Research

Soybean Yield Loss Estimates Due to Diseases in the United States and Ontario, Canada, from 2010 to 2014

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Abstract

Annual decreases in soybean (*Glycine max* L. Merrill) yield caused by diseases were estimated by surveying university-affiliated plant pathologists in 28 soybean-producing states in the United States and in Ontario, Canada, from 2010 through 2014. Estimated yield losses from each disease varied greatly by state or province and year. Over the duration of this survey, soybean cyst nematode (SCN) (*Heterodera glycines* Ichinohe) was estimated to have caused more than twice as much yield loss than any other disease. Seedling diseases (caused by various pathogens), charcoal rot (caused by *Macrophomina*

phaseolina (Tassi) Goid), and sudden death syndrome (SDS) (caused by *Fusarium virguliforme* O'Donnell & T. Aoki) caused the next greatest estimated yield losses, in descending order. The estimated mean economic loss due to all soybean diseases, averaged across U.S. states and Ontario from 2010 to 2014, was \$60.66 USD per acre. Results from this survey will provide scientists, breeders, governments, and educators with soybean yield-loss estimates to help inform and prioritize research, policy, and educational efforts in soybean pathology and disease management.

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Soybean (*Glycine max* L. Merrill) diseases reduce yield as well as grain and seed quality in the United States and Canada every year. Diseases of importance vary annually and from location to location. Occurrence of soybean diseases that cause yield losses are influenced by many factors, including environmental conditions, crop

production practices, previous disease history, and cultivar selection (Mueller et al. 2016).

The average annual yield losses due to soybean diseases in the United States are estimated to be approximately 11% (Hartman et al. 2015). Catastrophic losses to some specific diseases, for example stem canker (caused by *Diaporthe aspalathi* E. Jansen, Castl. & Crous and *D. caulivora* (Athow & Caldwell) J.M Santos, Vrandečić & A.J.L. Phillips), were commonplace during the 1980s due to lack of genetic resistance within commercially available cultivars (Backman et al. 1985). More recently, soybean rust (caused by *Phakopsora pachyrhizi* Syd. & P. Syd) has been reported to have resulted in 60% yield reduction on approximately 500 acres of soybean in southern Alabama (Sikora et al. 2014a, 2014b). Yield losses to diseases may also go unnoticed or not recognized due to misdiagnosis. For example, more than 30% yield loss as a result of soybean cyst nematode (SCN) (*Heterodera glycines* Ichinohe) can occur without noticeable aboveground symptoms, and symptoms caused by viral pathogens can be confused with those caused by herbicide injury (Mueller et al. 2016). Conversely, certain soybean-disease symptoms may be readily observed, but do not cause a significant reduction in soybean yield. Examples of frequently occurring

soybean diseases from which yield reduction is often minimal include bacterial blight (caused by *Pseudomonas savastanoi* pv. *glycinea* (Coerper) Gardan, Bollet, Abu-Ghorrah, Grimont & Grimont), downy mildew (caused by *Peronospora manshurica* (Naumov) Syd.), or Septoria brown spot (caused by *Septoria glycines* (Tak. Matsumoto & Tomoy) M.W. Gardner) (Cruz et al. 2010; Koenning and Wrather 2010; Mulrooney 1988a, 1988b; Pratt and Wrather 1998; Sciumbato 1993; Whitney 1978; Wrather and Koenning 2006, 2009; Wrather and Sciumbato 1995; Wrather et al. 1995, 1997, 2001, 2003).

Soybean diseases are important because resulting yield losses decrease the quantity and quality of grain grown for food, feed, and fuel production. The total soybean production in the United States and Ontario, Canada, from 2010 to 2014 was greater than 17.2 billion bushels, which was valued at over \$209 billion USD (USDA-NASS and Statistics Canada). Consequently, if the estimated annual yield losses of 11% were realized, the losses during these years would be greater than 1.9 billion bushels, translating to over \$23 billion USD in lost revenue.

Since 1974, soybean disease loss estimates for the southern United States have been published in the annual proceedings of the Southern Soybean Disease Workers (SSDW). Summaries of the results

TABLE 1
Total soybean production (bushels in thousands) in the United States and Ontario, Canada, from 2010 to 2014

	2010	2011	2012	2013	2014	Total
Alabama	8,970	9,735	15,075	18,705	18,800	71,285
Arkansas	110,250	126,280	137,025	140,940	158,400	672,895
Delaware	5,536	6,636	7,140	6,602	8,693	34,607
Florida	690	432	780	1,230	1,591	4,723
Georgia	6,630	2,970	8,063	9,315	11,600	38,578
Illinois	466,075	423,225	383,990	474,000	547,120	2,294,410
Indiana	258,505	240,695	225,280	267,285	301,920	1,293,685
Iowa	496,230	475,345	418,950	420,875	498,270	2,309,670
Kansas	140,250	103,400	87,860	130,980	140,580	603,070
Kentucky	47,260	57,720	58,800	83,000	83,125	329,905
Louisiana	41,820	35,280	51,848	54,320	78,818	262,086
Maryland	15,810	18,135	22,325	18,960	23,230	98,460
Michigan	88,740	86,330	85,570	85,440	86,700	432,780
Minnesota	328,950	274,560	304,500	278,040	301,705	1,487,755
Mississippi	76,230	70,200	87,750	91,540	113,880	439,600
Missouri	210,405	190,165	158,100	201,960	259,935	1,020,565
Nebraska	267,750	261,360	207,085	255,195	287,820	1,279,210
North Carolina	40,300	41,480	62,410	48,575	69,200	261,965
North Dakota	138,380	114,840	163,185	141,215	202,515	760,135
Ohio	220,320	217,920	206,550	222,255	246,225	1,113,270
Oklahoma	11,875	3,445	3,900	10,218	10,220	39,658
Pennsylvania	20,790	21,560	24,960	27,195	27,685	122,190
South Carolina	10,465	9,180	12,580	8,835	15,400	56,460
South Dakota	157,320	150,590	143,960	185,490	229,950	867,310
Tennessee	43,710	40,320	46,740	72,075	74,060	276,905
Texas	5,550	1,710	2,860	2,346	5,198	17,664
Virginia	14,040	22,000	24,360	23,100	25,280	108,780
Wisconsin	82,315	75,670	71,400	60,450	78,760	368,595
Ontario	115,000	117,200	125,000	119,000	139,300	615,500
Total	3,430,166	3,198,383	3,148,046	3,459,141	4,045,980	17,281,716
Southern U.S.^y	649,541	635,688	699,756	791,721	957,430	3,734,136
Northern U.S.^z and Ontario, Canada	2,780,625	2,562,695	2,448,290	2,667,420	3,088,550	13,547,580

^y Southern United States includes Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

^z Northern United States includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, Pennsylvania, South Dakota, and Wisconsin.

between 1977 and 2010 have been published in numerous refereed scientific journals (Koenning and Wrather 2010; Mulrooney 1988a, 1988b; Pratt and Wrather 1998; Sciumbato 1993; Whitney 1978; Wrather and Koenning 2005, 2006, 2009; Wrather and Sciumbato 1995; Wrather et al. 1995, 1997, 2001, 2003). The estimates of disease impacts on soybean yield have been extensively used, quoted, and cited in the literature. The most recent disease loss estimates from 2010 to 2014 from the southern United States have been published annually in the SSDW proceedings (Allen et al. 2016; Koenning 2011, 2012, 2013, 2014), but have not been summarized. In addition, the University of Illinois College of Agriculture posts (http://extension.cropsciences.illinois.edu/fieldcrops/diseases/yield_reductions.php) summaries of the yield losses estimated from both the northern and southern United States from 1996 through 2014.

Determining the relative importance of the various soybean diseases regionally and over time is important for equipping researchers, soybean breeders, government, and Extension specialists with data to track emerging trends that then help prioritize educational opportunities and

research needs. Thus, the objective of this survey was to determine the annual estimated disease losses in soybean for each of the major soybean producing states in the United States and Ontario, Canada.

Data Collection and Loss Estimate Determination

The disease loss estimates were provided by members of the North Central Extension and Research Activity (NCERA) 137 and the SSDW. These groups are comprised of university-affiliated plant pathologists in the 28 soybean-producing states where more than 99% of soybean production occurs in the United States, and one province of Canada. Members of the two groups were contacted after each growing season from 2010 to 2014 to provide loss estimates as a result of soybean diseases encountered in their respective state or province, including Alabama, Arkansas, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nebraska, North Carolina, North Dakota, Ohio, Oklahoma,

	2010 ^x	2011	2012	2013	2014	Total
Alabama	840	761	980	1,382	1,408	5,371
Arkansas	8,950	12,102	13,372	14,100	15,932	64,456
Delaware	280	638	497	703	343	2,460
Florida	60	23	44	95	75	297
Georgia	830	262	702	400	867	3,061
Illinois	80,707	41,990	27,219	39,109	52,632	241,657
Indiana	25,561	13,588	11,508	13,638	34,921	99,217
Iowa	70,889	24,016	44,964	24,300	46,437	210,606
Kansas	22,747	12,528	21,126	16,240	15,858	88,499
Kentucky	2,190	2,840	4,405	6,734	9,033	25,203
Louisiana	2,460	2,189	4,642	4,047	13,037	26,376
Maryland	110	306	415	1,997	781	3,608
Michigan	29,921	73,597	39,602	19,888	29,539	192,548
Minnesota	69,778	45,835	34,888	40,199	48,758	239,457
Mississippi	12,680	6,985	6,967	9,652	24,790	61,075
Missouri	12,268	10,728	4,976	32,074	24,190	84,236
Nebraska	5,219	11,814	8,885	8,566	11,540	46,024
North Carolina	3,270	2,188	3,726	3,290	7,314	19,789
North Dakota	19,049	20,335	9,378	10,432	14,079	73,273
Ohio	27,812	21,876	20,882	89,526	66,006	226,103
Oklahoma	710	170	214	628	686	2,408
Pennsylvania	1,862	6,623	6,635	4,794	6,507	26,421
South Carolina	1,000	832	1,156	579	1,269	4,836
South Dakota	36,901	24,515	29,105	32,355	30,471	153,347
Tennessee	9,000	6,691	7,445	11,610	10,697	45,442
Texas	30	0	20	7	33	90
Virginia	1,160	1,359	1,947	2,069	2,711	9,247
Wisconsin	32,014	22,609	53,222	17,633	24,872	150,350
Ontario	9,088	9,453	10,644	10,237	16,780	56,203
Total	487,386	376,857	369,567	416,286	511,566	2,161,662
Southern U.S.^y	55,838	48,075	51,509	89,369	113,166	357,956
Northern U.S.^z and Ontario, Canada	431,548	328,782	318,058	326,918	398,400	1,803,706

^x In 2010, several values for Kansas and South Dakota were labeled as “trace” amounts of disease and could not be translated into percentage of yield loss. In 2011 to 2014, values labeled as “trace” were translated into 0.000000001% yield loss.

^y Southern United States includes Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

^z Northern United States includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, Pennsylvania, South Dakota, and Wisconsin.

Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Virginia, and Wisconsin, as well as the Canadian province of Ontario. A composite list of diseases was sent to respondents each year, and pathologists were asked to estimate losses from a list of diseases provided, and to also include information about diseases that were not listed on the form. Various methods were used to obtain the disease losses by respondents, and most individuals relied on more than one method. The methods and sources of information employed included: field surveys; plant disease diagnostic clinic samples; cultivar performance trial ratings; questionnaires to Cooperative

Extension staff; research plots; grower demonstrations; private crop consultant reports; foliar fungicide trials; and sentinel plot data. In instances where a trace level of disease was observed by a specialist, a numerical value of 1×10^{-9} was inserted and used for the purposes of calculating yield losses from 2011 to 2014. In 2010, values reported as trace were not counted as part of the total yield losses as the data were unavailable.

Yearly per-acre soybean production totals and crop value for soybean grown in each state or province were determined using data from the United States Department of Agriculture - National

TABLE 3
Total estimated soybean yield losses (bushels in thousands) caused by disease or type of disease in 28 U.S. states^s and Ontario, Canada, from 2010 to 2014

Disease common name	Latin binomial for the pathogen causing the disease	2010 ^t	2011	2012	2013	2014	Total
Aerial blight	<i>Rhizoctonia solani</i>	3,310	2,995	1,502	470	2,467	10,744
Bacterial diseases	<i>Pseudomonas savastanoi</i> pv. <i>glycines</i> ; <i>P. syringae</i> pv. <i>tabaci</i> ; <i>Xanthomonas axonopodis</i> pv. <i>glycines</i> ; others	6,402	5,695	2,023	926	1,978	17,024
Cercospora leaf blight or purple seed stain^v	<i>Cercospora flagellaris</i> , <i>C. kikuchii</i> , and <i>C. sigesbeckiae</i>	... ^u	...	4,443	4,973	10,222	19,638
Purple seed stain^v	<i>Cercospora flagellaris</i> , <i>C. kikuchii</i> , and <i>C. sigesbeckiae</i>	7,157	4,380	...	...	...	11,536
Downy mildew	<i>Peronospora manshurica</i>	8,888	4,448	814	1,149	1,348	16,649
Frogeye leaf spot	<i>Cercospora sojina</i>	12,127	5,802	3,727	17,044	18,147	56,847
Phomopsis seed decay	<i>Diaporthe longicolla</i>	6,661	3,836	4,845	5,918	10,242	31,502
Septoria brown spot	<i>Septoria glycines</i>	27,466	19,301	7,297	21,842	27,398	103,305
Soybean rust	<i>Phakopsora pachyrhizi</i>	0	95	443	1,057	45	1,639
Viruses	See footnote ^w	3,609	3,573	12,110	8,886	5,294	33,471
Anthracnose	<i>Colletotrichum truncatum</i> and several related species	7,849	5,559	3,246	2,821	3,325	22,799
Brown stem rot	<i>Phialophora gregata</i>	13,695	15,955	12,535	10,508	13,715	66,407
Charcoal rot	<i>Macrophomina phaseolina</i>	38,553	41,722	73,366	39,171	26,793	219,605
Fusarium wilt and root rot	<i>Fusarium</i> spp.	10,689	16,502	15,114	8,840	5,662	56,807
Phytophthora root and stem rot	<i>Phytophthora sojae</i>	40,015	36,249	24,779	31,882	34,565	167,491
Pod and stem blight	<i>Diaporthe sojae</i>	10,299	9,295	5,454	9,779	13,383	48,211
Sclerotinia stem rot (White mold)	<i>Sclerotinia sclerotiorum</i>	24,520	12,775	5,530	17,666	40,855	101,346
Seedling diseases	See footnote ^x	57,903	48,227	25,083	46,125	64,457	241,796
Southern blight	<i>Sclerotium rolfsii</i>	250	374	1,016	101	696	2,437
Soybean cyst nematode	<i>Heterodera glycines</i>	121,603	101,360	129,042	136,344	129,056	617,405
Stem canker	<i>Diaporthe aspalathi</i> ; <i>D. caulivora</i>	6,184	6,166	4,370	6,840	12,842	36,402
Sudden death syndrome	<i>Fusarium virguliforme</i>	71,329	23,135	21,910	29,846	63,484	209,703
Other Nematodes	See footnote ^y	7,556	6,087	8,947	12,606	19,850	55,046
Other diseases	See footnote ^z	1,320	3,327	1,970	1,491	5,740	13,849

^s Alabama, Arkansas, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nebraska, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Virginia, and Wisconsin.

^t In 2010, several values for Kansas and South Dakota were labeled as “trace” amounts of disease and could not be translated into percentage of yield losses. Between 2011 and 2014, values labeled as “trace” were translated into 0.000000001% yield losses.

^u Indicates that values could not be calculated due to missing data for that disease-year combination.

^v In 2010 and 2011, purple seed stain losses were determined separately from *Cercospora* leaf blight, which was included in “Other diseases.” Between 2012 and 2014, estimated losses caused by both diseases were combined into a single category.

^w Includes *Alfalfa mosaic virus*, *Bean pod mottle virus*, *Bean yellow mosaic virus*, *Peanut mottle virus*, *Soybean dwarf virus*, *Soybean mosaic virus*, *Soybean vein necrosis virus*, *Tobacco ringspot virus*, *Tobacco streak virus*, and *Tomato spotted wilt virus*.

^x Includes disease caused by *Rhizoctonia*, *Pythium*, *Fusarium*, and/or *Phomopsis* spp.

^y Includes *Rotylenchulus reniformis*, *Belonolaimus longicaudatus*, and *Meloidogyne*, *Helicotylenchus*, *Hoplolaimus*, *Paratrichodorus*, and *Pratylenchus* spp.

^z Includes black root rot, *Cercospora* leaf blight, *Cylindrocladium parasticum* (red crown rot), green stem syndrome, *Neocosmospora* root rot, *Pythium* root rot, target spot, and Texas root rot.

TABLE 4
Ten most destructive diseases and associated estimated soybean yield losses (bushels in thousands) by disease or type of disease in the northern United States^w and Ontario, Canada, from 2010 to 2014

Rank	2010		2011		2012		2013		2014	
	Disease	Loss	Disease	Loss	Disease	Loss	Disease	Loss	Disease	Loss
1	Soybean cyst nematode	110,325	Soybean cyst nematode	90,525	Soybean cyst nematode	118,697	Soybean cyst nematode	112,394	Soybean cyst nematode	108,008
2	Sudden death syndrome	70,658	Seedling diseases	46,847	Charcoal rot	59,481	Seedling diseases	43,672	Seedling diseases	60,305
3	Seedling diseases ^x	55,000	Phytophthora root and stem rot	33,180	Phytophthora root and stem rot	23,950	Charcoal rot	31,865	Sudden death syndrome	46,815
4	Phytophthora root and stem rot	35,967	Charcoal rot	29,403	Seedling diseases	23,642	Phytophthora root and stem rot	29,134	Sclerotinia stem rot (White mold)	40,709
5	Charcoal rot	25,935	Sudden death syndrome	22,835	Sudden death syndrome	21,831	Sudden death syndrome	20,391	Phytophthora root and stem rot	32,864
6	Septoria brown spot	25,306	Septoria brown spot	17,954	Fusarium wilt and root rot	14,636	Septoria brown spot	20,209	Septoria brown spot	24,030
7	Sclerotinia stem rot (White mold)	24,520	Fusarium wilt and root rot	16,492	Brown stem rot	12,532	Sclerotinia stem rot (White mold)	17,663	Charcoal rot	18,347
8	Brown stem rot	13,465	Brown stem rot	14,064	Viruses ^y	11,661	Brown stem rot	10,385	Brown stem rot	13,686
9	Fusarium wilt and root rot	10,689	Sclerotinia stem rot (White mold)	12,770	Septoria brown spot	6,379	Viruses ^z	7,543	Stem canker	11,871
10	Pod and stem blight	9,514	Pod and stem blight	8,404	Sclerotinia stem rot (White mold)	5,530	Stem canker	6,052	Pod and stem blight	10,540

^w Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, Pennsylvania, South Dakota, and Wisconsin.

^x Seedling diseases include those caused by *Rhizoctonia*, *Pythium*, *Fusarium*, and/or *Phomopsis* spp.

^y Includes *Bean pod mottle virus*, *Soybean dwarf virus*, *Soybean mosaic virus*, and *Soybean vein necrosis virus*.

^z Includes *Bean pod mottle virus*, *Soybean dwarf virus*, *Soybean mosaic virus*, *Soybean vein necrosis virus*, *Tobacco ringspot virus*, and *Tobacco streak virus*.

TABLE 5
Ten most destructive diseases and associated estimated soybean yield losses (bushels in thousands) by disease or type of disease in the southern United States^q from 2010 to 2014

Rank	2010		2011		2012		2013		2014	
	Disease	Loss	Disease	Loss	Disease	Loss	Disease	Loss	Disease	Loss
1	Charcoal rot	12,618	Charcoal rot	12,319	Charcoal rot	13,885	Soybean cyst nematode	23,950	Soybean cyst nematode	21,048
2	Soybean cyst nematode	11,278	Soybean cyst nematode	10,835	Soybean cyst nematode	10,345	Frogeye leaf spot	11,422	Non SCN Nematodes ^y	18,754
3	Non SCN Nematodes ^r	6,711	Non SCN Nematodes ^t	5,217	Non SCN Nematodes ^v	8,571	Non SCN Nematodes ^x	11,340	Sudden death syndrome	16,669
4	Phytophthora root and stem rot	4,048	Other diseases ^u	3,327	Frogeye leaf spot	2,634	Sudden death syndrome	9,455	Frogeye leaf spot	13,748
5	Aerial blight	3,310	Phytophthora root and stem rot	3,069	Phomopsis seed decay	2,294	Charcoal rot	7,307	Charcoal rot	8,445
6	Frogeye leaf spot	3,085	Aerial blight	2,431	Cercospora leaf blight or purple seed stain	1,993	Fusarium wilt and root rot	4,632	Other diseases ^z	5,575
7	Anthrachnose	2,916	Brown stem rot	1,890	Other diseases ^w	1,970	Pod and stem blight	3,784	Cercospora leaf blight or purple seed stain	5,074
8	Seedling diseases ^s	2,903	Downy mildew	1,412	Seedling diseases ^s	1,441	Phytophthora root and stem rot	2,749	Seedling diseases ^s	4,152
9	Phomopsis seed decay	2,268	Seedling diseases ^s	1,381	Anthrachnose	1,380	Seedling diseases ^s	2,453	Septoria brown spot	3,368
10	Septoria brown spot	2,160	Septoria brown spot	1,347	Pod and stem blight	1,205	Phomopsis seed decay	2,143	Pod and stem blight	2,843

^q Southern United States includes Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

^r Includes *Hoplotaimus columbus*, *Rotylenchulus reniformis*, *Belonolaimus longicaudatus*, and *Meloidogyne* and *Paratrichodorus* spp.

^s Seedling diseases include those caused by *Rhizoctonia*, *Pythium*, *Fusarium*, and/or *Phomopsis* spp.

^t Includes *Rotylenchulus reniformis* and *Meloidogyne*, *Hoplotaimus*, *Belonolaimus*, *Paratrichodorus*, and *Pratylenchus* spp.

^u Includes Black root rot, *Cercospora* leaf blight, *Cylindrocladium parasticum* (red crown rot), target spot, and *Neocosmospora* stem rot.

^v Includes *Rotylenchulus reniformis*, *Belonolaimus longicaudatus*, and *Meloidogyne*, *Helicotylenchus*, *Hoplotaimus*, *Paratrichodorus*, and *Pratylenchus* spp.

^w Includes Black root rot, *Cylindrocladium parasticum* (red crown rot), *Neocosmospora* stem rot, *Cercospora* leaf blight, Texas root rot, and target spot.

^x Includes *Hoplotaimus columbus*, *Rotylenchulus reniformis*, and *Meloidogyne*, *Belonolaimus*, and *Paratrichodorus* spp.

^y Includes *Hoplotaimus columbus*, *Rotylenchulus reniformis*, and *Meloidogyne*, *Belonolaimus*, and *Paratrichodorus* spp.

^z Includes Texas root rot, red crown rot, and target spot.

Agricultural Statistics Service and Statistics Canada (USDA-NASS; Statistics Canada). Crop value for Ontario was determined by taking the product of yearly production in Ontario and the U.S. national marketing year price for soybean. Disease loss values (bushels per acre) were determined based on yield before estimated losses for each state or province: $\{[(100 - \text{percent estimated disease loss}) / 100] / \text{bushels harvested}\}$. Total bushels lost per disease (percent loss $\times$ yield before estimated loss) was then calculated for each state. Losses in crop value were determined by first dividing total production in U.S. dollars for each state in each year by the corresponding total production in bushels to obtain a price per bushel for each state in each year. Dollar amounts were not adjusted for inflation. Then, the product of the price per bushel and total estimated

losses by state were used to obtain a value for total estimated losses in U.S. dollars. Losses in crop value for Ontario were determined by taking the product of estimated yearly losses to disease in Ontario and the U.S. national marketing year price for soybeans. Total losses on a per-acre basis for each state or province were determined by dividing total estimated losses in U.S. dollars by the number of acres planted for each state or province as reported by USDA-NASS and Statistics Canada.

Results and Implications

Total annual soybean production in the states and province surveyed ranged from 3.15 billion bushels in 2012 to 4.05 billion

TABLE 6
Total estimated losses due to soybean diseases (USD^v in thousands) in the United States and Ontario, Canada, from 2010 to 2014

	2010 ^w	2011	2012	2013	2014	Total
Alabama	9,324 ^x	9,131	14,310	17,826	14,083	64,675
Arkansas	97,555	148,856	191,226	184,710	168,875	791,222
Delaware	3,416	7,785	7,156	8,714	3,289	30,360
Florida	660	250	617	1,126	669	3,322
Georgia	9,711	3,167	10,245	5,326	9,100	37,550
Illinois	952,343	537,477	397,402	516,236	536,846	2,940,304
Indiana	293,952	172,574	169,172	180,023	356,192	1,171,912
Iowa	793,957	302,607	647,478	318,327	462,515	2,524,884
Kansas	261,591	151,590	302,095	207,874	152,714	1,075,864
Kentucky	24,966	35,219	63,879	88,218	94,849	307,131
Louisiana	25,830	26,272	68,243	54,234	142,101	316,681
Maryland	1,320	3,704	5,886	24,760	7,668	43,338
Michigan	332,123	890,526	554,431	256,559	298,342	2,331,981
Minnesota	760,580	568,357	498,893	518,565	485,625	2,832,020
Mississippi	131,872	83,823	101,028	127,412	272,687	716,821
Missouri	143,536	134,103	72,148	420,167	241,660	1,011,614
Nebraska	57,409	141,768	125,279	108,791	112,285	545,531
North Carolina	39,240	26,476	52,164	43,104	74,606	235,591
North Dakota	207,634	241,990	131,291	129,360	133,606	843,880
Ohio	319,838	284,393	304,883	1,163,839	679,860	2,752,813
Oklahoma	8,094	2,022	3,085	8,099	6,794	28,095
Pennsylvania	22,530	82,788	94,216	62,322	63,773	325,629
South Carolina	11,800	9,981	16,758	7,702	13,075	59,316
South Dakota	402,221	299,079	413,294	404,435	285,517	1,804,545
Tennessee	99,900	81,628	108,697	150,928	113,385	554,538
Texas	312	0	294	90	311	1,007
Virginia	13,920	16,449	27,254	26,902	26,841	111,366
Wisconsin	345,751	280,353	745,107	225,706	248,720	1,845,637
Ontario	102,697	118,168	153,273	133,084	169,480	676,701
Total	5,474,081	4,660,538	5,279,805	5,394,438	5,175,467	25,984,328
Southern U.S.^y	621,456	588,868	742,991	1,169,318	1,189,992	4,312,626
Northern U.S.^z and Ontario, Canada	4,852,625	4,071,669	4,536,814	4,225,120	3,985,475	21,671,702

^v United States dollars.

^w In 2010, several values for Kansas and South Dakota were labeled as “trace” amounts of disease and could not be translated into percentage of yield losses. Between 2011 and 2014, values labeled as “trace” were translated into 0.00000001% yield losses.

^x To account for price fluctuations each year, losses in crop value were determined by first dividing total production in U.S. dollars by total production in bushels to obtain a price per bushel for each state in each year. Then, the product of the price per bushel and total estimated losses from disease by state were used to obtain a value for total estimated losses in U.S. dollars. Losses in crop value for Ontario were determined by taking the product of estimated yearly losses to disease in Ontario and the U.S. national marketing year price for soybeans. Data obtained from USDA-NASS and Statistics Canada.

^y Southern United States includes Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

^z Northern United States includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, Pennsylvania, South Dakota, and Wisconsin.

bushels in 2014 (Table 1). Individual state production values also varied widely from year to year and among states.

Estimates of total soybean production losses due to diseases differed greatly by state or province as well as year (Table 2). Total estimated bushels lost ranged from 370 million in 2012 to 512 million in 2014, a difference of 28% among the five years (Table 2). An overall decrease of 24% in disease losses was observed between 2010 and 2012, which then increased 28% between 2012 and 2014. From 2010 to 2014, the northern states and Ontario experienced slightly more than 5.0 times the amount of yield loss due to disease compared with southern states, while only producing approximately 3.6 times the number of bushels.

The estimated impact of each specific disease on soybean production in the United States was highly variable by disease and year.

Not including reports of “0”, losses ranged from approximately 45,460 bushels yield loss due to soybean rust in 2014 to more than 136 million bushels lost due to SCN in 2013 (Table 3). To better understand the economic impact of disease on soybean plants, results were grouped into four commonly used biological categories based on specific plant part affected or type of pathogen: foliar; stem; root; and seedling diseases. Stem diseases accounted for greater than 37% of the total yield losses regardless of year, with an average of 43% of the losses each year. Nematode diseases accounted for average yield losses of 31%, foliar diseases accounted for between 10 and 16% of the losses observed, and seedling diseases accounted for between 7% (in 2012) and 13% (in 2011) yield losses.

The most destructive diseases in the twelve northern-most United States and Ontario, Canada, varied slightly by year (Table 4). Yield

TABLE 7
Total estimated losses due to soybean diseases (USD^y) per acre in the United States and Ontario, Canada, from 2010 to 2014

	2010 ^w	2011	2012	2013	2014	Total
Alabama	26.64 ^x	30.44	42.09	40.51	29.34	33.80
Arkansas	30.58	44.70	59.76	56.49	52.28	48.76
Delaware	19.52	45.79	42.09	52.81	17.78	35.60
Florida	26.40	13.89	29.39	35.19	17.15	24.41
Georgia	35.97	20.44	46.57	22.66	30.33	31.19
Illinois	104.65	60.05	43.91	54.34	54.78	63.55
Indiana	54.94	32.56	32.85	34.62	65.36	44.07
Iowa	81.02	32.36	69.25	34.23	46.96	52.76
Kansas	60.84	37.90	75.52	57.74	38.18	54.04
Kentucky	17.83	23.64	43.16	52.83	53.89	38.27
Louisiana	25.08	25.76	60.39	47.99	100.78	52.00
Maryland	2.81	7.88	12.26	51.05	15.03	17.81
Michigan	162.01	456.68	277.22	132.93	145.53	234.87
Minnesota	102.78	80.05	70.76	77.40	66.07	79.41
Mississippi	65.94	45.81	51.28	63.39	123.39	69.96
Missouri	27.87	25.07	13.36	74.37	42.77	36.69
Nebraska	11.15	28.93	24.81	22.66	20.79	21.67
North Carolina	24.84	19.19	32.81	29.12	42.63	29.72
North Dakota	50.64	60.50	27.64	27.82	22.65	37.85
Ohio	69.53	62.50	66.28	258.63	144.65	120.32
Oklahoma	16.19	4.60	7.35	23.48	18.12	13.94
Pennsylvania	45.06	165.58	177.77	111.29	111.88	122.31
South Carolina	25.38	26.98	44.10	24.07	29.06	29.92
South Dakota	95.77	72.95	87.01	87.92	55.44	79.82
Tennessee	68.90	63.28	86.27	95.52	69.14	76.62
Texas	1.52	0.00	2.35	0.86	2.00	1.35
Virginia	24.86	29.37	46.19	44.10	41.29	37.16
Wisconsin	210.82	173.06	435.74	142.85	138.18	220.13
Ontario	42.09	47.94	59.18	51.19	55.21	51.12
Average	52.81	59.93	71.29	62.35	56.92	60.66
Ave. for Southern U.S. ^y	27.52	26.68	38.71	44.65	42.81	36.07
Ave. for Northern U.S. ^z and Ontario, Canada	83.95	100.85	111.38	84.12	74.28	90.92

^y U.S. dollars.

^w In 2010, several values for Kansas and South Dakota were labeled as “trace” amounts of disease and could not be translated into percentage of yield losses. Between 2011 and 2014, values labeled as “trace” were translated into 0.000000001% yield losses.

^x Total losses on a per-acre basis for each state or province were determined by dividing total estimated losses due to disease in U.S. dollars by the number of acres planted for each state or province each year as reported by USDA-NASS and Statistics Canada.

^y Southern United States includes Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

^z Northern United States includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, Pennsylvania, South Dakota, and Wisconsin.

loss estimates for SCN were far greater than any other disease each year. Seedling diseases, sudden death syndrome (SDS) (caused by *Fusarium virguliforme* O'Donnell & T. Aoki), Phytophthora root and stem rot (caused by *Phytophthora sojae* Kaufm. & Gerd.), and charcoal rot (caused by *Macrophomina phaseolina* (Tassi) Goid) were nearly always in the top five diseases causing the most estimated yield losses. Losses to SCN were greatest in the drought year of 2012, while losses from charcoal rot, a disease favored by hot and dry conditions, were greater in 2012 than losses caused by that disease any other year. In the 16 southern-most U.S. states, charcoal rot caused the most estimated yield losses for three years beginning in 2010, but losses from this disease greatly decreased in 2013 and 2014 (Table 5). Losses caused by other nematodes (*Meloidogyne* spp., *Rotylenchulus reniformis* Linford & Oliveira, and *Belonolaimus*, *Helicotylenchus*, *Hoplolaimus*, *Paratrichodorus*, and *Pratylenchus* spp.) were always in the top three rankings.

From 2010 to 2014, the total estimated economic loss due to soybean disease was \$26 billion in the United States and Ontario, Canada (Table 6). Yearly estimated economic losses were greatest in 2010 and least in 2011, a reduction in losses between the two years of 15%. Over the 5-year period, the average annual loss reached nearly \$5.2 billion. Estimated economic losses on a per-acre basis due to diseases varied greatly by state or province and year (Table 7). Averaged across states, per-acre losses per year were as follows: \$52.81/acre in 2010; \$59.93/acre in 2011; \$71.29/acre in 2012; \$62.35/acre in 2013; and \$56.92/acre in 2014. The average estimated per-acre yield loss due to soybean diseases during the five years of this survey (2010 to 2014) was \$60.66/acre across all states. Average per-acre disease loss estimates are approximately 2.5 times greater for the northern states and Ontario (\$90.92) compared with southern states (\$36.07).

Economic losses due to disease may be easily under-estimated. Costs associated with diagnosis and management of diseases are production expenses that are often not included in economic estimates of losses due to disease. Disease-related costs include time spent scouting fields, fees for consultant or diagnostic services, quantification of nematode population densities from soil samples, and costs associated with misdiagnosis. Management for various soybean diseases includes cultivar resistance, crop rotation, tillage, fungicide/nematicide-treated seed, soil-applied nematicide, foliar fungicide, and insect/vector and alternative host-plant management (Mueller et al. 2016). For example, estimated mean application cost for foliar fungicide was reported to be \$25.05/acre between 2009 and 2014 (Kandel et al. 2016). However, cost of fungicide product and application undoubtedly vary by region, supplier, product selected, and method of application. Additional costs incurred due to diseases that affect seed quality include refusal of soybean seed for export due to contamination with a quarantined pathogen or seed-coat mottling for food-grade production, grain quality reduction, and increased harvest difficulty due to lodging or green stem disorder (Hartman et al. 2015; Mueller et al. 2016; Ziems et al. 2007). Estimating the costs attributed to rejected grain is difficult since grain grading differs by entity.

Soybean disease risk is not static, and varies greatly over time and by location based on many factors. For example, changing environmental patterns that result in increased humidity, frequent and heavy rainfall events, warmer temperatures during winter to allow for survival of pathogens on crop residue, and changes in temperature may heighten the risk of some soybean diseases. Pathogens that infect soybean may change in virulence and diseases may spread to previously unaffected soybean production areas in the United States and Canada from other countries or may spread within the country. Also, farming practices continue to change, and those practices that

promote specific diseases may become more widespread. Thus, it is possible that reductions in crop yield and costs associated with disease management will increase, resulting in an increased need for ongoing scientific research on soybean pathogens and farmer/agribusiness education regarding soybean diseases. Our survey results will help scientists, governments, and educators direct research, funding, and educational efforts in soybean pathology and disease management.

Acknowledgments and Disclaimers

The values in this publication are intended to be relative estimates of soybean yield losses due to diseases. The authors used the most appropriate means available to estimate disease losses and assume no liability resulting from the use of these estimates.

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Literature Cited

- Allen, T. W., Damicone, J. P., Dufault, N. S., Faske, T. R., Hershman, D. E., Hollier, C. A., Isakeit, T., Kemerait, R. C., Kleczewski, N. M., Koenning, S. R., Mehl, H. L., Mueller, J. D., Overstreet, C., Price, P. P., Sikora, E. J., and Young, H. 2015. Southern United States soybean disease loss estimate for 2014. Pages 10-15 in: Proceedings of the Southern Soybean Disease Workers, 42nd Annual Meeting, Pensacola, FL.
- Backman, P. A., Weaver, D. B., and Morgan-Jones, G. 1985. Soybean stem canker: An emerging disease problem. *Plant Dis.* 69:641-647.
- Cruz, C., Mills, D., Paul, P. A., and Dorrance, A. E. 2010. Impact of brown spot caused by *Septoria glycines* on soybean in Ohio. *Plant Dis.* 94: 820-826.
- Hartman, G. L., Rupe, J. C., Sikora, E. J., Domier, L. L., Davis, J. A., and Steffey, K. L. 2015. Compendium of Soybean Diseases and Pests, 5th Ed. American Phytopathological Society Press, St. Paul, MN.
- Kandel, Y. R., Mueller, D. S., Hart, C. E., Bestor, N. R. C., Bradley, C. A., Ames, K. A., Giesler, L. J., and Wise, K. A. 2016. Analyses of yield and economic response from foliar fungicide and insecticide applications to soybean in the North Central United States. *Plant Health Prog.* 17:232-238.
- Koenning, S. R. 2011. Southern United States soybean disease loss estimate for 2010. Pages 1-5 in: Proceedings of the Southern Soybean Disease Workers, 38th Annual Meeting, Pensacola, FL.
- Koenning, S. R. 2012. Southern United States soybean disease loss estimate for 2011. Pages 1-5 in: Proceedings of the Southern Soybean Disease Workers, 39th Annual Meeting, Pensacola, FL.
- Koenning, S. R. 2013. Southern United States soybean disease loss estimate for 2012. Pages 1-5 in: Proceedings of the Southern Soybean Disease Workers, 40th Annual Meeting, Pensacola, FL.
- Koenning, S. R. 2014. Southern United States soybean disease loss estimate for 2013. Pages 1-5 in: Proceedings of the Southern Soybean Disease Workers, 41st Annual Meeting, Pensacola, FL.
- Koenning, S. R., and Wrather, J. A. 2010. Suppression of soybean yield potential in the continental United States by plant diseases from 2006 to 2009. *Plant Health Prog.* doi:10.1094/PHP-2010-1122-01-RS
- Mueller, D. S., Wise, K. A., Sisson, A. J., Smith, D. L., Sikora, E. J., Robertson, A. E., and Bradley, C. A. 2016. A Farmer's Guide to Soybean Diseases. American Phytopathological Society, St. Paul, MN.
- Mulrooney, R. P. 1988a. Soybean disease loss estimate for Southern United States in 1985 and 1986. *Plant Dis.* 72:364-365.
- Mulrooney, R. P. 1988b. Soybean disease loss estimate for Southern United States in 1987. *Plant Dis.* 72:915.
- Pratt, P. W., and Wrather, J. A. 1998. Soybean disease loss estimates for the Southern United States during 1994-1996. *Plant Dis.* 82:114-116.

- Sciumbato, G. L. 1993. Soybean disease loss estimate for the Southern United States during 1988-1991. *Plant Dis.* 77:954-956.
- Sikora, E. J., Allen, T. W., Wise, K. A., Bergstrom, G., Bradley, C. A., Bond, J., Brown-Rytlewski, D., Chilvers, M., Damicone, J., DeWolf, E., Dorrance, A., Dufault, N., Esker, P., Faske, T. R., Giesler, L., Goldberg, N., Golod, J., Gomez, I. R. G., Grau, C., Grybauskas, A., Franc, G., Hammerschmidt, R., Hartman, G. L., Henn, A., Hershman, D., Hollier, C., Isakeit, T., Isard, S., Jacobson, B., Jardine, D., Kemerait, B., Koenning, S., Langham, M., Malvick, D., Markell, S., Marois, J. J., Monfort, S., Mueller, D., Mueller, J., Mulroony, R., Newman, M., Osborne, L., Padgett, G. B., Ruden, B. E., Rupe, J., Schneider, R., Schwartz, H., Shaner, G., Singh, S., Stromberg, E., Sweets, L., Tenuta, A., Vaiciunas, S., Yang, X. B., Young-Kelly, H., and Zidek, J. 2014a. A coordinated effort to manage soybean rust in North America: a success story in soybean disease monitoring. *Plant Dis.* 98:864-875.
- Sikora, E. J., Conner, K., Delaney, D., Zhang, L., and Delaney, M. 2014b. Observations on soybean rust and soybean vein necrosis virus in Alabama in 2013. *Proc. Southern Soybean Dis. Workers. Proceedings of the Southern Soybean Disease Workers, 41st Annual Meeting, Pensacola, FL.*
- Whitney, G. 1978. Southern states soybean disease loss estimates-1977. *Plant Dis. Rep.* 62:1078-1079.
- Wrather, J. A., Anderson, T. R., Arsyad, D. M., Gai, J., Ploper, L. D., Portapuglia, A., Ram, H. H., and Yorinori, J. T. 1997. Soybean disease loss estimates for the top 10 soybean producing countries in 1994. *Plant Dis.* 81: 107-110.
- Wrather, J. A., Chambers, A. Y., Fox, J. A., Moore, W. F., and Sciumbato, G. L. 1995. Soybean disease loss estimates for the southern United States, 1974 to 1994. *Plant Dis.* 79:1076-1079.
- Wrather, J. A., and Koenning, S. R. 2006. Estimates of disease effects on soybean yields in the United States 2003-2005. *J. Nematol.* 38:173-180.
- Wrather, J. A., and Koenning, S. R. 2009. Effects of diseases on soybean yields in the United States 1996 to 2007. *Plant Health Prog.* doi:10.1094/PHP-2009-0401-01-RS.
- Wrather, J. A., Koenning, S. R., and Anderson, T. 2003. Effect of diseases on soybean yields in the United States and Ontario 1999-2002. *Plant Health Prog.* doi:10.1094/PHP-2003-0325-01-RV
- Wrather, J. A., and Sciumbato, G. L. 1995. Soybean disease loss estimates for the Southern United States during 1992-1993. *Plant Dis.* 79:84-85.
- Wrather, J. A., Stienstra, W. C., and Koenning, S. R. 2001. Soybean disease loss estimates for the United States from 1996-1998. *Can. J. Plant Pathol.* 23: 122-131.
- Ziems, A. D., Giesler, L. J., Graef, G. L., Redinbaugh, M. G., Vacha, J. L., Berry, S. A., Madden, L. V., and Dorrance, A. E. 2007. Response of soybean cultivars to Bean pod mottle virus infection. *Plant Dis.* 91: 719-726.