NPAG DATA: *PHAKOPSORA PACHYRHIZI*
AUSTRALASIAN SOYBEAN RUST

Draft - December 9, 2002

Exotic Fungus Not in the Continental United States

TAXONOMY

Phylum: Basidiomycota
Class: Urediniomycetes
Order: Uredinales
Family: Melampsoraceae

Full Name: *Phakopsora pachyrhizi* H. Sydow & Sydow
Synonyms: *Phakopsora sojae* Fujikuro
Phakopsora calothea H. Sydow
Malupa sojae (P. Hennings) Ono, Buritica, & Hennen comb. nov. (Anamorph)
Uredo sojae P. Hennings
(For additional synonyms, see the following: Green, 1984; Ono *et al*., 1992)

US DETECTION DATA

Initial Detection in Hawaii

Location: Mililani, Oahu Island, Hawaii
Date: May 1994
Host: Soybeans, grown as green vegetable (*Glycine max*)
Collector: Hawaii Department of Agriculture
Honolulu, HI
Identifier: Dr. J. Hennen, Arthur Herbarium
West Lafayette, IN
Identifier: Dr. Reid Frederick, Foreign Disease/Weed Research Unit
Frederick, MD (Promed 03/09/2001)
Iden. Date: 1994 (Dr. J. Hennen) (Killgore & Heu, 1994)
2000 (Dr. Frederick, Promed 03/09/2001)

Fields with infected plants were subsequently found in Waimanalo (100% infection) and Kahaluu (80% infection) on the windward side of Oahu, with neighboring fields apparently rust-free. In July 1994, moderate infection (10-20% of plants) was found in a field near Kakaha, Kauai and 80% infection occurred near Hilo, Hawaii (Killgore & Heu, 1994).

Subsequent Detections in the Continental US

Detections in the continental United States are not known.

QUARANTINES

Phakopsora pachyrhizi has long been considered a pest of major quarantine importance. In *The Emigrant Pests*, a 1973 report to the Administrator of APHIS, *Phakopsora pachyrhizi* was in a list of "The 100 Most Dangerous Exotic Pests and Diseases" (Number 22). The estimated loss in yield per acre was 50%. The cost per acre was estimated at $20 (McGregor, 1973). A 1984 PINKTO (Pests Not Known To Occur in the United States) No.56 also dealt with soybean rust (Green, 1984).

The initial, extensive range of Australasian soybean rust in Asia and Australia and its comparatively recent introduction to Africa and South America will render it less important as a pest of major quarantine importance. At this time, the only continents uninfested are Europe and North America (*see* Distribution *and* Pertinent Points).

LIFE HISTORY

According to Alexopoulos, Mims, and Blackwell (1996), a rust fungus may produce as many as five different stages in its life cycle:

Stage 0	Spermagonia bearing spermatia (n) and receptive hyphae (n)
Stage I	Aecia bearing aeciospores (n + n)
Stage II	Uredinia bearing urediniospores (n + n)
Stage III	Telia bearing teliopores (n + n → 2n)
Stage IV	Basidia bearing basidiospores (n)

Phakopsora pachyrhizi is usually described from the uredinial and telial stages; production of all five stages is uncertain (Green, 1984). Like all rust fungi, *Phakopsora pachyrhizi* is an obligate parasite, that is, it requires living host cells.

Stage 0: Spermagonia are not known to exist (Green, 1984).

Stage I: Aecia are not known to exist (Green, 1984).

Stage II: Uredinia are amphigenous (growing all round), mostly hypophyllous (on the under surfaces of leaves), minute, scattered or in groups on discolored lesions. Subepidermal in origin, the uredinia are surrounded by paraphyses arising from peridioid pseudoparenchyma; in addition the uredinia have hymenal paraphyses. Openings are through central apertures. In appearance, the uredinia are pulverulent (appearing as if powdered); in color, uredinia are pale cinnamon-brown (Ono *et al*., 1992).

Paraphyses are cylindric to clavate, 25-50 x 6-14 microns, slightly to conspicuously thickened apically (-18 microns). The color of the paraphyses ranges from pale yellowish-brown to colorless (Ono *et al*., 1992).

Urediniospores are sessile, obovoid to broadly ellipsoid, 18-34 to 15-24 microns, and minutely and densely echinulate. The walls are uniformly about 1 micron thick. The color of the urediniospores ranges from pale yellowish-brown to colorless. In number, germ pores are mostly 6 (2 or 4 to 8 or 10). In position, germ pores are equatorial or scattered on the equatorial zone; on occasion, germ pores are scattered on or above the equatorial zone (Ono *et al*., 1992).

Stage III: Often mixed with uredinia, the subepidermal telia are hypophyllous and crustose (crust-like). In color, the telia are chestnut-brown to chocolate brown. Internally, the telia are 2- to 7-spored layered (Ono *et al*., 1992).

The single-celled teliospores are irregularly arranged, angularly subglobose, oblong to ellipsoid. In size, the teliospores are (10-)15-26 x 6-12 microns. In color, the teliospores are pale yellowish-brown to colorless. Teliospore walls are uniformly around 1 micron thick; however, in the outermost teliospores the walls are thickened apically to 3 microns (Ono *et al*., 1992).

Stage IV: In 1984, Green could note “No germination of teliospores has been reported.” However, in 1991, Saksirirat and Hoppe reported germination of teliospores.

(*Also see* Pertinent Points.)

HOSTS

Because of confusion over the taxonomy of the pathogens causing soybean rust, *Phakopsora meibromiae* and *Phakopsora pachyrhizi*, the list of the hosts of *Phakopsora pachyrhizi* may be incomplete; however, according to various recent references, a large number of legume species are host plants for *Phakopsora pachyrhizi*. *Phakopsora pachyrhizi* naturally infects 31 legume species in 17 different genera (McBride, 1998; Sinclair & Hartman, 1996). *Phakopsora pachyrhizi* has been known to infect and sporulate in the field on 35 species in 18 genera of the Subfamily Papilionoideae in the Fabaceae. *Glycine max*, *G. sojae*, *Pachyrhizus erosus*, *Pueraria lobata*, and *Vigna unguiculata* are the principle hosts (CABI, 2001).

The following table (e-mail from Hartman citing Tschanz, 1985 & 1982; Ono *et al*., 1992; use information from Bailey & Bailey, 1976) lists legume species that develop rust symptoms and uredinia and urediniospores when inoculated with *Phakopsora pachyrhizi*:

Scientific Name	**Common Name**	
Alysicarpus glumaceus	Alyce clover	(Naturalized in West Indies and FL?)
Cajanus cajan	Cajan, pigeon pea	Widely cultivated in trop. countries
Centrosema pubescens	Butterfly pea	Frequent in fields; W. Indies & Mex.
Crotalaria anagyroides	Rattlebox	Tropical northern South America
Delonix regia	Royal Poinciana	Wide-branching tree
Glycine canescens	Soybean relative	
G. *clandestina*	Soybean relative	
G. falcata	Soybean relative	
G. max	Soybean	Major agricultural crop in US
G. tabacina	Soybean relative	
Lablab purpureus	Hyacinth bean	(*Dolichos purpureus*)
Lotus americana	(Not in *Hortus Third*)	
Lupinus hirsutus	Blue lupine	(Annual; southern Europe)
Macroptilium atropurpureum	Siratro; purple bean	Grows wild in Cen. and S. America
Macrotyloma axillare	(Not in *Hortus Third*)	
Medicago arborea	Medic	(Shrub; southern Europe)
Melilotus officinalis	Yellow sweet clover	Eurasia; naturalized in N. America
M. speciosus	(Not in *Hortus Third*)	
Mucuna cochinchinesis	Velvetbean relative	
Neonotonia (Glycine) wrightii	Glycine	(Old World probably)
Pachyrhizus erosus	Yam bean; jicama	C. America; naturalized in south FL
Phaseolus lunatus	Butter bean, lima bean	Tropical SA: important edible bean
P. vulgaris	Kidney bean; green bean	Tropical America; widely cultivated
Rhynchosia minima	(Not in *Hortus Third*)	
Sesbania exaltata	Colorado River hemp	NY to FL; west to southern CA
S. vescaria	(Not in *Hortus Third*)	
Trigonella foenum-gracecum	Fenugreek	(Asia & southern Europe; forage)
Vicia dasycarpa	Wooly-pod vetch	Europe; naturalized in US
Vigna unguiculata	Cowpea, black-eyed pea	Widely planted in warm regions

There are additional hosts (Ono *et al*., 1992). Kudzu, *Pueraria lobata*, is a host; in addition, *Pueraria phaseoloides* is a host (McBride, 1998; Ono *et al*., 1992). Because kudzu is a common weed in the southeastern United States, it might serve as a continual source of inoculum (*see* Pertinent Points).

DISTRIBUTION

Phakopsora pachyrhizi is present in Australasia where it occurs in Eastern Australia, Eastern Asia, and the islands between those land masses including Japan, the Philippines, and Taiwan (CMI Map No. 504; Sinclair & Hartman, 1996). (Sinclair and Hartman and also CMI Map No. 815 note that is found in the Caribbean, S. America and C. America.)

Asia:	Russia Far East (CABI, 2001; Ono *et al*., 1992)
	Korea (CABI, 2001; Ono *et al*., 1992; Shin & Tschanz, 1986)
	Japan (CABI, 2001; Ono *et al*., 1992; Sinclair & Hartman, 1996)
	China (CABI, 2001; Green, 1984; Ono *et al*., 1992)
	Taiwan (Ono *et al*., 1992; Sinclair & Hartman, 1996)
	Philippines (Ono *et al*., 1992; Sinclair & Hartman, 1996)
	Nepal (Ono *et al*., 1992; Sinclair & Hartman, 1996)
	India (Ono *et al*., 1992Sinclair & Hartman, 1996)
Australia:	Australia (Green, 1984; Ono *et al*., 1992)
Africa:	Nigeria (Akinsanmi *et al*., 2001)
	Mozambique, Rwanda, Uganda, S. Africa, Zambia, Zimbabwe (Kloppers, 2002)
S. America:	Brazil, Paraguay (Dr. Frederick, e-mail to J. Floyd 05/14/2002)
	Argentina (D. Wimmer, e-mail to S. Warner-Page on SENASA Nota 1692)
Oceania:	USA (HI; McBride, 1998; Sinclair & Hartman, 1996)

Phakopsora pachyrhizi is widespread in Asia and Oceania (CABI, 2001); additional countries, such as those in southeastern Asia, are infested (CABI Map No. 504; Ono *et al*., 1992). (*Also see* Pertinent Points)

DAMAGE WHERE ESTABLISHED AND ESTIMATES

Recent Observations in Africa: In Nigeria, premature defoliation occurred on infected plants. Seed weight of TGX 1485-Id, TGX 1448-2E, and TGX 1440-1E was reduced by 28%, 52%, and 49%, respectively. Disease severity was higher on the medium-maturing cultivars than those planted late (Akinsanmi *et al*., 2001). In Zimbabwe, yield losses in commercial crops ranged between 60-80%. In South Africa in 2001, yield losses were in the region of 10-80%. In some areas, losses of up to 100% have been reported if monocropping, with no rotations, is practiced (Caldwell & Laing, 2002).

Workshop on Soybean Rust - 1995: The Australasian species of soybean rust could cause yield losses of greater than 10% in any soybean-growing region of the United States. In the southeastern United States where climatic conditions would favor the spread and development of disease, losses of up to 50% are possible (McBride, 1998; Sinclair & Hartman, 1996). These sources are probably citing the work of Yang, Dowler, and Royer (1991).

Estimates on Soybean Rust: Kuchler and coworkers (1984) analyzed the potential economic consequences if a virulent race of the soybean rust fungus were to become established in the United States. The analysis used an econometric-simulation model under two alternative environmental and grower response assumptions. Total losses to consumers and other sectors of the US economy were forecast to exceed $7.2 billion/year even with a conservative estimate of potential damage; however, profits to some soybean farmers and producers of other feed grains would rise (CABI, 2001; Kuchler *et al*., 1984).

Pests Not Known To Occur in the United States (PINKTO) NO. 56: Soybean rust is a major problem in soybean-growing regions of the Eastern Hemisphere. Losses in soybean yield during the 1971 rainy season in Thailand ranged from 10 to 30 percent. Reports from the southeastern areas of China indicate that losses of 10 to 30 percent are common and losses of over 50 percent occur in years with severe rust (Bromfield, 1980; Green, 1984).

Observations in the Orient (CABI, 2001): The following information is in the *Crop Protection Compendium* produced by CAB International:

- Estimated yield loses due to the rust infection were 15-40% in southern Japan and up to 70-80% in individual fields and 20-30% in the total crop in Taiwan (Bromfield, 1976; Yang, Tschanz, Dowler, & Wang, 1991)
- In field trials in Taiwan, yield losses were 18-57% (Chen, 1989)
- In a field trial in Korea, yield losses were 68.7% in a susceptible cultivar and 22.3% in a tolerant cultivar (Shin & Tschanz, 1986)

Observations in Australia: In a field trial conducted in Australia, seed-yield losses were 60-70% in the most severely infected plots without chemical control (CABI, 2001; Ogle *et al*., 1979).

METHODS OF CONTROL

Chemical Control: According to Dr. Reid Frederick (e-mail to J. Floyd, 05/13/02), the best and most recent fungicide data comes from Zimbabwe. Below is a portion of the email that contains data from Dr. Clive Levy, at the Commercial Farmer's Union (CFU) of Zimbabwe in Harare:

The Chemical Registration Authority (not the CFU) has approved the following chemicals and rates for the control of rust in Zimbabwe:

Trade Name	**Chemical Name**	**Application Rate** (per spray; ml/ha)	
Alto 100SL	cyproconazole	300	
Folicur 250EC	tebuconazole	1000	
Funginex	triforine	1500	
Impact	flutriafol	800	
Punch Xtra	flusilazole/carbendazim	350/500*	*lower rate ground
Score 250EC	difenoconazole	300/500*	higher rate aerial
Shavit 25EC	triadimenol	500	
Tilt 250EC	propiconazole	500	

The following website lists fungicides registered for use in South Africa:

http://www.saspp.org/archived_articles/tablesoybeanrust_2002.html

Even an effective fungicide will have purchase and application costs that will cut profits. An effective fungicide may be of little or no economic value to small-scale and marginal growers of legumes because of the prohibitive expense and/or effort.

Cultural Control: Cultural practices may be of some value. Destruction of weed hosts may decrease the inoculum level. However, the weed hosts are probably numerous or extensive in range (for example, kudzu) and the pathogen probably has the ability to disperse long distances (s*ee* Pertinent Points).

Increasing phosphorus levels has been found to reduce incidence of soybean rust. Irrigation should take place either in the middle of the day (so leaves can dry before dew sets in) or at night (so as not to extend the dew period) (Caldwell & Laing, 2002).

Growing early-maturing soybeans may limit the disease loss. In Nigeria, disease severity was higher on the medium-maturing cultivars and all those planted late (Akinsanmi *et al*., 2001).

Natural Enemies: Viruses are known to infect *Puccinia* and probably other rust fungi. *Darluca filum* attacks rust fungi in the Genus *Puccinia* and even helps keep *Puccinia asparagi* in check (Horst, 1990). In the Far East, a *Darluca* species does attack *Phakopsora pachyrhizi*; however, although very common, the level of attack does not appear to reduce loss (A. Tschanz, pers. com.). *Urocladium* and *Sphaerolopsis* may be effective as biocontrol agents (Caldwell & Laing, 2002). Biological control is probably *not* possible now or in the immediate future.

Resistance: Resistance may be available. Apparently, work was done by E. Hartwig who developed some breeding lines with resistance to soybean rust; however, more work needs to be done to evaluate germplasm with strong resistance to soybean rust (Mc Bride, 1998).

Perennial *Glycine* species often contain resistance to *Phakopsora pachyrhizi* (Hartman, Wang, & Hymowitz, 1992). When isolates from Australia, India, Taiwan, and Puerto Rico were tested on 110 soybean accessions, only two showed resistant-type (RB) lesions against all 4 isolates. Three distinct infection types were recognized: TAN (a tan lesion of about 0.4 sq mm, usually with 2 to 5 uredinia); RB (a reddish-brown lesion usually with 0 to 2 uredinia); and 0 (with no macroscopically visible evidence of rust) (Bromfield, Melching, & Kingsolver, 1980).

A set of differentials allowed nine races of *Phakopsora pachyrhizi* to be identified; however, the predominant race was compatible with 10 of the 11 differentials, and all races were compatible with three or more of the differentials. Apparently, some races of *Phakopsora pachyrhizi* in the field possess multiple virulence factors to known and suspected genes for resistance (Hartman, Sinclair, & Rupe, 1999).

Four dominant, independently inherited genes for resistance to *Phakopsora pachyrhizi* have been identified: Rpp1, Rpp2, Rpp3, and Rpp4. Other genes for resistance are likely (Hartman, Sinclair, & Rupe, 1999).

In 1961, the USDA soybean germplasm collection was field tested in Taiwan for resistance to soybean rust. Only two accessions, both of Japanese origin, exhibited appreciable resistance to soybean rust. No commercial U. S. soybean cultivars are resistant (Bromfield, 1980; Green, 1984).

Although moderate levels of resistance or tolerance to soybean rust may exist, screening for rust resistance under field conditions will be difficult. Based on symptoms under field conditions, later-maturing cultivars appear to be more resistant than earlier-maturing cultivars at any given time because the rate of rust development tends to parallel the rate of cultivar maturation. Most of the soybean cultivars reported as having a level of resistance to rust were tested under field conditions at the Asian Vegetable Research and Development Center in Taiwan and none were identified as having a high level of resistance that was stable over time (Tschanz, personal communication).

PERTINENT POINTS/PREDICTED CONSEQUENCES

Identification by Morphology: In 1992, *Phakopsora pachyrhizi* was indentified as one of at least two species causing soybean rust; in that year, two species were established based on morphological differences between their anamorphs and teliomorphs (Ono *et al*., 1992):

Phakopsora pachyrhizi includes the Australasian populations with the following characteristics:

- Telia are irregularly 2- to 7-spore layered
- Teliospore walls are pale yellowish-brown to colorless
- Teliospore walls are equally about 1 micron thick or slightly thickened apically to 3 microns in the outermost spores

Phakopsora meibomiae includes the New World populations with the following characteristics:

- Telia are irregularly 1- to 4(5)-spore layered
- Teliospore walls are cinnamon-brown to light chestnut-brown
- Teliospore walls are 1.5 to 2 microns thick but thickened apically to 6 microns in the outermost spores

Identification by PCR Assays: Classical and real-time fluorescent PCR (polymerase chain reaction) assays are available to identify and differentiate between *Phakopsora pachyrhizi* and *Phakopsora meibomiae*. Identification of *Phakopsora pachyrhizi* from infected soybean leaves using the real-time PCR assay will allow for more rapid diagnoses to the species level (Frederick *et al*., 2002).

Long-distance Dispersal of the Rust Fungus: To most plant pathologists, the long-distance dispersal of rust fungi and other fungi is an accepted fact (Brown, 1984; Davis, 1987; Nagarajan & Singh, 1990; Odvody *et al*., 1998). Nagarajan and Singh (1990) mention several instances of trans-Atlantic spread.

In 1978, sugarcane rust, which is caused by *Puccinia melanocephala*, appeared in the Americas (in the Dominican Republic), probably as a result of transoceanic transport of urediniospores from West Africa (Purdy, Krupa, & Dean, 1985). After the appearance in the Dominican Republic in July 1978, the sugarcane rust pathogen spread rapidly: Jamaica by early September, 1978; Puerto Rico by October, 1978; and Florida by March 1979.

Caldwell and Laing (2002) mention that the soybean rust pathogen was thought to be wind-borne from Asia to Africa.

Note: Besides aerial transport of the spores, long-distance dispersal of the Australasian soybean rust fungus could *possibly* occur by one or more of the following means:

- Movement of a legume as an ornamental (example, *Poinciana*)
- Movement of a legume as a medicinal plant (examples, lablab or pigeon pea) (Duke, 1981)
- Movement of a legume as a vegetable (examples, lablab or soybean) (Duke, 1981)
- Movement in an aircraft (Killgore & Heu, 1994)
- Movement of a legume as a forage (Duke, 1981) (See following section.)

Significance of Forages as Hosts: A number of common tropical forage plants are hosts (Ono *et al*., 1992). Other potential hosts are species in the same genera as the known hosts (*see* Hosts). As forages, the following species appear in *Handbook of Legumes of Economic Importance* (Duke, 1981) or in *Tropical Feeds* (Gohl, 1981):

Alysicarpus vaginalis	Alyce clover	Introduced to tropical America; in FL
Centrosema pubescens	Butterfly pea	Frequent in fields; W. Indies & Mex. Brazil, Colombia, Paraguay
Clitoria ternatea	Kordofan pea	Widespread in the tropics
Crotalaria anagyroides	Rattlebox	Native to South America
Delonix regia	Poinciana	Grows well in frost-free areas
Desmodium triflorum	Three-flower beggarweed	Tropics throughout the world
Macroptilium atropurpureum	Siratro; purple bean	Siratro, popular pasture plant; tropics
Lablab purpureus	Lablab; hyacinth bean	Used for hay and silage
Neonotonia (Glycine) wrightii	Glycine	Has a number of cultivars
Pueraria phaseoloides	Tropical kudzu	In tropics; both pasture and fodder

Throughout South America and the Caribbean, these forages will provide extensively grown hosts in a suitable environment.

Significance of Weeds as Hosts: A number of common weeds are hosts (butterfly pea, kudzu) or potential hosts because they are in the same genera of known hosts (*see* Hosts). The following species appear in *Economically Important Foreign Weeds* (Reed & Hughes, 1977) or in *Selected Weeds of the United States* (USDA-ARS, 1970):

Alysicarpus nummularifolius	(No common name?)	Introduced to tropical America
A. rugosus	Alyce clover	West Indies
Centrosema pubescens	Butterfly pea	Frequent in fields; W. Indies & Mex. Brazil, Colombia, Paraguay
Crotalaria saltiana	Rattlebox	Cosmopolitan in tropics
Lupinus angustifolius	Narrow-leaved lupine	North America
L. luteus	Yellow lupine	North America
Medicago lupulina	Black medic	Widespread throughout N. America
Pueraria lobata	Kudzu	Throughout southeastern U. S.
Vicia angustifolia	Narrow-leaf vetch	Throughout United States
V. narbonensis	Broad-leaved vetch	Sparse in United States

This list is far from complete; for example, an examination of *A Geographical Atlas of World Weeds* (Holm *et al*., 1979) and other sources would indicate other potential hosts, such as *Pueraria phaseoloides*, which is a "principal" weed of Puerto Rico.

The significance of weed hosts is that they will aid the movement of the rust fungus to the United States (possibly by "island-hopping" in the Caribbean) or its establishment in the United States (by providing non-crop hosts).

Note: The rust fungus will probably *not* persist from season-to-season by means of overwintering urediniospores. If the urediniospores are not able to persist, the fungus will probably persist in the Deep South or in southern Florida on weed or crop hosts; in this case, the urediniospores will probably be transported northward for long distances.

Significance of the Spread of *Phakopsora pachyrhizi* in Africa: The spread of *Phakopsora pachyrhizi* in Africa (at least the pathogen that severely affects soybeans) appears to have been very rapid. In 1999, soybean rust was observed on soybean in Nigeria (Akinsanmi *et al*., 2001). In an on-line article dated "Jan 2002," Dr. R. Kloppers and other sources reported Asian soybean rust (severe and on soybeans) in the following countries:

Mozambique	1999	ProMed 20010309- 03/09/2001 11:47:44
Nigeria	1999	Akinsanmi *et al*., 2001
Rwanda	1998	ProMed 20010309- 03/09/2001 11:47:44
South Africa	2001	ProMed 20010309; ProMed 20010310
Uganda	1998	ProMed 20010309- 03/09/2001 11:47:44
Zambia	1999	ProMed 20010309- 03/09/2001 11:47:44
Zimbabwe	1998	ProMed 20010309- 03/09/2001 11:47:44

Presumably, because of abundant hosts (soybeans, beans, and other susceptible legumes) and a similar climate, the spread in South America will be as rapid as in Africa. According to Dr. R. Frederick (16May02 Soybean Rust Meeting), *Phakopsora pachyrhizi* is in Argentina (2002), Brazil (2002), and Paraguay (2001).

Note: CABI (2001) seems to indicate an early introduction (in 1937!) to Africa. The map on *Phakopsora pachyrhizi* that was published by CAB International (Map No. 504; October 2000) also indicates an early introduction to Africa. However, the serious losses on soybean seem to have occurred only recently in Africa. (CAB International has also published a map on *Phakopsora meibomiae*: Map No. 815, October 2000)

Potential Range of the Rust Fungus: The attached maps (Walter *et al*., 1975) indicate that the Australasian soybean rust can establish in a number of Climatic Zones:

Zone II	Tropical Climatic Zone	Taiwan
Zone V-II	An Intermediate Climatic Zone	China
Zone V	Warm Temperate Climatic Zone	China; Japan (Kyushu)
Zone V-VI	An Intermediate Climatic Zone	Japan
Zone VI	Typical Temperate Climatic Zone	Japan (Honshu); Korea
Zone VI-VIII	An Intermediate Climatic Zone	Japan (Hokkaido); Russia (Sakhalin)

These maps indicate the abilty to establish in the major soybean-growing areas of the United States, if the ecotype of the rust pathogen is suitable.

REFERENCES

Akinsanmi, A., Ladipo, J., and Oyekan, P. 2001. First report of soybean rust (*Phakopsora pachyrhizi*) in Nigeria. *Plant Disease* 85(1):97

Alexopoulos, C. J., Mims, C. W., and Blackwell, M. 1996. *Introductory Mycology.* John Wiley & Sons, Inc., New York

Bailey, L. H. and Bailey, E. Z. 1976. *Hortus Third*. MacMillan Publishing Company, New York

Bromfield, K. R. 1984. *Soybean Rust*. Monograph 11. The American Phytopathological Society, St. Paul, MN

Bromfield, K. R. 1980. Soybean rust: Some considerations relevant to threat analysis. *Protection Ecology* 2(3):251-257 (Requested)

Bromfield, K. R. 1976. World Soybean Rust Situation. A chapter in *World Soybean Research*. Hill, L. D. (editor). Pages 491-500

Bromfield, K. R., Melching, J. S., and Kingsolver, C. H. 1980. Virulence and agressiveness of *Phakopsora pachyrhizi* isolates causing soybean rust. *Phytopathology* 70:17-21

Brown, J. S. 1984. Recent invasions of Australia and New Zealand by pathogenic fungi and counter measures. *EPPO Bull*. 14(3):417-428

CABI. 2001. *Phakopsora pachyrhizi*. From *Crop Protection Compendium*, a CD-ROM available from CAB International, Wallinford, Oxon OX10 8DE. E-mail: cabi@cabi.org

Caldwell, P. and Laing, M. 2001. Soybean rust - A new disease on the move. Available at the following website: http://www.saspp.co.za/

Chen, C. M. 1989. Evaluation of soybean rust tolerance at Hualien. *Soybean Rust Newsletter* 9:4-5 (Requested)

Davis, J. M. 1987. Modeling the long-distance transport of plant pathogens in the amosphere. *Ann. Rev. Phytopath.* 25:169-188

Duke, J. A. 1981. *Handbook of Legumes of World Economic Importance*. Plenum Press, NYC

Frederick, R., Synder, C., Peterson, G., and Bonde, M. 2002. Polymerase chain reaction assays for the detection and discrimination of the soybean rust pathogens *Phakopsora pachyrhizi* and *P. eibromiae*. *Phytopathology* 92:217-227

Gohl, B. 1981. *Tropical Feeds*. Food and Agriculture Organization of the United Nations, Rome

Green, A. 1984. Soybean Rust. *Pests Not Known to Occur in the United States or of Limited Distribution*. No. 56. USDA-APHIS-PPQ

Hartman, G., Sinclair, J. and Rupe, J. 1999. *Compendium of Soybean Diseases*. APS Press

Hartman, G., Wang, T., and Hymowitz, T. 1992. Sources of resistance to soybean rust in perennial *Glycine* species. *Plant Disease* 76(4):396-399

Holm, L., Pancho, J., Herberger, J., and Pluckett, D. 1979. *A Geographical Atlas of World Weeds*. John Wiley & Sons, New York

Horst, R. K. 1990. *Westcott's Plant Disease Handbook*. Chapman & Hall, New York, Boston

Killgore, E. and Heu, R. 1994. First report of soybean rust in Hawaii. *Plant Disease* 78(12):1216

Kloppers, R. 2002. New soybean disease in South Africa. Available at the following website: http://www.saspp.org/new_disease/soybean_2001.php

Kochman, E., Ebrahim-Nesbit, F., and Hoppe, H. H. 1983. Light and electron microscope studies on the development of soybean rust (*Phakopsora pachyrhizi* Syd.) in susceptible soybean leaves. *Phytopathology* 106:302-320

Kuchler, F., Duffy, R., Shrum, R., and Dowler, W. 1984. Potential economic consequences of the entry of an exotic fungal pest: The case of soybean rust. *Phytopathology* 74(8):916-920

Mabberley, D. J. 1990. *The Plant-Book*. Cambridge University Press, Cambridge, New York (check)

Nagarajan, S. and Singh, D. V. 1990. Long-distance dispersion of rust pathogens. *Ann. Rev. Phytopath.* 28:139-153

McGregor, R. 1973. *The Emigrant Pests*. A report to the Administrator of APHIS by Dr. Russell McGregor

McLean, R., and Byth, D. E. 1976. Resistance of soybean to rust in Australia. *Australian Plant Pathology* 5(3):34-36 (Requested)

Ogle, H., Byth, D., and McLean, R. 1979. Effect of rust (*Phakopsora pachyrhizi*) on soybean yield and quality in southeastern Queensland. *Australian Journal of Agricultural Research* 30(5):883-893 (Requested)

Odvody, G. et al. 1998. Sorghum ergot goes global in less than three years. APSnet Feature. Available at the following website: http://www.apsnet.org/online/feature/ergot/top.html

Ono, Y., Buritica, P., and Hennen, J. 1992. Delimitation of *Phakopsora*, *Physopella*, and *Cerotelium* and their species on Leguminosae. *Mycol. Res.* 96:825-850

Purdy, L. H., Krupa, S. V., and Dean, J. L. 1985. Introduction of sugarcane rust into the Americas and its spread to Florida. *Plant Disease* 69(8):689-693

Reed, C. F. and Hughes, R. O. 1977. *Economically Important Foreign Weeds*. United States Department of Agriculture, Animal and Plant Health Inspection Service

Rytter, J., Dowler, W., and others. 1984. Additional hosts of *Phakopsora pachyrhizi*, causal agent of soybean rust. *Plant Disease* 68(9):818-819

Saksirirat, W. and Hoppe, H. H. 1991. Teliospore germination of soybean rust fungus (*Phakopsora pachyrhizi*). *Journal of Phytopathology* 132(4):339-342 (Requested)

Shin, D. C. and Tschanz, A. T. 1986. Studies on physiological reactions of soybean cultivars tolerant and susceptible to rust (*Phakopsora pachyrhizi*). *Korean Journal of Crop Science* 31(4):440-446 (Requested)

Sinclair, J. B. and Hartman, G. L (Editors). 1996. *Proceedings of the Soybean Rust Workshop*. (1995). National Soybean Research Laboratory, Publication No. 1

Tschanz, A. and Shanmugasundaram, S. 1985. Soybean rust. Pages 562-567 in *Proceedings World Soybean Research Conference, III*. R. Shibles, ed. Westview Press, Boulder, CO (Requested)

USDA-ARS. 1970. *Selected Weeds of the United States*. Agriculture Handbook No. 366. United States Department of Agriculture, Agricultural Research Service

USDA-WAOB. 1987. *Major Crop Areas and Climatic Profiles*. Agriculture Handbook No. 664. United States Department of Agriculture, World Agricultural Outlook Board (WAOB) Agricultural Research Service

Walter, H., Harnickell, E. and Mueller-Dombois, D. 1975. *Climate-diagram Maps of the Individual Continents and the Ecological Climatic Regions of the Earth*. Springer-Verlag, Berlin and New York

Yang, X. B., Dowler, W. M.and Royer, M. H. 1991. Assessing the risk and potential impact of an exotic plant disease. *Plant Disease* 75(10):976-982

Yang, X. B., Tschanz, A. T., Dowler, W. M.and Wang, T. C. 1991. Development of yield loss models in relation to reduction of components of soybean infected with *Phakopsora pachyrhizi*. *Phytopathology* 81:1420-1426