Accepted for publication 27 October 2009. Published 25 January 2010.

Effect of Diseases on Soybean Yield in the Top Eight Producing Countries in 2006

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Wrather, A., Shannon, G., Balardin, R., Carregal, L., Escobar, R., Gupta, G. K., Ma, Z., Morel, W., Ploper, D., and Tenuta, A. 2010. Effect of diseases on soybean yield in the top eight producing countries in 2006. Online. Plant Health Progress doi:10.1094/PHP-2010-0125-01-RS.

Abstract

The objective of this project was to compile estimates of yield loss in soybean [*Glycine max* (L.) Merr] to diseases in the top eight soybean-producing countries in 2006. The purpose was to provide information needed by local and world agencies to allocate funds for research and to help scientists focus and coordinate research efforts. Methods used by plant pathologists to estimate yield loss to diseases in these countries included systematic field surveys, cultivar trials, diagnostic clinic records, personal observations, and questionnaires sent to crop consultants and extension staff. The 2006 harvest of soybeans in the top eight soybean-producing countries was reduced an estimated 59.9 million metric tonnes (t) by diseases according to results of the current study. Soybean rust, caused by *Phakopsora pachyrhizi*, reduced yield in all these countries except Canada in 2006, and the total was more than any other. Next in decreasing order of total yield loss were soybean cyst nematode, brown spot, seedling diseases, anthracnose, and charcoal rot.

Introduction

The total soybean production for the world during 2006 was 220.4 million t (5). The top eight soybean-producing countries were the U.S. (83.4 million t), Brazil (57.0 million t), Argentina (40.5 million t), China (16.4 million t), India (7.0 million t), Paraguay (3.6 million t), Canada (3.16 million t), and Bolivia (2.0 million t). These countries produced about 97% of the world supply for 2006.

High yields are critical to soybean producer profit margins, even during periods when soybean prices are high. Unfortunately, yields in major soybean producing countries have been suppressed by diseases in the past (6), and income derived from this crop has been less than optimal. This financial loss is important to rural economies and to economies of allied industries.

Research must focus on management of diseases that cause extensive losses, especially when funds are limited. The objective of this project was to compile estimates of soybean yield losses to diseases in the top eight soybean-producing countries for the 2006 harvested crop. The goal was to show the extent of yield loss to help local and world agencies allocate funds for research and to help scientists focus and coordinate research efforts.

Estimates of Yield Loss Due to Diseases

Methods used by plant pathologists to estimate yield losses to diseases in these countries were based on systematic field surveys, cultivar trials, diagnostic clinic records, personal observations, and questionnaires sent to crop consultants and extension staff (6). Most of the individuals used several of these methods and consulted with their colleagues to develop their estimates. Losses in the United States were compiled from estimates submitted by plant pathologists in each state. Yield losses were based on estimates of yield in the absence of disease. Estimates for each country were specific for the causal organism or the common name of the disease as listed by Hartman et al. (1).

Effects of Environment and Production Practices

Soybean in most regions of these eight countries is grown under conditions that favor the survival of pathogens and development of disease. Soybean yield losses to diseases varied due to weather in most countries. Charcoal rot was most severe in the dry areas of Argentina, Bolivia, Brazil, India, Paraguay, and the United States. Cool, wet weather at planting enhanced seedling disease in the United States and Canada. Wet weather at bloom stage enhanced Sclerotinia stem rot in the United States and Canada, enhanced Rhizoctonia aerial blight in India, and enhanced anthracnose in the central and northern portions of Brazil and Paraguay. Wet weather at harvest enhanced Phomopsis seed decay in Canada. The severity of rust was related to the frequency of rain in Argentina, Bolivia, Brazil, China, India, Paraguay, and the United States.

Factors that have contributed to the escalation of disease problems in these countries include planting poor quality seed, increased monocropping of soybean, and increased use of crop management practices such as no-tillage which favor pathogen survival and the increase of inoculum. Phomopsis seed decay was more severe in early-maturing cultivars planted earlier than normal in the United States and Argentina, but Sclerotinia stem rot was less severe in Argentina due to this practice. Rust was more severe on late than early planted soybean in Paraguay due to more favorable weather for it late in the growing season.

Most soybean diseases were managed by resistant cultivars and fungicides. Because the use of these resources remains incomplete and limited to only certain diseases, soybean production continues to suffer losses to diseases. Soybean yield losses to rust have been reduced very little by planting resistant and tolerant cultivars in China and parts of South America because the resistance has not been durable. Yield losses to this disease have been reduced by application of fungicides to soybean foliage in China, Argentina, Bolivia, Brazil, and Paraguay. The effects of fungicides on rust incidence and severity in the United States vary among fungicides and time of application (4).

Argentina. Nearly 80% of soybean production in Argentina was from the central and Pampean region (provinces of Buenos Aires, Córdoba, La Pampa, San Luis, and Santa Fe), 9.5% was from the northwestern region (provinces of Catamarca, Jujuy, Salta, Santiago del Estero, and Tucumán), and 10.5% was from the eastern region (provinces of Corrientes, Chaco, Entre Ríos, Formosa, and Misiones).

The number and severity of infectious diseases have increased steadily, particularly since the early 1990s (3). Yields for the soybean crop harvested in 2006 were suppressed by several diseases (Table 1). Seedling diseases caused by various pathogens such as *Fusarium* spp., *Pythium* spp., *Rhizoctonia solani*, and *Phytophthora sojae* were only important in early plantings in the central and Pampean region.

Table 1. Estimated reduction of soybean yields (thousand metric tonnes) due to diseases in the top eight soybean-producing countries in 2006.

Disease	Argen -tina	Bolivia	Brazil	Canada	China	India	Para- guay	USA	Total
Anthracnose	45.3	Tr[w]	220.0	0	1663.5	117.6	0.3	492.9	2,539.6
Bacterial diseases	22.6	Tr	130.0	Tr	570.3	19.6	0	101.5	844.0
Brown spot	1176.5	Tr	340.0	0.8	2186.3	19.6	0.1	536.6	4,259.9
Brown stem rot	22.6	0	40.0	3.3	998.1	0	0	497.5	1,561.5
Charcoal rot	905.0	500.0	360.0	1.6	0	39.2	1.6	697.6	2,505.0
Downy mildew	0	Tr	50.0	1.6	1996.2	0	0	147.4	2,195.2
Frogeye leaf spot	22.6	Tr	40.0	0.3	0	19.6	0	345.1	427.6
Fusarium root rot	0	Tr	40.0	19.6	1615.9	19.6	0	169.1	1,864.2
Phomopsis seed decay	45.3	0	130.0	16.3	95.1	0	0	122.0	408.7
Phytophthora root and stem rot	67.9	0	Tr	26.1	760.5	0	0	1464.2	2,318.7
Pod and stem blight	181.0	0	0	11.4	95.1	19.6	0.1	208.3	515.5
Powdery mildew	0	Tr	0	0	0	0	0	0	0
Purple seed stain & Cercospora leaf blight	1086.0	Tr	720.0	0.3	0	19.6	0.7	85.2	1,911.8
Rhizoctonia aerial blight	0	0	300.0	0	1188.2	39.2	0	12.5	1,539.9
Root-knot and other nematodes[x]	22.6	Tr	260.0	7.1	2186.3	0	0.4	215.5	2,691.9
Sclerotinia stem rot	135.7	Tr	200.0	4.9	1520.9	0	0	362.0	2,223.5
Sclerotium blight	0	0	58.0	0	0	156.9	0	5.2	220.1
Seed diseases	45.3	0	70.0	16.3	1188.2	0	0.1	18.5	1,338.4
Seedling diseases	45.3	Tr	82.0	89.7	2043.8	19.6	0	1085.3	3,365.7
Soybean cyst nematode	22.6	0	520.0	97.8	3184.4	0	0	3368.1	7,192.9
Soybean rust	45.3	2000.0	4720.0	0	6368.9	78.4	1.9	24.5	13,239.0
Stem canker	0	Tr	0	11.4	0	0	0	211.7	223.1
Sudden death syndrome	769.3	0	320.0	16.3	0	0	0	743.4	1,849.0
Virus diseases[y]	45.3	Tr	100.0	9.8	1568.5	196.1	0	202.7	2,122.4
Other diseases[z]	45.3	500.0	0	26.1	1948.7	58.8	0	0	2,578.9
Total									59,936.5

[w] Tr = trace.

[x] Other nematodes were lance, lesion and reniform in Brazil; primarily lesion as well as lance, sting, and stubby root in Canada; and lance, lesion, reniform, sting and stubby root in the United States.

[y] Virus diseases were soybean mosaic, alfalfa mosaic, peanut mottle, tobacco streak, cucumber mosaic and bean common mosaic in Argentina; cucumber mosaic in Bolivia; mungbean yellow mosaic, soybean mosaic and peanut bud necrosis in India; and soybean mosaic, bean pod mottle, tobacco ringspot and peanut mottle in the United States.

[z] Other diseases were target spot in Argentina and Bolivia, Rhizoctonia root rot in Canada, grey spot in China, and Myrothecium leaf spot and target spot in India.

Brown spot, caused by *Septoria glycines*, was the most prevalent soybean disease during the vegetative stages of crop development during 2006. It was also important in the late reproductive stages, causing premature senescence.

Phomopsis seed decay, caused by *Phomopsis* spp., and purple seed stain, caused by *Cercospora kikuchii*, were variable and influenced primarily by environmental conditions during the late soybean reproductive stages. These pathogens were more common in the seed of early-maturing cultivars and early-planted fields.

Charcoal rot, caused by *Macrophomina phaseolina*, was the most prevalent disease affecting roots and lower stems in the 2005-2006 growing season, although at lower levels than observed in the previous three growing seasons. Warm and dry conditions prevailed in several provinces during the soybean reproductive stages, and these conditions enhanced charcoal rot.

Sclerotinia stem rot, caused by *Sclerotinia sclerotiorum*, was regarded as the most important soybean disease until the late 1990s (6), and yield losses in some fields reached 55%. However, the impact of this disease has declined due to farmers planting earlier and planting early maturing cultivars. Incidence of this disease in southeastern Buenos Aires was higher in 2005-2006 than in the two previous growing seasons.

Sudden death syndrome, caused by *Fusarium virguliforme*, has gradually increased in importance and has become one of the most destructive diseases. Sudden death syndrome was present in most regions at higher levels during 2006 compared to previous seasons. It reduced yield up to 14% in some fields in the Córdoba Province.

Soybean rust, caused by *Phakopsora pachyrhizi*, was first detected during the 2005-2006 growing season in the provinces of Misiones and Corrientes in the northeastern part of the country. It was soon detected on soybean in northwestern Argentina in the province of Salta in mid-February, and then in the provinces of Tucumán and Santiago del Estero by the end of February (3). In this region, the disease appeared earlier than in previous seasons, and reached severity levels not observed before. However, since most soybean fields were treated with fungicides, the impact of the disease on yield was minimal. Soybean rust did not develop in the eastern and central provinces until the end of March or April when seed filling was mostly complete.

Soybean cyst nematode, *Heterodera glycines*, and root-knot nematode, *Meloidogyne incognita* and *M. javanica*, are the most important nematodes that affect soybean in Argentina. Prevalence of soybean cyst nematode in central Argentina has remained at similar levels since the late 1990s; however, there has been a decrease in population levels in recent years. Field surveys in Northwestern Argentina have indicated the occurrence of HG types 2.5.7 and 5.7. Root-knot nematodes were detected in several provinces of central and northwestern Argentina.

Bolivia. The most damaging diseases in Bolivia were soybean rust, target spot, and charcoal rot (Table 1). Other diseases caused by fungi, bacteria, viruses, and nematodes were observed, but none were believed to suppress soybean yield.

Soybean rust was the most damaging disease of soybean. It was first identified in 2003, when it reduced soybean yield up to 65% in some fields. Overall, yield losses to soybean rust in Bolivia have varied among years: 27% in 2004/2005, 53% in 2005/2006, and 40% in 2006/2007. Since all soybean cultivars are susceptible to this disease, farmers have learned to monitor the health of their crop closely and apply fungicides two to three times for management of rust.

Target spot, caused by *Corynespora cassiicola*, spread throughout Bolivia just a few years ago, and this may be due to entry of infected soybean cultivars from Brazil, Paraguay, and Argentina. Many of these cultivars are susceptible to this disease which farmers are now managing with applications of foliar fungicides for control of soybean rust.

Charcoal rot reduced yield more than any single disease except rust. Yields were reduced by as much as 30% in many fields during 2006. Some farmers were expecting yields of 3.0 to 3.5 t/ha, but production was only 2.2 to 2.5 t/ha because of charcoal rot.

Brazil. About 60% of the soybean in Brazil is in the north central region in states of Bahia, Goiás, Minas Gerais, Maranhão, Mato Grosso, Mato Grosso do Sul, Piaui, and Tocantins. The remaining soybean is produced in the southern states of São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul where diseases cause less damage compared to the northern states.

Soybean rust caused more yield losses in Brazil than any other disease in 2006 (Table 1). It has spread over the entire country, and disease severity is related to the frequency of rain. Studies with fungicides, cultural practices, and varietal tolerance indicate that yield losses to soybean rust were greater than 60% in some fields. The constant presence of inoculum provided by planting soybean nearly every month of the year and availability of other hosts make rust management difficult.

Some diseases were restricted to certain regions: bud blight in the state of Paraná; brown stem rot, caused by *Phialophora gregata*, in the states of Rio Grande do Sul and Santa Catarina; Rhizoctonia aerial blight in Maranhão, Goiás, Mato Grosso, and Piauí; and Sclerotium blight, caused by *Sclerotium rolfsii*, and Rhizoctonia damping-off in the states of Paraná, São Paulo, and Rio Grande do Sul. Sclerotinia stem rot was a major disease in Goiás, Minas Gerais, and Sáo Paulo, but it was minor in Paraná, Santa Catarina, and Rio Grande do Sul.

Anthracnose, caused by *Colletotrichum* spp., and pod and stem blight, caused by *Diaporthe phaseolorum* var. *sojae*, have frequently been responsible for severe losses in some areas of the rainy central and northern portions of Brazil. When severe, these diseases may cause complete pod abortion or suppress seed value by reducing seed germination. However, pod and stem blight did not reduce soybean yield in 2006.

Brown spot and purple seed stain, caused by *C. kikuchii*, are less important since fungicides are routinely applied for rust management.

Charcoal rot was responsible for significant yield reductions in the drought-prone southern states; Paraná, São Paulo, Rio Grande do Sul, southern Mato Grosso do Sul, eastern Bahia, Tocantins, and northern Goias. This disease has reduced yield up to 50% where drought occurs in January. When abundant rainfall follows drought in January, plants weakened by charcoal rot become more susceptible to foliar diseases.

Yield losses to sudden death syndrome and Phytophthora root and stem rot have been of minor importance in the last few years.

Yield losses to soybean cyst nematode have increased during the last few years, and races 1, 2, 3, 4, 5, 6, 9, 10, and 14 have been detected in the central region. Root-knot nematodes, *M. incognita* and *M. javanica*, are widely distributed and frequently cause substantial yield reductions.

Canada. Soybean production in Canada was one of the highest on record in 2006 due to above average precipitation and temperatures. The primary yield limiting diseases in 2006 were: soybean cyst nematode; early season seedling diseases; late season root diseases caused by *Phytophthora sojae*, *Rhizoctonia solani*, and *Fusarium* spp.; sudden death syndrome; pod and stem blight; and Phomopsis seed decay (Table 1). Downy mildew, caused by *Peronospora manshurica*, was apparent in many areas, but the overall impact on yield was minimal. Soybean rust was not found in Canada in 2006.

The primary yield limiting soybean disease in Canada continues to be soybean cyst nematode. It was initially confirmed in southwestern Ontario in 1988, and it has spread extensively. In 2006, yield losses due to this nematode were estimated at 40% in some fields.

Cool, wet conditions in May 2006 resulted in 5% of the soybean crop being replanted due to emergence problems caused by early season seed rots, seedling blights, and/or root diseases especially on heavier clay soils. *Pythium* spp., *Phytophthora sojae*, *Fusarium* spp., and *Rhizoctonia solani* were most often associated with early-season emergence problems.

Yield losses to late season root diseases caused by *Phytophthora sojae*, *Fusarium* spp., and *Rhizoctonia solani* were greater in 2006 than previous years due to wet, cool weather. Yield losses to these diseases were only surpassed by soybean cyst nematode and early season seedling diseases. Phytophthora stem and root rot has been a problem since the 1960s and remains one of the most destructive diseases of soybeans. Fusarium root rot and Rhizoctonia stem and root damage have increased over the past decade primarily due to the increased frequency of soybean cropping and insufficient genetic resistance in commercial cultivars. Yield reductions to these diseases have been as high as 20% in some fields.

Losses from sudden death syndrome, brown stem rot, and stem canker caused by *Diaporthe phaseolorum* var. *caulivora* were noticeable in late July and August, and all three diseases have increased over the past decade in southwestern Ontario. The favorable environmental conditions in 2006 also resulted in Sclerotinia stem rot in many fields.

Leaf diseases such as frogeye leaf spot caused by *Cercospora sojina*, downy mildew, and powdery mildew caused by *Microsphaera diffusa* are usually of minor economic importance, which was the case in 2006. The only leaf disease to impact yields was brown spot, which reduced yield up to 10% in fields infected early in the season.

Adverse weather delayed harvest during 2006, and this contributed to an increase in Phomopsis seed decay and pod and stem blight in many areas of southwestern Ontario, especially the Niagara region. These diseases lowered soybean seed quality and in some cases the price farmers received for their crop, especially soybean for the identity preserved market.

China. Soybean has been grown in China at least 5000 years and is the most important source of edible oil and the major processing material for supplementary nutritious foods in China.

Soybean rust caused more yield loss in China than other diseases in 2006 (Table 1). It has reduced yield up to 50% in areas during high rainfall. The severity of rust in a particular region is related to the amount of inoculum available, the resistance of soybean cultivars planted, the growth stage of the plants when infected, and environmental conditions. Climatic factors such as, rainfall, cloud cover, dew period, and fog are important factors in the development of rust epidemics.

Rust is now managed somewhat in China by planting resistant soybean cultivars such as Zhong Dou 19, You 84-87, Zao Chun 1, Chiu Dou 1, Pingnan Dou, Zhang Zi Wu, Yushan Chingpi Dou, and Liu Dou 1. The resistance of these cultivars has not been very durable. Farmers also managed rust with fungicides, spring instead of autumn planting to avoid climatic conditions suitable for rust, planting later than normal, and by furrow rather than overhead irrigation.

India. Soybean is the main oil seed crop in India. The state of Madhya Pradesh, known as the soy state of India, produces about 55% of total production followed by Maharashtra (30%), Rajasthan (9%), Karnataka (2%), Chhatisgarh (1%), Andhra Pradesh (1%), and other states (2%).

About 35 diseases have been identified on soybean in India; 14 of these are important based on the magnitude of yield loss. The most yield losses in 2006 were caused by viruses, Sclerotium blight, anthracnose, rust, charcoal rot, and Rhizoctonia aerial blight (Table 1). A few diseases were distributed throughout all areas of the country while others were restricted to specific regions. Other diseases such as Myrothecium leaf spot, frogeye leaf spot, target spot, and brown spot reduced yield, but these do not occur regularly or only occur in small areas.

Soybean mosaic can be found in almost all soybean growing areas of India but usually in low to moderate intensity. A few cultivars with good resistance to this virus have been developed. Yellow mosaic, caused by Mung bean yellow mosaic virus, is a serious pathogen of soybean in the states of Uttarakhand, Punjab, Haryana, Madhya Pradesh, Uttar Pradesh, Rajasthan, Delhi, and Karnataka. Since no cultivars have adequate resistance to this virus, yield losses have been a serious problem in India. Indian bud blight, caused by peanut bud necrosis virus, is known to occur in the states of Maharashtra, Karnataka, Madhya Pradesh, Rajastahn, Delhi, and Chattisgarh. It is different than bud

blight which is caused by tobacco ring spot virus in other countries. Peanut bud necrosis virus has reduced soybean yield up to 80% in a few fields. Cultivars with moderate to good resistance to this virus are not available.

Sclerotium blight is one of the important diseases of soybean in India where it has reduced yield up to 40% in some areas. Seedling death due to girdling near the hypocotyl may appear 15 days after emergence.

Soybean rust is one of the worst soybean diseases in India and may reduce yields up to 100% depending on the time of infection, variety planted, and climate. Initially, soybean rust was restricted to the northeastern states of India and the hills of Uttar Pradesh and West Bengal prior to 1977 and caused little loss of soybean yield. Around 1993, it spread to other areas such as Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Andhra Pradesh, Himachal Pradesh, Tamil Nadu, and Kerala. It usually develops in India from the third week of July to the last week of September. This pathogen survives on volunteer and winter-sown soybean in southern India and then spreads to soybean in more northern areas during the rainy season.

Charcoal rot has accounted for more yield loss in India since 2004 due to erratic rainfall and greater periods of drought. It has caused the most damage to soybean in the major soybean states of Madhya Pradesh, Maharashtra, Rajasthan, and Karnataka. Yield losses have been as high as 77% in some fields.

Rhizoctonia aerial blight develops most often during periods of high rainfall predominantly in Uttarakhand, Chhatisgarh, and Madhya Pradesh. It has caused extensive yield loss especially in Madhya Pradesh.

Anthracnose occurs regularly in Delhi, Uttarakhand, Himachal Pradesh, Madhya Pradesh, and Rajasthan. This pathogen can attack soybean from early seedling stage to maturity. It reduces yield by causing pod blight in various parts of India.

Paraguay. Soybean is one of the most important crops in Paraguay, and the planted area has increased since the 1990s. Much of the pastures have been converted to fields for growing soybean due to its high price and economic return. The impact of diseases on soybean yield in Paraguay was especially high for the crop harvested during 2006 (Table 1). Increases in use of no-tillage production and the monoculture of soybean have increased disease incidence and severity.

Late-season leaf diseases caused primarily by *Cercospora kikuchii* and *Septoria glycines* reduced yield somewhat in 2006. These diseases have suppressed soybean yield up to 15% in some fields in previous years.

Stem canker, caused by *Diaporthe phaseolorum* var. *meridionalis*, became one of the most serious diseases on soybean following the first outbreak in the fall of 1992, when it reduced yield up to 50% in some fields. The effect of stem canker on soybean yield has declined recently and caused no reduction in yield in 2006 due to planting of resistant and tolerant cultivars.

Soybean rust was first confirmed in Paraguay during the fall of 2001, and yield losses were as high as 60% in some fields. Farmers have planted rust resistant cultivars, but resistance was not durable due to variability in the pathogen. Yield losses were greater in late-planted compared to early-planted soybeans because the late-planted crop reached R5 (beginning seed development stage) when air temperatures and humidity were more suitable for rust.

Charcoal rot has reduced soybean yield in Paraguay, but incidence and severity are erratic and favored by drought. It was an important disease in 1996, 2001, 2005, and 2006 when the crop was stressed by drought.

Yield losses due to root-knot nematodes have occurred in some areas. Soybean cyst nematode has not been a widespread problem.

United States of America. The greatest losses of yield to disease in the United States during 2006 were caused by soybean cyst nematode (SCN), followed by Phytophthora root and stem rot, seedling diseases, sudden death syndrome, and charcoal rot (Table 1).

The estimated total loss of yield to SCN increased from 1996-1998 and then began a general decline to 2006 (8). This may be due to greater farmer awareness of the problem because of soybean farmer check-off funding for the

Soybean Cyst Nematode Coalition, increased testing of field soils for the nematode, and greater use of crop rotation and resistant cultivars.

Phytophthora root and stem rot ranked second among diseases that reduced yield. Yield losses to this disease have been about the same from 1996 to 2006, with annual totals near 1.46 t (8).

Seedling diseases caused by *Rhizoctonia solani*, *Pythium* spp., *Fusarium* spp., and *Phomopsis* spp., ranked third among diseases that reduced yield during 2006. Yield losses to these diseases were greater in 2004, 2005, and 2006 when cool, wet weather persisted after planting (8).

Sudden death syndrome ranked fourth among diseases that reduced yield. Yield losses to it occurred most often in Iowa, Illinois, and Indiana and did occur in Arkansas, Missouri, Tennessee, Kentucky, Minnesota, and Wisconsin some years (7,9,10).

Charcoal rot ranked fifth among diseases that reduced yield and was most prevalent in Arkansas, Illinois, Indiana, Kansas, Kentucky, Missouri, Mississippi, and Tennessee (7,8,9,10).

Soybean rust was first detected in the United States during late-fall of 2004, but it did not suppress yields (7). Soybean rust did reduce yield in Georgia and South Carolina during 2005, and reduced yields by 7347 t in Alabama, 2721 t in Georgia, 7891 t in Louisiana, and 1633 t in North Carolina in 2006 (2).

Acknowledgments

This work was supported by the Missouri Agriculture Experiment Station, the United States Soybean Farmer Checkoff through the United Soybean Board and the Ontario Soybean Growers. The authors thank Joyce Elrod for her efforts in this project and thank God for guidance.

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