs to be conveyed to the soybean production sector on a timely and cost effective basis. New technologies such as the internet, online bulletins, and print on demand are examples of various vehicles that could assist in the transmitting of disease management information quickly and effectively. Although new technologies have promise and they must be integrated as a technology transfer tool we do run the risk of not reaching a considerable share of our audience by relying too heavily on the internet and other new technologies. A recent survey (Shaner, 2006) found that only about 20% of soybean growers surveyed accessed the internet directly.

Even if the technological infrastructure limitations in rural areas is addressed the need for print publications, on farm demonstrations, grower meetings and other forms of communication to reach our intended audience must continue to be developed, and delivered to growers on a “farm level”. The role of agricultural extension to “train the trainers” will continue to be an important delivery mechanism in the future since many producers receive disease management and other information through an intermediary, such as a crop consultant or agricultural products dealer. The role of these intermediaries will increase as farming becomes “more complex” and we must be involved in message delivery.

Websites

Technology has always played an important role in the field but with the advent of the internet, a new innovative technology transfer vehicle has emerged that has made the dissemination of disease management information easier. Although the internet has many benefits, its use does raise many concerns surrounding adoption of the information.

There are many examples of how agricultural internet websites in both the pubic and private sector have contributed to the disease management knowledge base available to producers. Some examples are the American Phytopathological Society sponsored Plant Health Network, state/university co-operative extension websites, North Central region state pest management newsletters, soybean commodity board websites, seed companies and many others.

The USDA sponsored **Pest Information Platform for Extension (PIPE)** and the **Plant Health Initiative** websites are examples of two innovative websites that transcend state and national borders. The information collected from the North American soybean rust “early warning system” sentinel plots are posted on the USDA soybean rust website (www.sbrusa.net). Information is presented in user friendly maps and commentaries. This “early warning” sentinel plot system in conjunction with education, monitoring, spore traps, prediction models, fungicides give producers the tools or weapons needed to track and combat this destructive disease and limit yield losses. Although the PIPE website began with soybean rust, other soybean pests such as soybean aphids, viruses have been included.
The Plant Health Initiative website developed by the North Central Soybean Research Program (NCSRP) with soybean check-off dollars is the main vehicle used to provide diagnostic tools, disease and pest

information, and agronomic information related to soybean diseases. The coverage in the disease section is adequate (basics, symptoms, scouting, agronomic impact, risk assessment, management and state links) for each disease included but needs to be expanded to include additional diseases addressed in this white paper. One of the challenges with this and any website is to keep information current. Some of the links for diagnostic tools need to be reviewed to be sure that they contain up-to-date information and are easy to use.

Geographical distribution surveys and monitoring: Sustainable soybean production in North America is constantly under threat from the many destructive soybean pathogens which can substantially reduce soybean yields. Unfortunately, threats from “new” invasive species will increase in the future and as we have with soybean rust, a considerable amount of fear can be associated with their spread.

Funding for general disease surveys has been difficult to obtain in the past even though disease surveys (yield loss, incidence, severity, population structure (races, pathotypes)) have proven to be irreplaceable and an effective tool in the management of many economically important soybean diseases besides having other benefits such as increasing awareness amongst producers, industry and consultants of these diseases. Local, state, regional or national surveys provides an opportunity for early disease detection in new areas which is critical and allows for targeted extension activities aimed at limiting or preventing dramatic losses in yield through the implementation of disease management strategies.

Understanding the pathogen population the geographical structure and distribution assists in detecting population shifts (increases or decreases), resistance or the development of new races/pathotypes. Population dynamics information not only assists both private and public breeders in soybean variety development but also allows for the deployment of soybean varieties containing effective resistance or tolerance genes into the appropriate areas.

Scouting networks: Resource limitations and the increased need for the documented geographical distribution of the major soybean diseases have led to some very innovative and cooperative approaches to the collection of this information. Although there are many examples two “scouting networks” will be discussed below.

a) PIPE - The threat of soybean rust has led to unparalleled international cooperation and partnerships. A comprehensive soybean rust “sentinel plot” monitoring program was developed in response to this very destructive invasive fungal pathogen of soybeans. This “early warning” sentinel plot system in conjunction with education, monitoring, spore traps, prediction models, fungicides give producers the tools or weapons needed to track and combat this destructive disease and limit yield losses. The sentinel plot system provides producers, extension, consultants and the soybean industry with an effective and successful decision support tool.

b) The Iowa Soybean Association provides partial funding for an innovative project to provide timely information for growers about crop diseases and pests. Through the On-Farm Network™, weekly field scouting reports are made from over 200 soybean and corn fields throughout the state and reported on the internet. Agronomists, extension agents and crop consultants cooperate to visit the same fields weekly, to provide current disease and insect findings and growth stage information. (View at http://isafarmnet.com/scouting/index.htm). The same scouting network approach could be adopted by other states and funded by state soybean boards. The information collected would provide good documentation for the geographical distribution survey.

Pathogen testing for variety trials: Soybean variety trials are held annually in many states to provide farmers, extension personnel and seed companies with agronomic information about soybean varieties submitted by private companies and public breeding programs. Often soybean checkoff dollars are used to help support the trials. Most of the trials include testing for a limited number of soybean pathogens.

Pathogen testing needs to be ongoing, rather than a single event, as pathogen populations and pressures change over time: The varietal information program for soybeans (VIPS) website (www.vipsoybeans.org/) lists trial results for Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Ohio and Wisconsin, including disease ratings taken. Soybean cyst nematode (SCN), Phytophthora root rot, and Sclerotinia stem rot (SSR) are the most commonly rated diseases in field trials. Soybean sudden death (SDS), brown stem rot (BSR), soybean mosaic virus (SMV) and green stem are rated in several states. Information that stresses the benefits of using resistant soybean varieties, such as dollars saved by growers in using resistant varieties, environmental benefits, decreased fungicide use, and reduced worker exposure to pesticides needs to be emphasized, to promote greater use of resistant varieties. Information collected is available on state websites, the Plant Health Imitative Website and in brochures. A good example of a brochure that stresses many of these benefits is produced by the National Soybean Research Laboratory and can be found at http://www.nsrl.uiuc.edu/news/nsrl_pubs/pathologybrochure.pdf .

Fact Sheets/ "dashboard diagnostics": Although most states have fact sheets, there are benefits to developing regionally-based extension materials. Coordinated regional pieces provide consistent information. Within the North Central Region, there are university researchers with expertise in all the major soybean diseases. Of necessity, researchers develop specializations in the particular disease(s) of importance in their states, and do not have the resources to be "experts" on all diseases. Expertise can be shared across the region to provide more consistent information for extension clients. Most states have experienced staffing cuts in extension and have fewer dollars to produce extension materials. Regionally-based materials help conserve dollars that would be spent for development of individual state publications. A basic fact sheet could be created for each disease and designed to allow room to add state-specific information and a state logo. These basic pieces could be placed on the Plant Health Initiative website, and made available to extension specialists and educators to customize for their state, and allow the fact sheet to be printed on demand. It is important to develop materials in formats (e.g. print, cd, video) that can be distributed to growers. Although the internet provides access to a great deal of extension information and has become the preferred means of disseminating information, not all of our clients access the internet.

Need for growers to sample for SCN and other soybean diseases: Soybean cyst nematode is often described as a "silent yield robber" and for very good reasons. In many cases, farmers are not even aware of their losses until it is too late and the SCN populations have become well established in the field. Once SCN reaches this point it will continue to have long term yield implications on the farm. One thing about SCN is that regardless of the year, unless it is managed (rotations, resistant varieties, etc) SCN will steal yield every year.

It is these hidden costs associated with SCN infection that is of great concern and is not appreciated. SCN symptoms are often confused with other common problems such as nutrient deficiencies, chemical injury, soil compaction, drought, flooding or root rots. These symptoms are more pronounced when soybeans are under stress from drought, soil compaction, aphids, low soil fertility or other stresses. Being able to distinguish SCN from these other problems is imperative to limiting further losses from this disease which has become the number one yield robbing disease in the North Central Region - with annual losses estimated at 48 million bushels.

Most states in the North Central Region offer soil testing for SCN, and testing for SCN is often funded by state soybean boards using check-off dollars. Testing of grower fields and determination of the HG types needs to be a continuing priority especially since new SCN (HG-Types) populations are developing in region which are able to infect soybean varieties containing the SCN resistant gene (PI 88788). The ramifications of this develop are new SCN resistance genes (such as Peking) need to be incorporated into soybean varieties for the region. Fortunately, more SCN varieties with new sources of resistance are being released but future extension efforts need to keep SCN as well as other soybean diseases front-and-center in producer minds.

Information technology transfer to the private sector: Developing strategic partnerships between public extension and the private sector can assist in reducing soybean disease losses in the region. The role of agricultural extension to “train the trainers” will continue to be an important delivery mechanism in the future since many producers receive disease management and other information through an intermediary, such as a crop consultant or agricultural products dealer. The role of these intermediaries will increase as farming becomes “more complex” and we must be involved in message delivery trough the private sector. Partnering with the agricultural private sector can expand our reach to those producers that rely on the private sector as their primary information source. It is critical though that these partnerships are “inclusive” and available to all private sector partners and not a select few to maximize message delivery and not be viewed as competition to the private sector. Strategic partnerships with the private sector can be a cost effective technology vehicle. It can also fulfill a primary need of extension – not only reaching as many producers as possible but having producers use the information pertaining to soybean disease management.

On-farm demonstration needs (strip trials): Demonstration plots provide opportunities for technology transfer related to important aspects of disease management. Small plot trial results need to be validated to field scale through the use of on-farm strip trials. Translating research from small research plots to field scale plots done in cooperation with extension educators and growers increases grower confidence in results. For example, the Iowa Soybean Association provides funding for an On-Farm Network™ of farmers who conduct strip trials in their own fields to evaluate production practices and pesticides on a larger scale. Their fungicide trials look at yield effects but do not evaluate for disease incidence or severity. Adding disease ratings would be useful to determine efficacy of products. Extension pathologists or agents could work with growers to provide disease ratings or training on how to recognize and rate diseases.

Extension Summary

Soybean disease management extension is constantly under pressure and changes in pathogen population dynamics, technology (ex. internet), the agricultural landscape (bioeconomy, biofuels), invasive species, climate change, etc. will assure that these challenges will continue if not become more complex in the future. Agricultural extension has met these challenges in the past by developing disease management information and distributing this information through various technology transfer mechanisms both new and old. As technology and disease management strategies advance they need to be incorporated into extension delivery and recommendation process. We must be cautious not to rely only on new technological advances since success of these technologies as a extension vehicle is dependent on the willingness of producers and the agricultural sector to adopt these new technologies. Extension must continue to be “people-oriented, knowledge-based and problem focused” in order to respond to future soybean disease challenges.

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