Soybean disease loss estimates for the top ten soybean-producing countries in 1998

J.A. Wrather, T.R. Anderson, D.M. Arsyad, Y. Tan, L.D. Ploper, A. Porta-Puglia, H.H. Ram, and J.T. Yorinori

Abstract: Soybean (*Glycine max* (L.) Merr.) disease loss estimates were compiled for the 1998 harvested crop from the top 10 soybean-producing countries in the world. These 10 countries (United States, Brazil, China, Argentina, India, Canada, Paraguay, Indonesia, Italy, and Bolivia) produced 97.6% of the world's total soybean crop in 1998. Total yield losses caused by soybean cyst [*Heterodera glycines* Ichinohe] in these 10 countries were greater than those caused by any other disease. Next in decreasing order of total yield reduction were brown spot [*Septoria glycines* (Hemmi)], charcoal rot [*Macrophomina phaseolina* (Tassi) Goidanich], and sclerotinia stem rot [*Sclerotinia sclerotiorum* (Lib.) de Bary]. The total yield loss due to diseases in these countries in 1998 was 28.5×10^6 t, valued at U.S. \$$6.29 \times 10^9$. Yield losses due to specific diseases varied by country. For example, yield losses due to rust were reported only from China and Indonesia. Soybean disease controls are needed to provide more effective preventive and therapeutic disease management strategies and systems to producers.

Key words: Argentina, Bolivia, Brazil, Canada, China, India, Indonesia, Italy, Paraguay, United States of America.

Résumé : Les valeurs estimées des pertes dues aux maladies du soja (*Glycine max* (L.) Merr.) pour la récolte de 1998 furent compilées pour les 10 plus grands pays producteurs au monde. En 1998, ces 10 pays (États-Unis, Brésil, Chine, Argentine, Inde, Canada, Paraguay, Indonésie, Italie et Bolivie) ont fourni 97,6% de tout le soja produit dans le monde. Les pertes totales de rendement causées par le nématode à kystes des racines [*Heterodera glycines* Ichinohe] dans ces 10 pays étaient plus élevées que celles causées par toute autre maladie. Suivaient, dans l'ordre décroissant de pertes totales de rendement, la tache brune [*Septoria glycines* (Hemmi)], la pourriture charbonneuse [*Macrophomina phaseolina* (Tassi) Goidanich] et le pourridié sclérotique [*Sclerotinia sclerotiorum* (Lib.) de Bary]. En 1998, les pertes totales de rendement dues aux maladies dans ces pays se chiffraient à $28{,}5 \times 10^6$ t, équivalant à $6{,}29 \times 10^9$ \$ US. Les maladies responsables des pertes de rendement différaient d'un pays à l'autre. Par exemple, les pertes de rendement par la rouille ne furent rapportées qu'en Chine et en Indonésie. Des moyens de lutte sont nécessaires pour fournir aux producteurs des stratégies et des systèmes plus efficaces de gestion préventive et thérapeutique des maladies.

Mots clés : Argentine, Bolivie, Brésil, Canada, Chine, Inde, Indonésie, Italie, Paraguay, États-Unis d'Amérique.

Introduction

During 1998, 154.1×10^6 t of soybean, *Glycine max* (L.) Merr, were produced in the world from 71.1×10^6 ha (United States Department of Agriculture 1998). Over 97% was produced in 10 countries as follows: United States (75.0×10^6 t), Brazil (29.0×10^6 t), Argentina (17.0×10^6 t), China (13.5×10^6 t), India (5.7×10^6 t), Paraguay (3.1×10^6 t), Canada (2.8×10^6 t), Indonesia (1.5×10^6 t), Bolivia (1.3×10^6 t), and Italy (1.2×10^6 t). These were followed by North Korea (0.40×10^6 t), Thailand (0.35×10^6 t), Russian Federation (0.30×10^6 t), and France (0.28×10^6 t). The soybean crop harvested in 1998 in Argentina, Bolivia, Brazil, and Paraguay was planted in 1997 and is hereafter referred to as the 1997–1998 crop.

Soybean has been a significant source of income for many countries. At U.S. \$220.50/t, the value of the 1998 harvested world crop was estimated at U.S. \$$33.98 \times 10^9$. Factors that reduce soybean production, such as diseases,

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J.A. Wrather.[1] University of Missouri-Delta Center, P.O. Box 160, Portageville, MO 63873, U.S.A.
T.R. Anderson. Greenhouse and Processing Crop Research Centre, Agriculture and Agri-Food Canada, Harrow, ON N0R 1G0, Canada.
D.M. Arsyad. Agency for Agriculture Research and Development, RILET, Ministry of Agriculture, P.O. Box 66, Malang 65101, Indonesia.
Y. Tan. Oil Crops Research Institute, Chinese Association for the Advancement of Science, Wuhan, Hubei 430062, China.
L.D. Ploper. Estación Experimental Agro-Industrial Obispo Colombres, CC 9, Las Talitas, 4101 Tucumán, República Argentina.
A. Porta-Puglia. Istituto Sperimentale per la Patologia Vegetale, Via Bertero 22, 00156 Roma, Italy.
H.H. Ram. Govind Ballabh Pant University of Agriculture and Technology, Pantnagar 263145, Uttar Pradesh, India.
J.T. Yorinori. CNPSoja, Empresa Brasileira De Pesquisa Agropecuária, CP 231, 86001–970 Londrina, PR, Brasil.

[1]Corresponding author (e-mail: wratherj@missouri.edu).

insects, weeds, and weather can influence the economic or general welfare of many countries and individuals.

Research must focus on management of diseases that cause extensive losses, especially when funds are limited. Clearly, knowledge of the losses caused by various soybean diseases is essential to develop research priorities.

The objective of this project was to estimate the soybean yield losses due to diseases in the top 10 soybean-producing countries for the 1998 harvested crop. Our purpose was to provide this information to help local and world agencies allocate funds for research and to help scientists focus and coordinate research efforts. This information may also serve as a basis for future comparisons to determine changes in severity of individual diseases.

Materials and methods

Methods used to estimate soybean disease losses in the 10 countries were systematic field surveys, cultivar trials, and questionnaires sent to field workers and extension staff (Wrather et al. 1995, 1997, 2001). Most of the authors used several of these methods. The estimates from the United States were compiled by the senior author from individual state estimates by scientists in those states. Production losses were based on estimates of yield in the absence of disease. The disease loss estimates should not be construed as actual losses.

Production loss estimates for each country are specific for the causal organism or the common name of the disease. The causal organisms of the commonly occurring diseases are in Table 1. Additional information on each disease can be found in Hartman et al. (1999).

Results and discussion

Argentina

Soybean has been the most important crop in Argentina because most of the production enters the international market. Production and hectarage continued to increase in the 1990's although at a slower pace than in the 1970's and 1980's. The 1997–1998 season was very favorable for production in Argentina. Adequate environmental conditions and suitable technology resulted in a record crop.

Over 90% of the soybeans from Argentina are produced in the northern Pampean subregion (provinces of Córdoba, central and southern Santa Fe, northern Buenos Aires, and northeastern La Pampa). About 5% are produced in the northwestern region (Tucumán, Salta, Jujuy, northwestern Santiago del Estero, and east central Catamarca). An additional 4% are produced in the eastern provinces (Entre Ríos, Chaco, Corrientes, and Misiones). Numerous cultivars ranging from maturity groups III to IX (Johnson 1987) are available from public institutions as well as from private national and international companies. Soybean in Argentina is planted as a single annual crop or as a second crop following wheat.

Diseases have gradually become a major problem for soybean production in many areas of Argentina, particularly since the early 1990's. Several new diseases have appeared since the 1993–1994 season, and some of them caused major losses in 1998 (Table 2).

Sclerotinia stem rot [*Sclerotinia sclerotiorum* (Lib.) de Bary] has been the most important disease affecting soybean in the northern Pampean subregion. In the 1997–1998 growing season, abundant rainfall and mild temperatures favored the disease, and it caused yield losses greater than in previous seasons. In addition, this disease continued to spread into new areas, favored by monocropping and no-till production practices.

Phytophthora root and stem rot [*Phytophthora sojae* (Kaufman & Gerdemann)], sudden death syndrome (SDS) [*Fusarium solani* f. sp. *glycines* Roy], and brown stem rot [*Phialophora gregata* (Allington & Chamberlain) Gams] caused more soybean yield losses in 1998 than in previous years. Race 1 of *Phytophthora sojae* continued to be prevalent in this region, although race 4 was also found in a few fields.

Stem canker [*Diaporthe phaseolorum* f. sp. *meridionalis* (Fernandez)] incidence decreased in 1997–1998 after causing major losses in susceptible cultivars in the previous year. The lower levels of this disease were mostly due to farmers planting resistant cultivars and the absence of favorable environmental conditions for the disease.

Soybean cyst (SC) [*Heterodera glycines* Ichinohe] was identified as a problem for the first time in the Pampean region in the 1997–1998 season. It is now estimated that there are more than 500 000 ha infested with this nematode. Soybean yield losses of up to 58% were caused by SC in individual fields in Córdoba and Santa Fe.

Other endemic diseases detected during the season in the northern Pampean subregion were anthracnose [*Colletotrichum truncatum* (Schwein) Andrus & Moore], phomopsis seed decay [*Phomopsis* spp.], purple stain of seed [*Cercospora kikuchii* (Matsumoto & Tomoyasu) Gardner], downy mildew [*Peronospora manshurica* (Naumov) Syd.], bacterial blight [*Pseudomonas savastanoi* pv. *glycinea* (Coeper) Gardan et al.], soybean mosaic virus, and root knot nematodes [*Meloidogyne* spp.].

In the northwestern region of Argentina, sclerotinia stem rot and SDS continued to increase in severity and incidence. Environmental conditions were favorable for stem canker and significant losses occurred in fields planted with susceptible cultivars in 1997–1998. Overall levels of this disease decreased considerably from previous years because of the use of resistant cultivars.

Other diseases that increased in the northwestern region during 1997–1998 were brown spot [*Septoria glycines* (Hemmi)], bacterial blight, phomopsis seed decay, and purple stain of seed, and all were favored by above average rainfall.

The most important soybean viral disease in this northwestern region, detected for the first time in Salta in 1988, is caused by a white fly transmitted gemini virus. In 1997–1998, a decline in incidence and severity was observed throughout the region, probably due to unfavorable conditions for the vector.

Three new diseases were detected in the northwestern region in the 1997–1998 season. Frog-eye leaf spot [*Cercospora sojina* Hara] and powdery mildew [*Microsphaera diffusa* Cooke & Peck] appeared late in the growing season and caused minor yield loss. Postharvest soil sampling also

Table 1. The causal organisms of commonly occurring soybean diseases in the top 10 soybean-producing countries in 1998.

Common name	Causal organism
Anthracnose	*Colletotrichum truncatum*
Bacterial diseases	*Pseudomonas savastanoi* pv. *glycinea* and *Xanthomonas axonopodis* pv. *glycines*
Brown spot	*Septoria glycines*
Brown stem rot	*Phialophora gregata*
Charcoal rot	*Macrophomina phaseolina*
Diaporthe–phomopsis complex	*Diaporthe* and *Phomopsis* spp.
Downy mildew	*Peronospora manshurica*
Frog-eye leaf spot	*Cercospora sojina*
Fusarium root rot	*Fusarium* spp.
Phytophthora root and stem rot	*Phytophthora sojae*
Pod and stem blight	*Diaporthe phaseolorum* var. *sojae*
Powdery mildew	*Microsphaera diffusa*
Purple stain of seed and cercospora leaf blight	*Cercospora kikuchii*
Rhizoctonia foliar blight	*Rhizoctonia solani*
Rhizoctonia–pythium root rot	*Rhizoctonia solani* and *Pythium* spp.
Root knot nematodes and other nematodes	*Meloidogyne* spp., *Hoplolaimus* spp., *Pratylenchus* spp., and *Rotylenchulus reniformis*
Rust	*Phakopsora pachyrhizi* and *Phakopsora meibomiae*
Sclerotinia stem rot	*Sclerotinia sclerotiorum*
Seed diseases	*Alternaria* spp., *Cercospora* spp., *Corynespora*, *Cladosporium*, *Phomopsis*, and *Fusarium* spp.
Seedling diseases	*Rhizoctonia*, *Pythium*, and *Fusarium* spp.
Southern blight	*Sclerotium rolfsii*
Soybean cyst	*Heterodera glycines*
Stem canker	*Diaporthe phaseolorum* var. *caulivora* and var. *meridionalis*
Sudden death syndrome	*Fusarium solani* f. sp. *glycines*
Virus diseases	Soybean mosaic virus and bud blight

showed the presence of SC in this region; it is restricted to a few locations in Tucumán.

In the eastern provinces, stem canker and phytophthora root and stem rot were the most prevalent problems in the 1997–1998 season. Pre- and post-emergence damping-off due to phytophthora root and stem rot caused frequent reductions in stand and resulted in weak plants that were later affected by other minor diseases.

Bolivia

In 1998, Bolivia harvested 490 000 ha of soybean in the summer (mean yield was 1980 kg/ha) and 109 000 ha in the winter (mean yield was 1100 kg/ha). Soybean production in 1998 was 1 090 100 t. About 95% of Bolivia's soybean crop in 1998 was produced in the Santa Cruz de la Sierra county.

Santa Cruz de la Sierra can be divided into three soybean production regions (north, south, and east) based on climate and soil types. The northern region is characterized by flat fields, fertile soils rich in silt, and frequent flooding in the summer months. The majority of Bolivia's soybean crop is produced in this region. Soils in the south region are sandy, and drought occurs frequently. The eastern region, where soybean production is expanding, consists of flat fields of fertile soils with frequent droughts. The climatic conditions in each region have a great influence on disease development. Foliar diseases are more serious where rainfall is more abundant, and root diseases, especially charcoal rot [*Macrophomina phaseolina* (Tassi) Goidanich], are more severe in the drought prone lands.

Bolivia's summer crop of soybean is planted in late October and harvested in April. The winter crop, which equals about one third of the summer crop, is planted in May and harvested in September. The winter crop is primarily used as seed for the summer crop. The average yield of the winter crop (1600 kg/ha) is much lower than that of the summer crop (2500 kg/ha), but the seed quality is better.

Soybean yield losses due to diseases in Bolivia during 1998 (Table 2) were estimated at 20% (258 150 t) and valued at U.S. $\$57 \times 10^6$ (U.S. \$220.50/t). The diseases most commonly seen in Bolivia were brown spot, cercospora leaf blight [*Cercospora kikuchii* (Matsumoto & Tomoyasu) Gardner], purple stain of seed, target spot [*Corynespora cassiicola* (Berk & Curtis) Wei], anthracnose, downy mildew, charcoal rot, southern blight [*Sclerotium rolfsii* Sacc.], fusarium root rot [*Fusarium* spp.], rhizoctonia root and stem rot [*Rhizoctonia solani* Kühn], soybean mosaic virus, bud blight, bacterial blight, and root knot nematodes. The winter soybean crop in 1998 was severely affected by powdery mildew.

Losses due to stem canker were lower in 1998 than in recent years because of high temperatures and reduced rainfall. In addition, during 1998, more than half of the soybean area in Bolivia was planted to stem canker resistant cultivars. The planting of resistant cultivars contributed to the decreased incidence of this disease.

Brazil

Yield losses to diseases in Brazil in 1998 (Table 2) were estimated at U.S. $\$1.6 \times 10^9$.

Table 2. Estimated reduction of soybean yields in thousand metric tons for the top 10 soybean-producing countries during 1998.

Disease	Argentina	Bolivia	Brazil	Canada	China	India	Indonesia	Italy	Paraguay	United States	Total
Anthracnose	36.8	0.3	2.0	—	16.6	—	5.0	2.1	0.5	188.9	252.2
Bacterial diseases	18.4	—	—	—	16.6	—	10.0	—	—	27.0	72.0
Brown spot	55.2	50.3	2194.9	0.8	—	—	—	—	120.0	167.0	2588.2
Brown stem rot	73.6	—	—	2.9	—	—	—	—	—	398.8	475.3
Charcoal rot	18.4	26.5	750.0	2.9	—	—	—	0.7	180.0	1036.8	2015.3
Downy mildew	—	—	—	0.3	182.3	—	5.0	1.4	—	24.1	213.1
Frog-eye leaf spot	—	—	—	—	497.2	—	2.5	—	—	106.3	606.0
Fusarium root rot	—	0.2	—	7.3	248.6	438.5	5.0	—	—	86.6	786.2
Phomopsis seed decay	73.6	0.3	2.5	1.5	—	—	—	1.4	0.5	243.8	323.6
Phytophthora root and stem rot	92.0	—	—	14.6	8.3	—	—	2.1	—	1149.0	1266.0
Pod and stem blight	36.8	0.2	627.1	1.5	82.9	438.5	—	2.8	0.6	143.6	1334.0
Powdery mildew	—	40.0	156.8	—	—	—	—	—	80.0	—	276.8
Purple stain of seed	36.0	60.0	940.7	—	49.7	—	2.5	—	115.0	112.4	1316.3
Rhizoctonia foliar blight	—	—	14.4	—	16.6	876.9	—	—	—	111.5	1019.4
Root knot nematodes and other nematodes	73.6	—	313.6	—	16.6	—	—	—	—	128.0	531.8
Rust	—	—	—	—	198.9	—	60.0	—	—	—	258.9
Sclerotinia stem rot	423.2	—	1.5	11.7	82.9	438.5	—	6.4	1.0	509.0	1474.2
Seed disease	18.4	0.5	2.0	—	82.9	—	—	0.7	0.5	45.8	150.8
Seedling disease	36.0	—	1.5	20.4	82.9	—	5.0	1.4	—	776.9	924.1
Southern blight	—	—	—	—	—	—	2.5	—	—	9.2	11.7
Soybean cyst	55.2	—	480.0	94.9	745.9	—	—	—	—	7593.4	8969.4
Stem canker	128.8	10.0	10.0	2.9	—	—	—	7.9	1.5	30.0	191.1
Sudden death syndrome	147.2	—	200.0	1.8	—	—	—	—	5.0	900.6	1254.6
Virus diseases	55.2	—	—	—	580.1	438.5	50.0	2.8	—	250.6	1377.2
Other diseases*	18.4	70.0	130.0	7.3	165.7	438.5	—	0.7	3.5	—	834.1

*Rhizoctonia root and stem rot in Canada; root rot due to *Fusarium* spp., *Pythium* spp., and *Rhizoctonia* spp. of plants during pod development in India; target spot in Brazil and Paraguay.

Several diseases appeared in localized areas in 1997–1998. Rust [*Phakopsora meibomiae* (Arth.) Arth.] and ascochyta leaf spot [*Ascochyta soja* Miura] developed in south Paraná and on the high plains of central Brazil. Myrothecium leaf spot [*Myrothecium roridum* Tode ex Sacc.] developed in the warm, humid regions of central and north Brazil. These diseases caused little if any yield loss.

Some diseases were restricted to certain areas and caused losses up to 50–60% in some fields. Brown stem rot and phytophthora root and stem rot developed in Rio Grande do Sul and Santa Catarina. Rhizoctonia root and stem rot developed in southern Paraná and Santa Catarina. Sclerotinia stem rot developed in southern Paraná, Santa Catarina, Rio Grande do Sul, and in the high plains of the savannah region of central Brazil. Rhizoctonia foliar blight [*Rhizoctonia solani* Kühn] occurred in the Mato Grosso, Tocantins, Maranhão, Piauí, Pará, Rondònia, and Roraima. Damping-off, due to *Sclerotium rolfsii* and *Rhizoctonia solani*, occurred in the states of Paraná, São Paulo, and Rio Grande do Sul. Target spot was important in southern Paraná and in many fields in central Brazil. Anthracnose and phomopsis seed decay occurred in central and northern Brazil.

Two of the most conspicuous and widely distributed diseases in Brazil were brown spot and cercospora leaf blight. Yield reductions of as much as 47% occurred in some fields because of these two diseases. Currently, more than 10% of soybean fields in Brazil are sprayed with fungicides to control late season foliar diseases.

Charcoal rot has caused great losses of soybean in the drought prone regions of the states of Paraná, Sao Paulo, Rio Grande do Sul, Mato Grosso, Bahia, Tocantins, and Goiás. Yield losses to this disease have reached 50% in some fields.

Sudden death syndrome has increased in southern parts of Brazil and in the cooler high plains of the savannah region. Yield losses have reached 30–40% in some fields. This disease is widely distributed and no controls are available; it is now regarded as the most important fungal disease in Brazil.

Root knot nematodes [*Meloidogyne incognita* (Kofoid & White) Chitwood and *Meloidogyne javanica* (Treuls) Chitwood] are widely distributed in Brazil and have caused significant yield reduction in many fields. Successful control has been achieved in some fields by crop rotation and by planting tolerant cultivars.

More than 2 000 000 ha in Brazil are infested with SC, and yields were reduced, in 1998, by 480 000 t. This pest was not detected in 1992. Eleven races of *H. glycines* have now been identified in Brazil.

Losses due to bacterial pustule [*Xanthomonas axonopodis* pv. *glycines* (Nakano) Vauterin et al.], frog-eye leaf spot, and stem canker in Brazil have declined recently because farmers plant disease resistant soybean cultivars. Other diseases, such as brown stem rot, phytophthora root and stem rot, SC, and root knot nematodes have been partially controlled either by planting resistant cultivars or by crop rotation and soil management. Powdery mildew and target spot have been controlled by planting resistant cultivars and foliar fungicides. Recently, more than 10% of the soybean fields have been treated with fungicides in Brazil, and about 80% of the seed has been treated with fungicides prior to sowing for disease control.

Canada

Soybean production in Canada has increased since 1994, especially in eastern Ontario and in Quebec. This was the result of development of high yielding short-season cultivars adapted to cool conditions. Total area planted to soybean increased from 836 000 ha in 1994 to 966 000 ha in 1998. Some annual variation occurred depending on production of rotation crops such as corn and wheat.

Disease management practices involving minimum tillage have increased in all production areas, and this has had some impact on the incidence of certain pathogens that overwinter on debris, such as those that cause brown stem rot and stem canker. Both diseases have increased in incidence and severity, and resistant and tolerant cultivars will be required in the future.

The most important soybean pathogen in Canada is SC (Table 2). Since 1987 SC has been identified in eight counties of Ontario that produce approximately 80% of the crop in Canada. Infestations in four new counties have been identified since 1994, and the infested area has increased from 60 000 in 1994 to 100 000 ha in 1998. Race 3 of SC is predominant in Ontario field populations, although additional virulence types can be found in certain fields. Originally SC was found only on coarse textured soils, but recently it has also been found causing yield losses on fine textured soils. Soil sampling, crop rotation, and resistant cultivars are recommended to reduce losses from SC.

Sclerotinia stem rot continues to be a major problem in wet, cool years. The disease has spread to the new short-season growing areas of Ontario and Quebec.

Sudden death syndrome was identified in Ontario in 1996. This disease is generally found in association with SC and is increasing in severity and distribution.

Fusarium–rhizoctonia root rot complex was observed in many areas following heavy rainfall early in the growing season in 1998. *Fusarium solani* was isolated from roots of wilted plants.

Phytophthora root and stem rot continues to be an important disease, but cultivars with tolerance and the *Rpsl-k* gene for resistance are still effective in reducing damage in most areas. Isolates of *Phytophthora* with numerous genes for virulence against genes for resistance are present in Ontario and Quebec.

China

Since 1994, farmers in China have harvested soybean from 8×10^6 to 10×10^6 ha each year. Production over this time averaged between 13×10^6 and 15×10^6 t. Recently, several diseases have seriously reduced production (Table 2). The diseases that caused the most yield losses were soybean mosaic, rust, frog-eye leaf spot, downy mildew, SC, and fusarium root rot.

Soybean mosaic virus has been a problem in all soybean production areas of China and has caused yield losses exceeding 50% in some fields. The yield losses, 5–7%, vary among regions because of planting dates, cultivar resistance, time of infection, and the virulence of existing soybean mosaic virus strains.

Soybean cyst and root knot nematodes caused yield losses mainly in northeast China and the Huanghuai district. Losses to SC have been estimated to exceed 50% in some fields. Races 1 and 3 of *H. glycines* have been found in northeast China and races 2, 4, 5, and 7 have been found in the Huanghuai district. Root knot nematodes were found in Huanghuai and some provinces in the south. Root knot nematode [*Meloidogyne hapla* Chitwood] was found most often in the region between 35 and 40°N. *Meloidogyne incognita* and *Meloidogyne arenaria* (Neal) Chitwood were found most frequently in areas south of 35°N and *M. javanica* was most often found in areas south of 25°N.

Rust has been found in most soybean-producing areas of China, although severity is greater in south China. Yield losses of 10–30% due to rust are common in southern China. Several races have been differentiated in China. No immune soybean lines have been identified, but 74 lines of 8700 tested have some level of resistance. The soybean cultivars Jiuyuehuang, Yushanqingpidou, Zhongdou 19, Zhongyou 84–87, and Zhongyou R-34 have some resistance to rust.

Downy mildew has occurred in most soybean-producing areas of China, though it is most severe in Heilongjiang and Jilin. Three races of this pathogen have been found in China. Soybean lines resistant to downy mildew have been identified and several resistant cultivars have been released to farmers.

Frog-eye leaf spot has caused severe damage to soybean in northeast China, especially in Heilongjiang. Yield losses have exceeded 50% in a few fields. Race 1 of *C. sojina* has been most often isolated from tissue samples collected from Heilongjiang, but race 7 has also been frequently isolated from these samples. Eleven races of this fungus have been identified in China. The incidence of the disease is greatly increased by rain and high relative humidity between early July and mid-August. In addition, several resistant cultivars, such as Hefeng No. 27 and Suinong No. 8, have been released.

Pod and stem blight [*Diaporthe phaseolorum* var. *sojae* (Lehman) Wehmeyer], purple stain of seed, and sclerotinia stem rot caused heavy losses in some areas of China in 1998.

Phytophthora root and stem rot and black root rot [*Cylindrocladium crotalariae* (Loos) Bell & Sobers] have become of great concern in China but have not seriously reduced yield. Phytophthora root and stem rot, first found in the northeast regions of China in 1989, has recently been found in Heilongjiang, Beijing, and Shandong. Race 1 of the pathogen has been identified from samples collected in Heilongjiang. A quarantine has been established in China to prevent the spread of this pathogen. Black root rot has caused losses up to 20% in a few fields since it was first reported in Jiangsu in 1987.

India

The major soybean-producing states in India are Madhya Pradesh, Maharastra, Rajasthan, Gujarat, and Uttar Pradesh. Soybean is now the number two oilseed crop in India after groundnut. About 90% of India's soybean crop is planted during July, and the remainder is planted during the spring but only in central and southern India.

Several diseases have reduced soybean yields in India (Table 2). Extensive yield losses occurred during 1998 because of fusarium root rot, pod and stem blight, rhizoctonia foliar blight, and sclerotinia stem rot. Soybean cultivars resistant to yellow mosaic virus and bacterial pustule have been planted by farmers and losses to these two diseases were low in 1998.

Indonesia

The major areas for soybean production in Indonesia are East Java (30% of production), Central Java (20%), West Nusa Tenggara (15%), Lampung (10%), and Aceh (10%), with other provinces accounting for a total of 15%. About 60% of this crop is produced during the dry months (April–August) and is usually planted in lowland fields after rice. The remainder is grown during the rainy season in upland fields after the harvest of upland rice, maize, or legumes. The cropping patterns in the lowland areas are rice–rice–soybean, rice–soybean–soybean, or rice–soybean, whereas in the upland areas, the patterns are maize–soybean, rice–soybean, or soybean–soybean.

Disease incidence has varied from location to location, from season to season, and with cropping system or crop rotation. In general, disease incidence has been low in soybean grown during the dry season (soybean planted after rice), but it has been high in soybean grown during the rainy season. The incidence of diseases has been greater for soybean following soybean. Late plantings suffered more from diseases than earlier plantings.

The major diseases of soybean in Indonesia, during 1998, were rust and virus diseases (Table 2). Bacterial diseases, anthracnose, fusarium root rot, rhizoctonia root and stem rot, downy mildew, frog-eye leaf spot, southern blight, and purple stain of seed also damaged crops. Estimated yield losses to diseases in Indonesia for 1998 were valued at U.S. $\$32.5 \times 10^6$ (147 500 t × U.S. $220.5/t). Losses to virus diseases have been increasing over time, but losses to other diseases have been unchanged.

Italy

Soybean, although subject to competition with other oil crops (sunflower, canola, etc.) because of agriculture regulations within the Europe, has remained important in most areas of northern Italy in the last 4 years.

Soybean disease incidence and severity has remained rather stable recently, probably because of crop rotation. Nevertheless, slight increases have been observed for stem canker, charcoal rot, and anthracnose. Soybean losses due to phytophthora root and stem rot have declined recently, except in areas in which susceptible cultivars are still planted.

Soybean yields in 1998 were exceptionally low because of an unusual summer drought followed by a rainy period during harvest. Except for a few areas in the northeast (Mantova, Padova, Venice) where the yield averaged 4.0–4.5 t/ha, yield was often lower than 3.0 t/ha, with an average of 3.5 t/ha for the country. Some fungal diseases contributed to further yield losses in 1998 (Table 2). Bacterial and viral diseases were present but caused little yield loss. The impact of the difficult growing season in 1998 on growers will likely cause a reduction in soybean growing areas in the near future.

Paraguay

Soybean production in Paraguay is concentrated in counties neighboring Brazil. The average rainfall during the soybean growing season (October–May) varies from 1200 to 1450 mm.

Until a few years ago, soybean diseases were regarded as of little importance in this country. It was only after the outbreak of stem canker in 1993 that diseases gained some recognition. Soybean disease development in Paraguay is favored by monocropping of soybean, high plant populations, and the generalized adoption of no-tillage without crop rotation. Most of the diseases that occur in Brazil also damage the crop in Paraguay.

The main diseases that affect soybean in Paraguay are brown spot, cercospora leaf blight, target spot, powdery mildew, and especially charcoal rot (Table 2). Under normal conditions, late season diseases such as brown spot and cercospora leaf blight may reduce yields as much as 20%. In 1997–1998, charcoal rot caused yield losses up to 50% in many fields. Soybean cyst, phytophthora root and stem rot, and brown stem rot have not been reported in Paraguay.

Other diseases that occasionally cause yield reduction in Paraguay are anthracnose, phomopsis seed decay, rhizoctonia root and stem rot, SDS, and southern blight. Root knot nematodes are regarded as of minor importance in Paraguay. The average soybean yield losses due to diseases in Paraguay in 1998 were estimated at 15%.

United States of America

The majority of soybean produced in the United States during 1998 was from Iowa, Illinois, Minnesota, Indiana, Ohio, Missouri, Nebraska, and South Dakota. These north central states produced 78% of the 1998 United States crop. Fifteen states in the southern region produced 12% of the crop in 1998 compared to 18% in 1994.

Estimated soybean yield losses in the United States in 1998 (Table 2) were valued at U.S. $\$3.1 \times 10^9$ (14.1×10^6 t $\times$ U.S. \$220.5/t) compared to U.S. $\$0.9 \times 10^9$ in 1994 (Wrather et al. 1997). The estimated losses due to individual diseases varied among years from 1996 to 1998 (Wrather et al. 2001). No losses were reported in 15 southern states because of brown stem rot, and no losses were reported in 13 northern states because of rhizoctonia foliar blight or southern blight. Root knot nematodes and other nematodes, frog-eye leaf spot, and phomopsis seed decay were estimated to have caused more losses in the south than the north regions of the United States.

The greatest losses across the United States in 1998 were caused by SC, followed by phytophthora root and stem rot, charcoal rot, SDS, and seedling diseases. The estimated losses due to sclerotinia stem rot in 1998 (509 000 t) declined from those reported for 1996 (614 000 t) and 1997 (958 000 t) (Wrather et al. 2001). The decline in losses due to sclerotinia stem rot between 1997 and 1998 were probably due to weather patterns.

Conclusion

Clearly, diseases caused extensive reductions in soybean yield in the top 10 soybean-producing countries during 1998. The total estimated loss due to diseases in these countries was 28.5×10^6 t, valued at U.S. $\$6.29 \times 10^9$, in contrast to 14.99×10^6 t, valued at U.S. $\$3.31 \times 10^9$ in 1994. Yield losses in some countries may have been worse if not for the use of disease management strategies and systems. Scientists at the universities developed most of the disease-resistant cultivars and other disease management strategies and systems. To reduce disease losses, research and extension efforts must be expanded to provide more effective preventive and therapeutic strategies and systems.

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References

Hartman, G.L., Sinclair, J.B., and Rupe, J.C. (*Editors*). 1999. Compendium of soybean diseases. 4th ed. American Phytopathological Society, St. Paul, Minn.

Johnson, R.R. 1987. Crop management. *In* Soybeans: improvement, production, and uses. 2nd ed. *Edited by* J.R. Wilcox. American Society of Agronomy, Madison, Wis., Agronomy monograph No. 16. pp. 355–390.

United States Department of Agriculture. 1998. World agriculture production: crop production tables. Foreign Agriculture Service, Washington, D.C. (Available on line: http://www.fas.usda.gov/WAP/circular/1998/98–12/tables.html)

Wrather, J.A., Chambers, A.Y., Fox, J.A., Moore, W.F., Sciumbato, G.L. 1995. Soybean disease loss estimates for the Southern United States, 1974 to 1994. Plant Dis. 79: 1076–1079.

Wrather, J.A., Anderson, T.R., Arsyad, D.M., Gai, J., Ploper, L.D., Porta-Puglia, A., Ram, H.H., and Yorinori, J.J. 1997. Soybean disease loss estimates for the top 10 soybean-producing countries in 1994. Plant Dis. 81: 107–110.

Wrather, J.A., Stienstra, W.C., and Koenning, S.R. 2001. Soybean disease loss estimates for the United States from 1996 to 1998. Can. J. Plant Pathol. 23: 122–131.